ARBITRATION UNDER ANNEX VII OF THE UNITED NATIONS CONVENTION ON THE LAW OF THE SEA

PEOPLE'S REPUBLIC OF BANGLADESH

V.

REPUBLIC OF INDIA

REPLY OF BANGLADESH

VOLUME III
ANNEXES

31 JANUARY 2013

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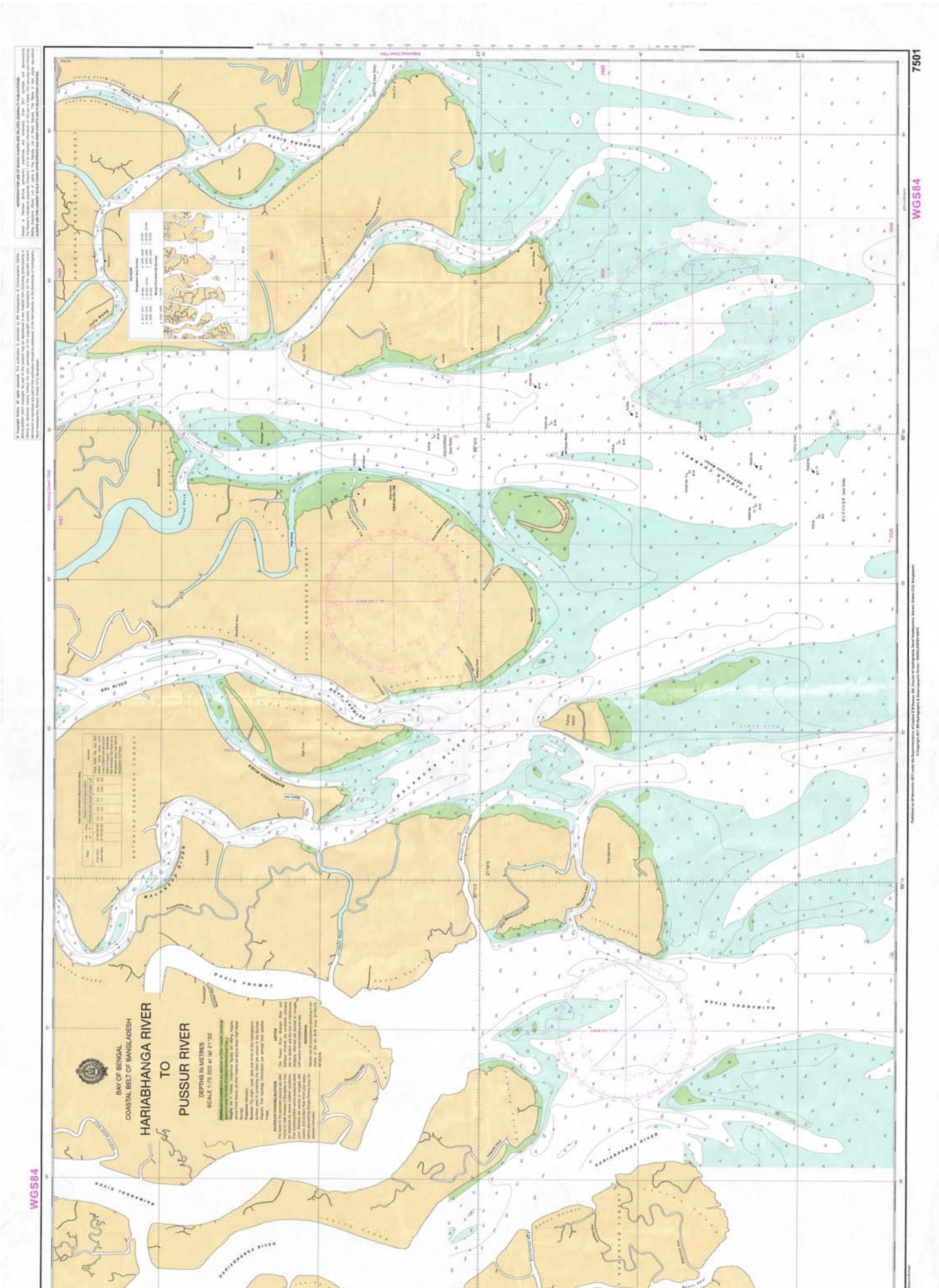
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Annex BR2

OPPENHEIM'S INTERNATIONAL LAW

NINTH EDITION

Volume I

PEACE

PARTS 2 TO 4

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of the United Nations, based in Geneva. There is of course provision in the 1982 Convention for continuity with the former regime: by Article 42, acceptance of the new Convention 'involves acceptance of the Administrative Regulations in force at the time'.

BOUNDARIES OF STATE TERRITORY

Holdich, *Political Frontiers and Boundary Making* (1916) Kaekenbeeck, *International Rivers* (1918) Fawcett, *Frontiers* (1918) Adami, *National Frontiers in relation to International Law* (1919, trans from the Italian) Carpenter, AJ, 19 (1925), pp 517–29 Lindley, *The Acquisition and Government of Backward Territory* (1926), pp 270–83 de la Pradelle, *La Frontière* (1928), and in *Répertoire*, vii, pp 487–514 Boggs, *International Boundaries* (1940) Ireland, *Boundaries, Possessions, and Conflicts in Central and North America and the Caribbean* (1941) Jones, *Boundary Making* (1945) Duncan Hall, AJ, 42 (1948), pp 42–65 Rousseau, RG, 58 (1954), pp 23–52 Lachs, *The Polish–German Frontier* (1964) Doherty, *The Jordan Waters Conflict* (1965) Prescott, *The Geography of Frontiers and Boundaries* (1965) Bastid, Hag R, 107 (1962), iii, pp 361–495 Sharma, *International Boundary Disputes and International Law* (1976) Prescott, *Boundaries and Frontiers* (1978) Cuckwurah, *The Settlement of Boundary Disputes in International Law* (1967) Charles de Visscher, *Problèmes de confins en droit international public* (1969) Luard, *The International Regulation of Frontier Disputes* (1970) McEwen, *International Boundaries of East Africa* (1971) Boutros Ghali, *Les Conflits de frontières en Afrique* (1973) Munkman, BY, 46 (1972–73), pp 1–116 Bernstein, *Delimination of International Boundaries* (1974) Taha, *The Settlement of the Sudan–Ethiopia Dispute* (1975) Sharma, *International Boundary Disputes and International Law* (1976) Bardonnet, 'Les Frontières terrestres et la relativité de leur tracé', Hag R, 153 (1976), v, pp 9–166 Menon, ICLQ, 27 (1978), pp 738–68 Cervenka and Friedman, *The Unfinished Quest for Unity in Africa and the OAU* (1977) Prescott, *Boundaries and Frontiers* (1978); Brownlie, *African Boundaries: A Legal and Diplomatic Encyclopaedia* (1979) Voelckel (technical aspects of maritime frontiers), AFDI, 25 (1979), pp 693–711 Menon, ICLQ, 27 (1978), pp 738–68 Shaw, *Title to Territory in Africa* (1986) Chang, *China's Boundary Treaties and Frontier Disputes* (1982) Weil, *The Law of Maritime Delimitation – Reflections* (1989).

§ 226 Territorial boundaries Boundaries of state territory are, it was said in earlier editions of this work, the imaginary lines on the surface of the earth which separate the territory of one state from that of another, or from unappropriated territory, or from the open sea.[1] International boundaries are sometimes called

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[1] Basdevant's *Dictionnaire de la terminologie du droit international* (1960) speaks of (adopted from Rivier): 'la ligne intellectuelle qui sépare le territoire d'un Etat des territoires limitrophes'.

On boundaries and the recognition of a state, see *Deutsche Continental Gas-Gesellschaft v Polish State*, AD, 5 (1929–30), No 5. The tribunal held that statehood is not absolutely dependent on the existence of rigidly fixed boundaries. See also the *North Sea Continental Shelf Cases*, ICJ Rep (1969), p 3, at p 32: 'There is for instance no rule that the land frontiers of a State must be fully delimited and defined . . .'. For an analysis, see Crawford, BY, 48 (1976–77), pp 111–14; and also Crawford, *The Creation of States in International Law* (1979), p 36; see Reuter, *Droit International Public* (1976), p 168; also Bardonnet, *op cit*, ch 1, where he shows from examination of practice that a state may exist, with uncertain or disputed frontiers, and may also 'frontiers'; though that may also refer to a frontier zone, possibly a disputed zone, rather than to an established line. The different question of the limits of certain maritime zones of jurisdiction, is dealt with below; but the limits of maritime zones, such as territorial sea or continental shelf, or exclusive economic zones, may sometimes also be international boundaries;[2] but they are even so subject to legal principles and rules different from those applicable to the land boundaries which are the subject of the following sections.[3] There is also the question of the boundaries of territorial airspace, which will normally be defined by reference to the land boundary, but over sea areas will normally follow the limit of the territorial sea. But all these other boundaries and limits depend ultimately upon the location of the land boundary line.

The distinction sometimes made between artificial and natural boundaries is geographical rather than legal, for so-called natural boundaries, making use of natural features such as rivers or mountains, usually need further definition in order to produce a precise boundary line.[4] The common practice for land boundaries is, in a boundary treaty or award, to describe the boundary line in words, ie to 'delimit' it; and then to appoint boundary commissions, usually joint, to apply the delimitation to the ground and if necessary to mark it with boundary posts or the like, ie to 'demarcate' it.[5]

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be admitted to membership of an international organisation. See also Menon, ICLQ, 27 (1978), pp 738–68, an article on the Guyana–Surinam boundary, but has valuable material on boundaries generally.

It should not be supposed that the boundary line must divide the two state authorities for all purposes. Frequently other lines or zones or arrangements are made for such purposes as mining, the construction and running of an airport, the better administration of customs, and so on. For many examples see Bardonnet, *op cit*, pp 74–83.

2 See §§ 323, 346. In the case concerning *Delimitation of the Maritime Boundary in the Gulf of Maine Area*, ICJ Rep (1984), p 246, the two parties submitted to the Chamber the 'question as to the course of the single maritime boundary that divides the continental shelf and fisheries zones of the two Parties'. The Chamber's Judgment in para 19 draws a distinction seemingly between boundaries between areas of 'sovereign rights', and boundaries between areas of sovereignty ('between two sovereign States').

On maritime boundaries generally see Weil, *The Law of Maritime Delimitation – Reflections* (1989).

3 See ICJ Rep (1986), at paras 27 and 47, with particular relation to the special place of equitable principles in maritime boundaries. But see *Burkina Faso and Mali Frontier Dispute*, ICJ Rep (1986), p 554, where a Chamber of the ICJ said it would apply equity *infra legem* to interpret the frontier established by the principle of *uti possidetis*, but would not resort to equity in order to modify an existing frontier; and see also *Rann of Kutch Case*, ILR, 50 (1968), p 2, where this question was put in issue by the parties.

4 A classical example is the Argentina–Chile Boundary Treaty of 23 July 1881, for which see § 231, n 1. See also *Canton of Valais v Canton of Tessin* (1980), ILR, 75, p 114 (Swiss Federal Tribunal), where, applying international law by analogy, the Tribunal, after finding acquiescence and prescriptive arguments indecisive of a disputed land boundary, fell back upon the criterion of the 'natural configuration of the land', and determined a boundary following the course of a mountain watershed. For the possibility of a watershed line itself changing at different periods, see Judge Wellington Koo's Dissenting Opinion in the *Temple of Preah Vihear Case*, ICJ Rep (1962), at p 100.

See the 8th ed of this vol, p 531, n 2 for an explanation of '*Natural Boundaries* sensu politico'.

5 For this convenient terminology see McMahon, *Journal of the Royal Society of Arts*, 84 (1935), p 4. But many writers and even judgments and awards use either term for either process. For its strict use also in French, see Charles de Visscher, *Problèmes de confins en droit international*

§ 227 Boundary treaties It is provided in Article 11 of the Convention on Succession of States in respect of Treaties 1978 that a succession of states does not as such affect a boundary established by a treaty, or obligations and rights established by a treaty and relating to the regime of a boundary. Also Article 62 of the Vienna Convention on the Law of Treaties 1969 excepts a boundary treaty from the operation of the rule of *rebus sic stantibus*. Furthermore Article 62 of the Convention on the Law of Treaties between States and International Organisations or between International Organisations 1986, provides likewise that a fundamental change of circumstances 'may not be invoked as a ground for terminating or withdrawing from a treaty between two or more States and one or more international organizations if the treaty establishes a boundary'.[1] Nevertheless, although it is clear in law that a boundary established by treaty is not to be called in question by the mere fact of a succession of states, or by a fundamental change in circumstances since the treaty was made, it does not follow that boundaries established by treaties are never to be questioned; or that boundaries established by treaty are necessarily more permanent in law than those established in other ways.[2]

§ 228 Boundary maps Either stage, delimitation or demarcation, may or may not be accompanied by a map. It used sometimes to be said[1] that, if there be a map, the text should prevail in the case of discrepancy; but there is no rule to that effect and it would be unreasonable if there were, for words are as susceptible to error as maps. The true position was stated by Judge Fitzmaurice in the *Temple of Preah Vihear* case,[2] when faced with the converse proposition that the map should prevail:

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public (1969), eg p 12. See, however, comment in Brownlie, *op cit*, p 4. For the importance of a boundary being both delimited and demarcated, see Bardonnet, *op cit*, ch 1; also Weil, Israel Law Rev, 23 (1989), pp 1–25, and Bowett, *ibid*, pp 429–42, on the *Taba Award*.

Much material on the task of a boundary commission, the establishment of a natural boundary, and the effects of demarcation can be found in the Report of a Honduras–Nicaragua Mixed Commission (1961), ILR, 30, p 76.

For the status of disputed territory *pendente demarcatione*, see Bardonnet, *op cit*, pp 52–66, especially for his proposition that there is no such thing as acquired rights in a zone of disputed sovereignty (see *loc cit*, p 63). But this depends upon the critical date, for which see § 273. Much material on this matter will also be found in *ICJ Pleadings* (1956), *Antarctica* cases.

1 For these three treaties, see respectively ILM, 17, (1978), p 1488; ILM, 8 (1969), p 679; ILM, 25 (1986), p 543.

2 See eg Bowett, *AS Proceedings* (1966), p 132: 'Traditionally the boundary treaty, the "dispositive" treaty *par excellence*, has been regarded as passing on succession. But, if one looks at the Somali dispute with both Kenya and Ethiopia, then one sees the 'colonialist' boundary treaty rejected precisely because it fails to be consistent with the principle of self-determination. It is almost as if Huber's doctrine of "inter-temporal" law (in the *Palmas Islands Arbitration*) is being developed so as to imply that title to territory, whatever its origin, must be consistent with the right of self-determination in order to qualify for acceptance in the Charter era.'

But see also *Case concerning the Arbitral Award of 31 July 1989*, ICJ Rep (1991), where an Award concerning a maritime boundary was attacked as being 'inexistent' or 'null'.

1 See 8th ed of this vol, p 532, n 1.

2 ICJ Rep (1962), at p 65. See also Sandifer, *Evidence before International Tribunals* (revised ed 1975), § 50, pp 229ff; Hyde, AJ, 27 (1933), p 311; Weissberg, AJ, 57 (1963), p 781; Charles de

'There is of course no general rule whatever requiring that a conflict of this kind should be resolved in favour of the map line and there have been plenty of cases ... where it has not been, even though the map was one of the instruments forming part of the whole treaty settlement (as here) and not a mere published sheet or atlas page – in which case it would in itself, have no binding character for the parties. The question is one that must always depend on the interpretation of the treaty settlement, considered as a whole, in the light of the circumstances in which it was arrived at.'

General maps, not part of, or illustrating the delimitation or demarcation process may, of course, be used as evidence of an interpretation of a boundary settlement. In this case their weight as evidence will depend in each case on their relevance and merit.[3]

§ 229 Boundary rivers Boundaries in rivers, lakes, and land-locked seas call for particular mention.

Boundary rivers[1] are those which separate different states from each other. If such a river is not navigable, the boundary line as a rule follows the mid-line of the river; or of its principal arm if it has more than one. If navigable, the boundary line as a rule follows the mid-line of the so-called *thalweg*, of the

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Visscher, *Problèmes de confins en droit international public* (1969), ch VII and Akweenda, BY, 60 (1989), pp 202–55. See also the *Palmas Case* (1928), RIAA, 2, pp 853–4 and 859–62; the *Jaworzina Case*, PCIJ, Series B, No 8, at pp 32–3; the *Status of Eastern Greenland Case*, PCIJ, Series A/B, No 53, p 52; the *Frontier Land Case*, ICJ Rep (1959), p 225; and the *Beagle Channel Award* (1977), ILR, 52, p 93, at p 195. On the Beagle Channel award generally, see Dutheil de la Rochère, AFDI, 23 (1977), pp 408–35; and for the later history E Lauterpacht, 'Whatever happened to the Beagle Channel Award?', *Mélanges Michel Virally* (1991) pp 359–71. See also the very full treatment of maps and other cartographic materials in the *Burkina Faso and Mali Frontier Dispute*, ICJ Rep (1986), at p 554, paras 53ff.

There are many cases where inadequate maps of only partially explored territory have led to problems of error: see eg the celebrated arbitration between Great Britain and the US over the *Sainte Croix River Boundary*, Moore, *International Arbitrations*, ii, p 373; the *Encuentro/Palena Case, McNair's Award* (1966), ILR, 38, p 10, between Argentina and Chile; and the *Temple Case*, ICJ Rep (1962), p 6. On error generally and with an examination of boundary problems, see Dubois, AFDI (1963), pp 191–227.

3 The use, as one form of evidence, of whatever means are found and submitted by the parties is illustrated by the *Taba Award* (1988), ILR, 80, p 226. (For the agreement to arbitrate the Taba question, see ILM, 26 (1987), pp 1–15.)

See also the important paras 53–56 on the place of maps in the Chamber's Judgment in the *Burkina Faso and Mali Frontier Dispute*, ICJ Rep (1986), p 554, where it is said that maps cannot of themselves constitute title since they lack intrinsic legal force; though they may acquire such legal force if annexed to, or integrated with, an official text; though it is not clear from what general principle this proposition was deduced, and it may be that this is to be regarded as a holding related only to the particular circumstances of the case.

There is a careful consideration of maps in the *Rann of Kutch Case* (1965), ILR, 50, p 2; for an analysis of the decision see Untawale, ICLQ, 23 (1974), pp 818–39.

1 See Huber, ZV, 1 (1907), pp 29–52 and 159–217; Hyde, AJ, 6 (1912), pp 901–9; Schulthess, *Das internationale Wasserrecht* (1915), pp 8–16 and 19–24; Adami, *National Frontiers* (1919), pp 13–27; Kercea, *Die Staatsgrenzen in den Staatsflüssen* (1916); Gleditsch, 22 *Acta Scandinavica* (1952), pp 14–32; Charles de Visscher, *Problèmes de confins en droit international public* (1969), pp 58ff; Bouchez, ICLQ, 12 (1963), pp 789–817. See also Jayewardene, *The Regime of Islands in International Law* (1990), ch 6.

principal channel of the river,[2] and this general rule for the two kinds of rivers was adopted by the Treaties of Peace 1919 except in special cases.[3] But it is possible for the boundary line to be one bank[4] of the river, so that the whole bed then belongs to one of the riparian states only. This is an exceptional case whether created by immemorial possession, by treaty, or by the fact that a state has occupied the lands on one side of a river at a time prior to the occupation of the lands on the other side by some other state.[5] If a boundary river changes its course as a result of gradual accretion on one bank and destruction of the other, the general rule is that the boundary line continues to be the mid-channel or middle-line, as the case may be, but shifts with the shifting course of the river.[6]

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2 See definition in *Annuaire* (1887), Art 3: 'La frontière des Etats séparés par le fleuve est marqué par le thalweg, c'est-a-dire par la ligne médiane du chenal'. For an interesting application of the rule relating to the thalweg, see *State of New Jersey v State of Delaware* (1934) 291 US 361; AD, 7 (1933–34), No 48; AJ, 29 (1935), p 331; and comment by Garner, *ibid*, p 309, and Hyde, BY, 18 (1937), pp 4, 5. See also *Wisconsin v Michigan* (1935) 295 US 455; AD, 8 (1935–37), No 54; *Iowa v Illinois* (1893) 147 US 1, and Dickinson, *Cases*, p 336; *Louisiana v Mississippi* (1906) 202 US 1, and Dickinson, *Cases*, p 351; *Arkansas v Mississippi* (1919) 250 US 39; *Arkansas v Tennessee* (1940) 310 US 563; AJ, 35 (1941), p 154; ILR, 51, p 28. See also *Re Village of Fort Erie and Buffalo*, decided in December 1927 by the Supreme Court of Ontario: AD, 4 (1927–28), No 82.

For other examples, and especially the question of changes in the thalweg, see Bouchez, *op cit*, pp 799–814.

3 Eg by the Treaty of Peace (1919) with Germany, Art 30. See also *British Guiana Boundary Case*, BFSP, 99 (1904), p 930. For consideration of a river mouth as a boundary, see the case of the *King of Spain's Award*, ICJ Rep (1960), p 192.

For the more important and more complicated boundary rivers, the parties will often devise special solutions embodied in a treaty. See eg the complex solution arrived at for the River Plate in the Montevideo Treaty of 7 April 1961 between Argentina and Uruguay; see US Department of State, *International Boundary Study*, No 68 (1966); and Basso, *El tratado del Rio de la Plata* (1985). See also La Plata River Treaty 1973, ILM, 13 (1974), p 251. For boundary of the Colorado River between Mexico and US, see Eaton, AJ, 69 (1975), pp 255–71.

4 As to the definition of the bank, usually accepted to be the low-water mark, see *Vermont v New Hampshire* (1933), 289 US 593, also AJ, 27 (1933), p 779.

5 See eg the Frontier Treaty and Protocol between Iran and Iraq 1937, in regard to the boundary river the Shatt-al-Arab, by which the river boundary followed sometimes the Iranian low-water mark; E Lauterpacht, ICLQ, 9 (1960), p 208. But later see the Treaty on International Borders and Good Neighbourly Relations 1975 (ILM, 14 (1975), p 1133, at p 1137), where a thalweg boundary was restored. It is defined as the 'thalweg line, i.e. the median line of the main channel, navigable when the water level is at its lowest navigation levels . . .'. This boundary was one of the objects of dispute in the Iraq–Iran war of 1980 but was accepted and confirmed by Iraq in a statement of President Hussein in August, 1990. See Kaikobad, *The Shatt-al-Arab Boundary Question* (1980).

6 Unless it is otherwise provided by treaty (see, for example, Treaty of Peace (1919) with Germany, Art 30). See *Dermit v Sergeant Bluff Consolidated Independent School District* (1935) 261 NW 636, decided by the Supreme Court of Iowa. And see further *Hogue v Stricker Land and Timber Co* (1934) 69 F (2d) 167, decided by the US Court of Appeal (5th Circuit). *Nebraska v Iowa* (1892) 143 US 359; *Arkansas v Tennessee* (1918) 246 US 158; *Arkansas v Mississippi* (1919) 250 US 39; the *Chamizal* arbitration between the USA and Mexico set out in AJ, 5 (1911), pp 782–833, the question being further regulated by treaties of 29 August 1963, and 23 November 1970, see ILM, 2 (1963), p 874 and TIAS No 7313 and see also Wilson, ICLQ, 29 (1980), pp 38–53; *Kansas v Missouri*, AJ, 39 (1945), p 122; Carpenter, AJ, 19 (1925), at p 523; for the *Chamizal* question generally, see Jessup, AJ, 67 (1973), p 423; see also Treaty between the USA and Mexico of 1963 for agreement on the basis of the centre line of a relocated channel, UNTS, 505, p 185, AJ, 58 (1964), p 336; also Treaty on the Rio Grande Boundary and the Colorado River of 23 November 1970, UNTS, 830, p 55.

But if a boundary river suddenly leaves its old bed and forms a new one, the boundary remains where it was.[7] Where a boundary is said to follow a river with more than one branch, there may be a question which branch is meant and possibly which is to be regarded geographically as the 'major channel'. This was considered in the *Encuentro/Palena Case, Argentine–Chile Frontier Case* (1966), ILR, 38, p 10, the boundary case between Argentina and Chile, where the Court laid down that 'the three principal criteria to be applied in a problem of this kind' were 'length, size of drainage area, and discharge, preferably in terms of annual volume'.[8] When a bridge is built over a boundary river, the boundary line runs, failing special treaty arrangements,[9] through the middle of the bridge.[10]

§ 230 Boundary lakes and inland seas Boundary lakes and land-locked seas are such as separate the lands of two or more states from each other. The boundary line normally follows the median or equidistance line of these lakes and seas, but often boundary treaties delimit such lakes and seas between riparian

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For an example of international regulation and rectification of a river boundary exposed to frequent fluctuations and constituting a danger of flooding see the Convention of 1 February 1933, between the USA and Mexico for the rectification of the Rio Grande in the El Paso–Juarez Valley: AJ, 28 (1934), Suppl, p 98. See also Reinhard, *ibid*, 31 (1937), pp 45–54.

7 On this proposition generally, see Andrassy, Hag R, 79 (1951), p 149; also Charles de Visscher, *Problèmes de confins en droit international public* (1969), pp 60ff. A very useful survey of the different kinds of possible change is in Bouchez, ICLQ, 12 (1963), pp 789–817; and Jayewardene, *The Regime of Islands in International Law* (1990), pp 201ff.

An important example of the effect of natural changes in the river bed is on the Sino-Soviet border in the region of Oussouri which led to fighting in 1969. An island in the boundary river, called Tchenpao by the Chinese, and Damansky by the Soviet Union, was said by China to have been formally part of the Chinese river bank, and to have been created by erosion, but that the newly formed channel forming the island was never navigable: see Doolin, *Territorial Claims in the Sino-Soviet Conflict: Documents and Analysis* (1965); Bettati, *Le conflit sino-soviétique* (1971); *Le Monde*, 30 December 1981.

8 At p 93; see also p 93 where the Court refers to 'the general principle that where an instrument (for example, a treaty or an award) has laid down that a boundary must follow a river, and that river divides into two or more channels, and nothing is specified in that instrument as to which channel the boundary shall follow, the boundary must normally follow the major channel. The question which is the major channel is a geographical question . . .'. The Award is also in Cmnd 7438.

For other examples, see Jayewardene, *op cit*, p 199.

9 For an example see Treaty of Peace 1919 with Germany, Art 66, under which existing bridges across the Rhine within the limits of Alsace-Lorraine were to belong to France: see Lederle, ZV, 12 (1923), pp 298, 299; Schwalb, *ibid*, pp 365–8; Norden, *Die Rechts – und Verkehrsverhältnisse der Rheinbrücken zwischen Baden und Elsass-Lothringen nach dem Versailler Vertrag* (1921); and Goellner, *Les ponts français sur le Rhin* (1933).

10 This sentence has been left unchanged from the 8th ed of this vol; but see also Cukwurah, *The Settlement of Boundary Disputes in International Law* (1967), pp 66–69, who denies the existence of any general rule, whilst dealing usefully with the precedents. As to the whole matter of islands in relation to boundary rivers, see Bowett, *The Legal Regime of Islands in International Law* (1979), ch 3; and Jayewardene, *op cit*, pp 198ff; and see also p 228, n 39 of that work for list with references of treaties which allocate sovereignty over islands depending on which side of the thalweg they occur. But cf the River Plate Boundary Treaty, § 176, n 6, where the Island of Martin Garcia is recognised as Argentinian though on the Uruguayan side of the main channel.

states.[1] The boundary between states may, of course, coincide with the limit of territorial seas or of the exclusive economic zone, or of the continental shelf.[2]

§ 231 Mountain boundaries A boundary may follow a mountain chain separating two countries. A mountain chain, however, is a complex structure and the delimitation should indicate whether the line follows the line of the highest peaks, a ridge, a continental water divide, or a local water divide. The notion that a mountain chain can provide a clear boundary alignment without further qualification is fallacious.[1]

§ 232 Boundary disputes Boundaries are, for many reasons, of such importance, that disputes relating thereto are relatively frequent. The location of a land boundary line is usually a matter of the correct interpretation of some instrument, by which the boundary has been established.[1] The commonest way of doing this is by a boundary treaty. In other cases an arbitral award or judicial decision can be the final determination, especially where the meaning of a boundary treaty had been disputed.[2] In that event, the tribunal will have it in

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1 See Jayewardene, *The Regime of Islands in International Law* (1990), ch 7, for examples, different methods, sketches and references. An important example of such a treaty is the 1909 Convention regulating the boundary between Canada and the USA in the Great Lakes; see BFSP, 102 (1908–9), 137, and Hackworth, i, p 616; also Cohen, Hag R, 146 (1975), iii, pp 219–340.

2 See §§ 197, 323 and 346. Also for a putative territorial sea boundary, *James Buchanan & Co v Société Hanappier-Peyrelongue etc* (1959), ILR, 39, p 425. For international boundaries in channels between islands, see *Civil Aeronautics Board v Island Arlines* (1964), ILR, 35, p 68, and *Hooker v Raytheon* (1962), *ibid*, 33, p 148, for position in Santa Barbara Channel.

1 The classic example is the assumption written into the Argentine–Chile Boundary Treaty of 1881 (BFSP, 72, (1880–81), p 1103, and RIAA, 9, p 29 (for 1902 Award)) that the 'most elevated crests' are identical with the continental water divide. This fallacy was perpetuated in the 8th ed of this vol (§ 200, p 534), when it referred to a 'mountain ridge along the watershed'. Sir Thomas Holdich, who was the architect of the very successful 1902 Award which, for the most part, solved the problems raised by the 1881 Treaty, observed, 'The fundamental basis of nearly every boundary dispute of any magnitude in history has been geographical ignorance' (*The Countries of the King's Award* (1904), p 30).

1 See eg the boundary treaty between Great Britain and the USA respecting the demarcation of the international boundary between the USA and the Dominion of Canada, signed at Washington on 11 April 1908 (see Parry and Hopkins, *An Index of British Treaties 1101–1968*, vol 2, p 542). For numerous boundary arbitrations between South American states see Cukwurah, *The Settlement of Boundary Disputes in International Law* (1967); Woolsey, AJ, 25 (1931), pp 324–33; and Accioly, RI (Paris), 15 (1935), pp 36–45. As to Brazilian boundary disputes, see *Bulletin of the American Union* (1935), pp 155–68.

In the *Burkina Faso and Mali Frontier Dispute*, ICJ Rep (1986), p 554, it was said that distinction between 'delimitation disputes' and 'disputes as to attribution of territory' are more important in theory than in practice; and that the nature and extent of the Chamber's tasks and functions could not be determined by the classification of the dispute but by the Statute of the Court and the terms of the Special Agreement (para 18).

2 See the *Temple of Preah Vihear Case*, p 6, ICJ Rep (1962) 34; see also *Aegean Sea Continental Shelf* case (Greece v Turkey), ICJ Rep (1978) at p 36. The delimitation of land boundaries was the subject-matter of two Advisory Opinions of the PCIJ, PCIJ, Series B, No 8 (Poland and

mind that 'one of the primary objects' of boundary settlement is 'to achieve stability and finality'.[3] Sometimes international commissions are specially appointed to settle the boundary lines.[4]

§ 233 Boundary and territorial disputes distinguished Boundary questions are distinguishable from questions of title to territorial sovereignty: a matter which is subject to a body of law which is discussed below.[1] As the International Court of Justice said in the *North Sea Continental Shelf* cases, 'The appurtenance of a given area, considered as an entirety, in no way governs the precise delimitations of its boundaries, any more than uncertainty as to boundaries can affect territorial rights'.[2] A dispute often involves both kinds of argument, however; and the question which is the correct approach may be one of the points at issue.[3] Even in the strictly territorial dispute the boundaries of the disputed territory

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Czechoslovakia), and *ibid*, 9 (Albania and the Serb-Croat-Slovene State). An instance of such a settlement was the 1903 Award in the *Alaska Boundary dispute* between Great Britain (representing Canada) and the US; see Balch, *The Alaska Frontier* (1909); also Whiteman, *Digest*, 2, pp 1190–1. For later cases, see the *Frontier Land Case*, ICJ Rep (1959), p 209; the *King of Spain Award Case*, ICJ Rep (1960), p 192; the *Rann of Kutch Case*, ILM, 7 (1968), p 633; and see Salmon in AFDI, 14 (1968), p 217; the *Encuentro/Palena Case, Argentine–Chile Frontier Case* (1966), ILR, 38, p 19 and ICLQ, 12 (1967), p 550, and AJ, 12 (1967), 1071 (a dispute between Argentina and Chile), and Cot, AFDI, 14 (1968), p 237; the *Beagle Channel Case* (1977), ILR, 52, p 93 (between Argentina and Chile) which depended principally on the proper interpretation of the words 'south of the Beagle Channel' in the 1881 Boundary Treaty (see Brouillet, AFDI, 35 (1979), pp 47–73 for the Papal mediation of the award in the Beagle Channel dispute); see also the *Taba Award* (1988), ILR, 80, p 226, between Egypt and Israel where the question for the tribunal was the proper location of certain boundary posts during 'the critical period'; but the tribunal was, by the *compromis*, precluded from establishing a location other than one advanced by either Egypt or Israel, ILM, 27 (1988), p 1421, ILR, 80, p 226. For the Taba Agreement of 26 February 1989 between Egypt and Israel, see ILM, 28 (1989), p 611. Note also that by Art IX of the *compromis*, three of the five arbitrators were charged to 'explore the possibilities of a settlement', and thus conciliation was to continue till the written pleadings had been completed. See Bowett, Israel Law Rev, 23 (1989), pp 429–42; also Weil, *ibid*, pp 1–25, E Lauterpacht, *ibid*, pp 443–68. Award in the *Dubai-Sharjah* case (1981) (unpublished); the *Burkina Faso and Mali Frontier Dispute*, ICJ Rep (1986), p 554.

3 See the *Temple of Preah Vihear Case*, ICJ Rep (1962), p 34. But for the 'relativity' of the principle of finality, see Bardonnet, *op cit*, pp 67–71.

4 For an example of a boundary agreement following upon the delimitation of the boundary by a joint commission see the Agreement of 6 May 1929, between Great Britain and France concerning the boundary between Senegal and Gambia: TS No 13 (1929), Cmd 3340. The work of a boundary commission was crucial to the *Temple of Preah Vihear Case*, ICJ Rep (1962), p 6; see also the Award in the *Argentine/Chile Frontier Case* (1967), Cmnd 7438 and ILR, 38, p 10. See the *Taba Award* (1988), ILR, 80, p 226, where it was held that, 'If a boundary line is once demarcated jointly by the parties concerned, the demarcation is considered as an authentic interpretation of the boundary agreement even if deviations may have occurred or if there are some inconsistencies with the maps' (para 210).

1 See § 241. Nevertheless, some law is common to both kinds of dispute, eg the question of the 'critical date' (see § 273). The Taba boundary dispute (§ 232, n 2) thus involved a dispute as to the critical date or, as the award had it, the 'critical period'.

2 ICJ Rep (1969), at p 32; but see also *Burkina Faso and Mali Frontier Dispute*, ICJ Rep (1986), p 554, at para 17 for a different view.

3 See eg the *Rann of Kutch Case*, ILM, 7 (1968), pp 633ff (between India and Pakistan). Also the *Aegean Sea Case*, ICJ Rep (1978), p 3, at para 84, where the Court said: 'it would be difficult to accept the broad proposition that delimitation is entirely extraneous to the notion of territorial

must be part of the relevant facts, though not disputed. There is also a sense in which a question of title to territory must always be implicitly involved in a pure boundary dispute; except that in this case it is not the fact and mode of acquisition of territorial title that is disputed but the proper interpretation of some instrument, award or adjudication, or course of historical development, that is claimed to have established the boundary of the territory in question.

§ 234 Third states Boundary questions, as well as questions of territorial title, often concern more than one state for an international boundary dispute is concerned essentially with rights opposable *erga omnes*; as, for example, where the boundaries of three states converge on a tri-point. When a dispute between two of the states is submitted to a tribunal for settlement, there may therefore also arise questions about the extent of the tribunal's jurisdiction, or, in the International Court of Justice, of intervention under Articles 62 or 63 of the Court's Statute.[1]

§ 235 *Uti possidetis* The doctrine of the *uti possidetis juris* (*uti possidetis ita possideatis*), adopted by the Spanish-American states after their independence, was intended to solve, or even to avoid, boundary problems between them. This doctrine in effect conflates boundary and territorial questions by assuming as a governing principle that boundaries must be as they were in law at the declaration of independence; viz 1810 for former Spanish colonies in South America and 1822 for those in Central America. It is a necessary part of this doctrine that there could have been no *terra nullius* in those parts at those times.[1] In practice in

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status. Any disputed delimitation of a boundary entails some determination of entitlement to the areas to be delimited.' See also Bardonnet, *op cit*, pp 48–52. On whether an award on a boundary dispute is declaratory and so self-executing, see *Maghaubhai Ishwarbhai Patel v Union of India*, Indian JIL, 9 (1969), p 234.

See also § 232, n 1 for an observation in the *Burkina Faso and Mali* award.

1 See ICJ Rep (1984), p 3, and *ibid* (1985), p 13 (Libya/Malta continental shelf and Italy); and specifically on land frontiers and a tri-point, see ICJ Rep (1986) (*Burkina Faso and Mali*), p 554, at para 49. See also the Nicaraguan Application to Intervene in the case between El Salvador and Honduras, with particular reference to the maritime boundary in the Gulf of Fonseca, ICJ Rep (1990), p 92.

1 See Alvarez, *Le droit international américain* (1910), p 65, and the *Award by the Swiss Federal Council in a dispute between Colombia and Venezuela* decided in 1922 by the Swiss Federal Council, RIAA, i, p 224; *the Opinion and Award of the Special Boundary Tribunal between Guatemala and Honduras* (1933), Washington, DC (AD, 7 (1933–34), No 46, at pp 117, 118; comment thereon by Fisher, AJ, 27 (1933), pp 403–27; and Waldock, BY, 25 (1948), pp 325–7); as to the boundary dispute between Peru and Ecuador in 1936, see Woolsey, AJ, 31 (1937), pp 97–100. See also the *Beagle Channel Award*, (1977) ILR, 52, p 93, paras 9ff. For similar principles in relation to boundaries in Africa, see Cairo Resolution of the OAU of 1964, cited in Brownlie, *African Boundaries*, p 11. See the *Frontier Land Case*, ICJ Rep (1959), p 209, at pp 240–55, for treatment of the doctrine as a general principle of law. Also see Bardonnet, *op cit*, pp 55–6 and references there given.

For cases involving *uti possidetis juris* in Latin America, see *Award of 1891, between Colombia and Venezuela*, RIAA, I, p 292; also the *King of Spain's Award of 1906 over the dispute between Nicaragua and Honduras*, and the case before the ICJ over that Award's validity (see ICJ Rep (1960), p 192; also *Pleadings*, I, pp 354–61 for the text of the Award); the 1922 *Award by the Swiss Federal Council in a dispute between Colombia and Venezuela*, RIAA, I, p 227; and Judgment of a Special Tribunal in 1933 in a *Dispute between Guatemala and Honduras*, RIAA, II, p 1322.

Central and South America the doctrine, owing to the uncertainty of many of the Spanish colonial administrative boundaries at that time, especially in remote and often unexplored areas, has not always led to a ready and certain answer. Nevertheless the doctrine is of great importance, for it may be relevant to the proper interpretation even of subsequent boundary treaties. Moreover, it aptly enshrines the vital principles of stability of state boundaries.[2] It was also adapted to the African continent by the Cairo Resolution of the Organisation of African Unity of 21 July 1964,[3] according to which 'all Member States pledge themselves to respect the borders existing on their achievement of national independence'; and a Chamber of the International Court of Justice, in the *Burkina Faso and Mali Frontier Dispute* case applied the principles so as to 'photograph' the territorial situation at the moment of independence, and so freezing the territorial title. Moreover, it was there said to be 'a principle of a general kind which is logically connected with this form of decolonialization wherever it occurs'.[4]

STATE SERVITUDES

McNair, BY, 6 (1925), pp 111–27 Crusen, Hag R, 22 (1928), ii, pp 1–74 Henrich, *Theorie des Staatsgebietes* (1922), pp 85–98 Münch, *Ist an dem Begriff der völkerrechtlichen Servitut festzuhalten?* (1931) Reid, *International Servitudes in Law and Practice* (1932), and Hag R, 45 (1933), iii, pp 1–73 Mercier, Les servitudes internationales (1939) O'Connell in Can Bar Rev, 30 (1952), pp 807–18 Farran, ICLQ, 4 (1955), pp 294–307 Váli, *Servitudes of International Law* (2nd ed, 1958) Krenz, *International Enclaves and Rights of Passage with Special Reference to the Case Concerning Rights of Passage over Indian Territory* (1961) Dominice, *Ann Suisse*, 19 (1962), pp 71–102 Glassher, *Access to the Sea for Developing Land-locked States* (1970).

§ 236 So-called state servitudes State servitudes is the term sometimes used to denote exceptional restrictions made by treaty or otherwise on the territorial supremacy of a state by which a part or the whole of its territory is in a limited

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2 For a most valuable analysis of the materials on this matter, including both writers and cases, see Waldock's Special Rapporteur's fifth report on succession in respect of treaties, Doc A/CN 4/256 and Add 1–4, and YBILC (1972), ii, pp 44–59.

3 See *International Organisation*, 21 (1967), pp 102–27.

4 Para 23. The States of Upper Volta (as it then was, now Burkina Faso) and Mali in their Special Agreement of 20 October 1983, submitting the determination of a dispute over their 'common frontier' to a Chamber of the ICJ, mention in preamble, 'respect for the principle of the intangibility of frontiers inherited from colonization'. For important observations on *uti possidetis* as 'a general principle, which is logically connected with the phenomenon of the obtaining of independence, wherever it occurs'; the history of the principle as its relation with 'effective possession as a basis of sovereignty'; and its relation to state succession, and self-determination, see *Burkina Faso and Mali Frontier Dispute*, ICJ Rep (1986), p 554; ILR, 80, p 440, at paras 20–6, and para 30.

Cf, however, Boutros-Ghali, *Les conflits de frontières en Afrique* (1973); also the remarks of Bardonnet, *op cit*, pp 95ff; and see especially Yasseck, AFDI, 24 (1978), pp 59–113; and of Cervenka and Friedman, *Unfinished Quest* (1977), pp 69–71 on the difficulties over tribal areas and a list of potential disputes.

Annex BR3

A. Read & D. Fischer, *The Proudest Day: India's Long Road to Independence* (1998)

Annex BR3

THE PROUDEST DAY

INDIA'S LONG ROAD TO INDEPENDENCE

Anthony Read and David Fisher

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Epilogue

After the party came the reckoning. Radcliffe left India on Independence Day; so, too, did Jenkins, Abell and the remaining members of the ICS. None of them felt like joining in the celebrations. Neither did Gandhi, who had decided to take himself to Calcutta as a 'one-man boundary force', hoping that by his very presence he could prevent any fresh outbreak of killings there. Ismay was absent, too, laid low by a severe bout of dysentery. 'This dispensation was painful,' he wrote, 'but not altogether unwelcome. I was convinced that the right thing had been done, but I was in no mood for unrestrained rejoicing . . . I had deep forebodings about the immediate future . . . Many of my Indian friends were likely to lose their lives, and many more were certain to lose their homes.[1]

At 5.00 p.m. next day, Saturday, 16 August, the newly-elevated Earl Mountbatten of Burma handed copies of Radcliffe's awards to the Indian and Pakistani leaders – Liaquat and Muhammad Ali had flown to Delhi from Karachi that morning for an emergency meeting of the Joint Defence Council. They were all given two hours to take the documents away and study them, before returning to Government House for another meeting.

Both sides were incensed by what they read. As expected, Calcutta had gone to India, and Lahore to Pakistan – in both cases there was sadness, but no shock. The Indians were angry to find that the Chittagong Hill Tracts had gone to Pakistan, while the Pakistanis were furious to discover that not only Ferozepur but also an important part of the Muslim-majority district of Gurdaspur, in the northern Punjab, had gone to India.

Gurdaspur was not a rich district by any standard, but it had great strategic and symbolic significance, since it provided India's only road into Kashmir. Like the legendary Shangri-La, the valley of Kashmir is protected on all other sides by mountains, with few passes. All Kashmir's other road and rail communications with the rest of the sub-continent ran through West Pakistan. So did the great rivers Indus, Jhelum and Chenab, the lifeblood of West Pakistan, which flowed down from Kashmir into the dusty plains, carrying Kashmiri timber exports with them. With the maharaja, Hari Singh, still dithering over accession to either dominion, Gurdaspur had become the key to Kashmir's future. Without it,

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Kashmir would have no viable land connection with India, and would be obliged to accede to Pakistan.

The Indian leaders, of course, were well aware of the strategic importance of Kashmir, despite its significant Muslim majority. If Kashmir became part of India, then West Pakistan would be virtually surrounded, and India would also control the great rivers on which Pakistan's economic survival depended. This might well hasten the collapse of Pakistan, which most Indian leaders thought was inevitable within a few months anyway, and lead to the reunification of the sub-continent under a Congress government.

For Nehru, there was also an emotional involvement: Kashmir was the home of his Brahman ancestors, and its political leader, Sheikh Muhammad Abdullah, was a close personal friend. While Radcliffe was working on his awards, Nehru worried about the fate of Kashmir and of Sheikh Abdullah and his followers, who supported Congress: how would they fare in Pakistan? Congress must be able to defend its own, which meant being able to get troops into the valley if necessary. He badgered Mountbatten mercilessly about the boundary line, so much so that Mountbatten described him as 'pathological' on the subject.[2]

On 9 August, the day after Abell's sketch map had reached Jenkins in Lahore, Jinnah and Liaquat told Muhammad Ali, who was making a flying visit to Karachi from Delhi, that they had heard disturbing reports about the likely border between East and West Punjab, particularly in the Gurdaspur district. They gave him a message for Ismay, which he delivered as soon as he returned to Delhi later that day, driving straight from the airport to the Viceroy's House. When Muhammad Ali arrived, however, Ismay was closeted with Radcliffe. He had to kick his heels for an hour before he could tell Ismay of Jinnah's fears that the award in Gurdaspur would be political rather than judicial: 'if the boundary actually turned out to be what these reports foreshadowed, this would have a most serious impact on the relations between Pakistan and the United Kingdom, whose good faith and honour were involved in this question'.[3]

The reports turned out to be correct. Clearly, Nehru had prevailed. When he finally saw the awards on 16 August, Liaquat immediately accused Radcliffe of bending to pressure from Mountbatten and Nehru. Once again, there is no documentary proof of this, only strong circumstantial evidence. But at the time, there was nothing to be done. Both sides had given their word, as had Baldev Singh for the Sikhs, that they would accept whatever Radcliffe decided, and they stood by their promises. Baldev complained bitterly of the wrongs done to the Sikhs by having many of their sacred places left in Pakistan, but he was silenced by Muhammad Ali, who pointed to the many Muslim-majority areas that had been assigned to India. Nehru and Patel said nothing. Next day, Jinnah broadcast his reactions to his new nation:

> The division of India is now finally and irrevocably effected. No doubt we feel that the carving out of this great independent Muslim State has suffered injustices. We have been squeezed in as much as it was possible, and the latest blow that we have received was the Award of the Boundary Commission. It is an unjust, incomprehensible and even perverse award ... and it may not be a judicial but a political award, but we have agreed to abide by it and it is binding upon us. As honourable people we must abide by it.[4]

By the time Mountbatten unlocked his safe on 16 August, it had been just one week since Radcliffe had finished drafting his award for the Punjab. But a week is a very long time for communities riven by uncertainty and fear. During that week confidence in government, in the police and in the army had finally collapsed. Policemen were themselves Hindus, Muslims and Sikhs, and were affected like everyone else by the fear of being caught in the wrong place at the wrong time. They had seen their own people butchered, raped and dispossessed. For them, the safety of their families came before their duty as policemen. Given time, the police force, like the army, could have been reorganized and prepared, under impartial British officers. Given time, local and national governments could have made arrangements for an orderly transfer or exchange of populations. Given time, and firm government, it is even possible that some of the worst fears could have been allayed. But time was precisely what no one was given, so panic set in, and catastrophe became inevitable and unstoppable.

With no announcement of the awards, many towns and villages in the Punjab had greeted independence nervously with the flags of both India and Pakistan flying defiantly in competition with each other. There were reports that Sikhs in Amritsar had celebrated on the morning of 15 August by rounding up a group of about 30 Muslim women and girls, stripping them naked and forcing them to parade in a circle before a jeering crowd. They had then picked out the most attractive and repeatedly raped them, chopping down the rest with their *kirpans*. When news of the outrage reached Lahore, Muslims there took their revenge by attacking the chief *gurdwara*, the Sikh temple, where scores of Sikhs had taken refuge. They burned it to the ground with the Sikhs trapped inside, while Muslim police stood by, doing nothing to stop them. But this was only the beginning of the holocaust.

The emergency meeting of the Joint Defence Council on 16 August agreed to strengthen the Punjab Boundary Force as quickly as possible. Nehru and Liaquat visited Lahore, Ambala, Jullundur and Amritsar together, to see for themselves what was going on and to appeal for peace. They tried to remind everyone that both India and Pakistan had pledged to protect the minorities after partition, and that there was no need for anyone to move home. But they were shouting against a hurricane. Each new outrage, each new murder or massacre, brought a thirst for revenge and a desperate need to flee from the terror. As the scale of the disaster mounted, Tara Singh and other Sikh leaders toured the province in military vehicles, appealing for an end to the violence, but their followers had tasted blood, and it was too late for Tara Singh to stop what he had begun.

When the boundary commission awards were finally made public on 17 August, they did nothing to bring peace but only increased the general frenzy not to be trapped on the wrong side of the line. The flow of refugees soon became a raging torrent. In the sub-continent as a whole, some 14 million people left their homes and set out by every means possible – by air, train, and road, in cars and lorries, in buses and bullock carts, but most of all on foot – to seek refuge with their own kind. Ten million of them were in the central Punjab. In an area measuring about 200 miles by 150 miles, roughly the size of Scotland, with some 17,000 towns and villages, 5 million Muslims were trekking from east to west, and 5 million Hindus and Sikhs trekking in the opposite direction. Many of them never made it to their destinations.

The long, winding columns of frightened souls trudging through the landscape carrying as many of their worldly possessions as they could manage, to say nothing of their old and their young, were easy targets. Some of the columns stretched for miles – the longest was some 50 miles long (some say 74 miles), with 800,000 refugees heading towards India from West Punjab and it is said to have taken eight days to pass any given spot. Sometimes, when columns heading in different directions passed on the road, they fell upon each other with whatever weapons they had to hand, before moving on, leaving a trail of dead and dying behind them.

The massacres and slaughters have become the most abiding memory of that time. Sadly, in northern India and much of Pakistan, people talk of the horrors of partition rather than the joys of independence. There have been hundreds, possibly thousands, of books and memoirs written by those who lived through it. Perhaps the most succinct writings are a number of pieces by the Urdu poet, Saadat Hasan Manto, such as one entitled 'Compassion':

> Please don't kill
> my young daughter
> before my eyes ...
>
> All right, let's do as he says ...
> Strip her
> and drag her away[5]

One of the most powerful and recurring images is of the trains. They left Delhi and Lahore and other stations packed with refugees as only Indian trains can be packed; with people clinging to the sides and roof like a vast swarm of bees. As often as not, the trains arrived at their destinations filled with nothing but bloated, butchered corpses, stinking and silent apart from the buzzing of flies. Some coaches were scrawled with chalked graffiti: 'A Present from India', 'A Present from Pakistan'. Both sides stopped trains in the countryside, or fell upon them in sidings while the drivers watered their engines, systematically sorting out the travellers from the other side and hacking them to pieces, while studiously avoiding any harm to Britons and other Europeans heading for home. Manto again captured the essence, in another short piece, this time entitled 'Hospitality Delayed':

> Rioters brought the running train to a halt.
>
> People belonging to the other community were pulled out and slaughtered with swords and bullets.
>
> The rest of the passengers were treated to halwa, fruits and milk.
>
> The chief assassin made a farewell speech before the train pulled out of the station: 'Ladies and gentlemen, my apologies. News of this train's arrival was delayed. That is why we have not been able to entertain you lavishly – the way we wanted to.'[6]

Not even the trains carrying Indian troops back from Pakistan were safe, presenting an especially tempting target for Pathan tribesmen. General Menèzes recalls that his own battalion was twice attacked whilst travelling home by train, having 26 soldiers killed and 72 wounded, including seven officers.[7]

The Punjab Boundary Force did its best, but could do little to prevent the killings. The one obvious way in which the exodus could have been monitored and protected, in which the armed gangs on both sides could have been spotted and wiped out, was with aircraft: there were eight squadrons of modern Tempest fighter-bombers from the old RIAF, seven of which had been given to India and one to Pakistan. Between them they could easily have covered likely trouble spots in the open country, and protected trains and railway lines. But for some reason both sides refused to use them, or to declare martial law. The Boundary Force was confined to acting 'in assistance to the civil authorities' and forbidden from mounting any offensive operations. As the then Brigadier Ayub Khan explained: 'The force could only rush to a place that was being attacked, and by the time the troops arrived it was looted, burnt and the Muslim inhabitants massacred. In the end, all that this force could do was to try and keep the roads clear for the refugees. This was done by patrolling the main thoroughfares and the railway lines.'[8]

By the end of August, communal distrust had reached such levels that both sides were accusing the Boundary Force of bias, of failing to protect *their* people, and it was wound up amid general recriminations. Most of its British officers, who had been sickened both by the hopelessness of their task and the gruesome horrors they had been forced to witness, were relieved. Mountbatten decided he could retire to Simla for 10 days' much-needed rest. Meanwhile, the killings continued.

It is impossible to give an accurate figure for those who perished. Most were massacred by the other side, but many were struck down by cholera, dysentery and all those other diseases that afflict undernourished refugees everywhere, or died from starvation, or sheer exhaustion. The official British estimates at the time were between 200,000 and a quarter of a million – but it was in the British government's interest to minimize the extent of the slaughter for which they bore the ultimate responsibility. At the other extreme, there were those with other political axes to grind who claimed two million had perished. Over the years, a consensus has been reached that the true figure was around one million. It is a truly terrible indictment.

Looking back after 50 years, the horror of those days is not diminished by the passage of time. But it is worth remembering that the real trouble was confined to that one part of the Punjab, though it did eventually spill over into neighbouring areas, including Delhi and part of the UP. For the first two weeks after partition, the rest of India remained quiet, with little trouble. The south, as usual, stayed that way. Bengal began quietly, then threatened to erupt as news of what was happening in the Punjab arrived. Serious trouble, however, was prevented by one man, who somehow managed to work a miracle that had been beyond General Rees and his 50,000 men in the Punjab. That man, of course, was Gandhi.

Gandhi had chosen to go and live in Hydari House, an old Muslim residence, open on all sides, in Beliaghata, an area of Calcutta which had been torn by earlier riots. To highlight his pleas for communal unity, he invited Suhrawardy – the man most Hindus blamed for inciting the Calcutta killings the year before – to stay there with him. Suhrawardy, who with partition was about to lose his position as chief minister of Bengal, agreed readily, and together the two men set an example which most of Calcutta, and indeed most of Bengal, followed. Independence Day itself was marked in Calcutta by unbelievable scenes of fraternization, with Hindus and Muslims embracing each other and dancing together in the streets. Gandhi's public prayer meetings on the *maidan* attracted crowds estimated at half a million. That year, the great Muslim festival of Id el Kebir fell on 18 August, while the spirit of friendship and reconciliation was still at its height. When Gandhi greeted the crowd in Urdu with '*Id Mubarak*', 'Happy Id', they went wild with delight.

By 31 August, however, the tensions had returned and the first communal killings began. At 10.00 p.m. that night, as Gandhi lay sleeping naked between his two great-nieces, Hydari House was besieged by a gang of young Hindu fanatics from the RSSS. Stones were thrown, Muslims in the street nearby were attacked, Gandhi himself was in danger. The police arrived before he was harmed, and managed to restore order. Severely shaken, Gandhi told his followers, 'The miracle of Calcutta has proved to be a nine-days wonder.' Next day, as the flames of communal hatred threatened to consume the city again, he prayed for guidance. The answer he received was a familiar one: a fast unto death, to be broken only when all sides repudiated their violence.

It would not be a long fast: Gandhi was now nearly 78 years old, and in failing health. Even after one day, his condition was giving his doctors cause for alarm. The riots continued, and so did he – but suddenly the message seemed to get through, and by the second day the calls for peace were becoming louder than the noises of riot, as an anxious crowd began to build in the street outside the house. By the end of the third day, peace had returned and the *goondas* responsible for much of the killing had come to bow before the frail old man and surrender their weapons, literally by the truckload. Rajagopalachari, now governor of Bengal, sent a handwritten message telling Gandhi complete calm had been restored.

At 9.15 p.m. on 4 September, after just 73 hours, Gandhi broke his fast with a few sips of orange juice. The miracle had been worked once again, and this time it lasted. There was no more trouble in Calcutta, and very little elsewhere in either part of Bengal. The province that had always been the epicentre of violent rebellion had become India's exemplar of peace. Gandhi celebrated his success by announcing that he would leave next day for the Punjab.

At almost exactly the same time as Gandhi was breaking his fast in Calcutta, Mountbatten was receiving a telephone call in Simla. It was from V.P. Menon in Delhi, telling him he must abandon his holiday and return. The troubles in the Punjab had spread to Delhi and were threatening to engulf the city. There were wild rumours that the Muslims, hundreds of thousands of whom were seeking sanctuary in the vast refugee camps in parks and open spaces, were plotting to seize the city and restore the Muslim hegemony of the Mughal emperors. The rumours were fuelling murder and mayhem by Hindus and by the embittered Sikhs who were flooding in from the Punjab. Under these pressures the administration was breaking down. If the government were to lose control of its own capital, then the whole new state might collapse in anarchy and chaos.

Nehru and Patel were at their wits' end. They had had years of experience of agitation and prison, but virtually none of the administration of a huge and complex country. And certainly, they did not have the knowledge or the experience to deal with what Ismay described as 'a cataclysm of this kind'. It was

V.P.'s idea to ask Mountbatten to come back and take charge of the emergency. Patel agreed at once. So did Mountbatten, and he and Edwina returned next day.

Mountbatten liked to claim that Nehru and Patel had offered him executive power to run India, and that he had replied 'My God, I've just got through giving you the country and here you two are asking me to take it back!' In fact, they asked him to set up and chair an emergency committee, on which they would serve. This was something entirely within Mountbatten's training and experience, and he swung into action with all his usual dynamism. He formed a committee of 15 members, consisting of Cabinet ministers and representatives of all the appropriate military and civil services, and set up a military style operational headquarters in Ismay's office, complete with map room, covering the whole area of the Punjab. Alongside this, V.P. and H.M. Patel, who was then Cabinet secretary, set up a similar emergency committee to deal exclusively with the situation in Delhi.

Mountbatten was in his element, and at his most effective. 'He was captain of a destroyer flotilla, chief of combined operations, supreme commander, and governor-general, all rolled into one,' wrote Ismay. 'The Emergency Committee was in practically permanent session; and questions which would have taken days, or even weeks, to settle by the normal procedure were decided in a matter of minutes.'[9] For once, Mountbatten faced a situation where speed really was vital, and he revelled in it. Edwina, meanwhile, plunged into relief work in the refugee camps, where the misery was compounded by the arrival of the monsoon, turning the dust of the camps into a morass of mud. Both Mountbattens rendered great service to the new dominion over this terrible period.

Gradually, over a period of weeks, things were brought under control, both in the city and in the Punjab. By the end of the year, the killings and the mass migrations were coming to an end, and some sort of order was restored. But the scars would be slow to heal. Much of the bitterness and hatred of those traumatic days still remain in both India and Pakistan. And the arguments still rage over whether Mountbatten's madcap rush to grant independence was the main cause of so much suffering. It is easy to be wise 50 years after the event, but on balance the answer must surely be yes. Too many dangerous loose ends were left undone, too many complex problems left unresolved or botched for the sake of speed. In the final analysis, when all the excuses about the threat of civil war and total breakdown of public order are stripped away, we are left with the conclusion that those million lives and several million homes were sacrificed to fulfil a deal between Mountbatten and Vallabhbhai Patel to keep India in the Commonwealth in return for the transfer of power in two months. And we are left with another question: was it worth it?

Among the loose ends left dangling after independence were the three states that had avoided acceding to either dominion: Hyderabad, Kashmir and Junagadh. Junagadh, the smallest of the three with an area of 3,337 square miles and a population of about 700,000, was the most easily dealt with. A maritime state on the Kathiawar Peninsula, it was more or less equidistant by sea from Karachi and Bombay, and by land was about 150 miles south of the Pakistan border. It was also surrounded by smaller Indian states. The nawab, Sir Mahabthakhan Rasulkhanji, was a Muslim though 80 per cent of his subjects were Hindu. After partition, he declared his intention of acceding to Pakistan, which he was legally entitled to do, in spite of the geopolitical chaos it would cause.

Jinnah was happy to accept the state, which could of course connect with Pakistan by sea. The government of India, however, retaliated by imposing an economic blockade of Junagadh, and surrounding it with troops, supplemented by troops from the neighbouring Hindu states, which had acceded to India. A provisional government of Junagadh was formed in Bombay, with Gandhi's nephew Shamdaldas as president. At the end of October, the nawab fled to Karachi, and a week later a Hindu people's liberation army, 20,000 strong and armed and equipped with armoured cars and other modern weaponry by India, marched in and seized the state. Some months later, a referendum produced a vote for accession to India.

Hyderabad was a very different matter. The state lay in the very centre of India, covered an area of 82,000 square miles, had a population of 16 million and annual revenues of Rs 260 million. It had its own currency, issued its own postage stamps, had its own army and even its own airline, Deccan Airways. Its ruling dynasty had been founded in the early eighteenth century by Nizamul Mulk, one of Aurangzeb's most successful generals, whose descendant, His Exalted Highness the Nizam Sir Mir Osman Ali Khan, was one of the richest men in the world. He was also one of the most tight-fisted – the local joke was that he didn't know the word 'spend' was in the dictionary – shuffling around his palace in old carpet slippers and threadbare pyjamas.

The nizam had declared his intention of reverting on 15 August to his status as an independent sovereign of an independent state. He had hoped to acquire separate dominion status for Hyderabad, and was horrified to discover that this was impossible under the Indian Independence Act. Various attempts were made, largely by Sir Conrad Corfield, to win Hyderabad time to come to terms with India. Eventually, Nehru and Patel accepted a one-year moratorium, with the state's future to be decided in August 1948. When the time was up and the nizam still refused to accede, Patel sent in two divisions of the Indian army, in what he described as a 'police action', code-named 'Operation Polo'. After four days' fighting, Hyderabad became part of India.

Kashmir was more complicated, and more dangerous. At 84,471 square miles it was the biggest of all the princely states. It had boundaries with Tibet, China and Afghanistan, and was separated from the Soviet Union only by a small strip of Afghan territory. But although its area was bigger than that of Hyderabad, its population was only about 4 million, the vast majority of whom were Muslims. They celebrated 15 August as Pakistan Day, but the Dogra Hindu maharaja, Hari Singh, continued to procrastinate. As V.P. Menon put it, he was 'in a Micawberish state of mind, hoping for the best while doing nothing'. He played with various political options without following through on any of them. One was to declare Jammu and Kashmir an independent state under his own rule, another was to achieve some sort of *rapprochement* with Jinnah, or with India. In the face of some local unrest, he decided to remove his most dangerous political adversary from the scene and arrested Sheikh Abdullah, who was immediately seen as a prisoner of conscience.

Still trying to buy time, Hari Singh signed a standstill agreement with Pakistan. Patel, however, showed no inclination of signing one on behalf of India – indeed, he took a leaf out of the maharaja's book and did nothing. His policy, as with all the states, was no standstill agreement without accession. And in any case, he was not particularly keen to have Kashmir and all the problems it would bring: he had earlier said that if the maharaja chose to accede to Pakistan, it 'would not be taken amiss by India'.

Unfortunately, Patel's prudence was overtaken by events. On 21 October, some 5,000 Pathan tribesmen from the NWFP invaded Kashmir in lorries and buses. Incensed by crude attempts by the Hindus of Jammu to alter the communal balance in their part of the state, they had declared a jihad in defence of their co-religionists. It was passed off as a spontaneous action, and not an invasion by Pakistan. Others saw the tribesmen as Pakistan's Afghan mercenaries. By the time news reached Delhi three days later, the Pathans had been joined by most of the Muslim soldiers of the maharaja's army, and were well on their way to the Kashmiri capital, Srinagar. Kashmir's only airfield was at Srinagar, and if they could take that before the winter snows closed off the road through Gurdaspur, there would be no way Indian troops could get in for several months. Auchinleck wanted to send in British troops immediately, to protect the 200 or so British residents of Kashmir, but Mountbatten overruled him, refusing to allow British troops to become involved in Kashmir, just as he had refused to allow them to be used in the Punjab. The Defence Committee sent V.P. Menon by plane to Srinagar, to assess the situation and report back.

The maharaja was in a high state of panic, begging to be allowed to accede to India, and calling for military aid. Menon advised him to flee at once to his other palace in Jammu, then himself flew back to Delhi. Mountbatten by this time was advocating immediate military action to defend Srinagar and the Kashmir valley from the tribesmen, but this could only be done if Kashmir was part of India. If the maharaja wanted to accede, then the Indian government should agree. A plebiscite could be held later, after the raiders had been driven out, giving the Kashmiri people the choice of staying with India, joining Pakistan, or becoming independent. The committee agreed. Menon was dispatched to Jammu, with the instrument of accession. The maharaja signed. At first light next morning, the first aircraft carrying Indian troops took off, and by nightfall 329 men of the 1st Battalion the Sikh Regiment had secured Srinagar airport. By the end of the month two more battalions and their support units had secured Srinagar itself and the surrounding area.

Kashmir was now firmly part of the Union of India, but was to remain a running sore, poisoning relations between India and Pakistan for at least the next half century, keeping them perpetually on the brink of war and actually tipping them over the brink in 1965, when General Ayub Khan, by then the president of Pakistan, sent Muslim infiltrators into Kashmir to provoke a rising. The Indian government retaliated by invading West Punjab, pushing its tanks to within gunshot range of Lahore before calling a halt and withdrawing. Since then, Kashmiri guerrillas and Indian police have been keeping the conflict alive, conducting a secret war – a continuing cycle of outrage and reprisal, terror and repression, that seems more reminiscent of Ireland or Algeria than India, a seemingly permanent reminder of the consequences of the mindless haste of 1947. The plebiscite promised 50 years ago is still to be held.

Gandhi never reached the Punjab. He got no further than Delhi, where he stayed in G.D. Birla's luxurious Birla House – his usual abode in the sweepers' quarter was swamped by refugees. He held daily prayer meetings, received deputations, toured the city visiting many of the refugee camps, growing increasingly pessimistic. His feeling of helplessness was profound. On 12 January 1948, he announced another fast unto death, saying he did not wish to live unless there was total peace between India and Pakistan. He was soon in genuine danger of his life: his kidneys stopped working on the third day, and there was acid in his urine. But many Hindus regarded Gandhi's fasts as weakness in the face of Muslim demands. Hindu extremists stood at the gates of Birla House shouting 'Let Gandhi die!' This enraged Nehru, but does not seem to have surprised the object of their anger. Just over three weeks before, Gandhi had written in a letter: 'I know that today I irritate everyone. How can I believe that I am right and all others are wrong?'

Gandhi had done more than irritate people, however. He had driven four members of the Hindu RSSS to plot his assassination. They were Madanlal Pahwa, a 20-year-old refugee from the Punjab; Vishnu Karkare, 37-year-old head of the Poona branch of the RSSS; Narayam Apte, 34, chairman of the RSSS newspaper, the *Hindu Rashtia* (*Hindu Nation*); and Nathuram Godse, 37, editor of the *Rashtia*. On 14 January, Pahwa set off a bomb while the Mahatma was circulating among the crowds in the grounds of Birla House. A second assassin, Digambe Badge, was to start shooting at Gandhi from a window in the servants' quarters. Although the bomb went off, the attempt was a failure. Pahwa was caught by the police, but Badge got away. Gandhi treated the whole thing as little more than a tiresome inconvenience – as did the police, who increased the guard of four men to 16 but otherwise did little to improve security. This was later to become a scandal, reflecting badly on the minister responsible – Patel.

Gandhi continued with his fast, holding court on his death bed as various notables, including the Mountbattens, came to see him. Every hour, on the hour, All-India Radio broadcast bulletins on the state of his health. Clement Attlee, caught up in the drama, sent a message to Jinnah suggesting he make some gesture of reconciliation in order to save Gandhi's life. Jinnah did not respond. It was left to Maulana Azad to negotiate Gandhi's return to life. If total peace was not possible, he asked, what would Gandhi settle for? As so often in the past, the answer turned out to be far less grandiose than the initial demand, and altogether more practical. Gandhi said he was prepared to give up his fast if Hindus would promise to permit the feast day of a local Muslim saint to be celebrated without interference; if 117 mosques were restored to the Muslims; if Muslims were allowed to move freely about the country, and even return from Pakistan if they wished, without threats or intimidation; and if there was no economic boycott of Muslim businesses. Finally, the Indian government must repay the £40 million it had been refusing to hand over to Pakistan as its share of government assets. The government agreed, and Gandhi ended his fast.

On 30 January, Gandhi was late for his prayer meeting – Patel had visited him after a particularly violent row with Nehru at that day's cabinet meeting. At 4.30 p.m. Gandhi left the house and headed for the prayer ground in the large garden to the left of the house, supporting himself as usual with one hand on the shoulders of each of his 'walking sticks' as he called his two young great-nieces, Abha and Manu. As he climbed the steps to the raised wooden platform on which he sat during the service, Nathuram Godse thrust his way towards him through the crowd. Manu tried to stop him, but he pushed her aside so violently that she fell. He drew a Biretta pistol from his jacket pocket and shot Gandhi twice through the abdomen. Gandhi fell. As he was lying on the ground Godse fired a third shot, which lodged in his lung. Gandhi's last words were '*Hey Ram!*' 'Oh God!' The Mahatma was dead, killed by a Hindu who believed he had betrayed his own people, his own religion, his own country.

Jinnah did not survive his old adversary by very long. He was now 72; he had won the longest and most difficult case of his distinguished career, representing the cause of Indian Muslims before the court of history with skill, panache and iron determination. More to the point, he had won for them what he believed they needed. He had defeated the tiresome little Hindu 'god-man' and seen him gunned down by people Jinnah would have described as his fellow fanatics, men who worshipped cows. Surely now, like any successful professional man, he had earned the right to sit in the garden of his house in Mount Pleasant Road on Malabar Hill in Bombay, a welcome glass of Scotch in one hand and one of the Craven-A cigarettes which were undoubtedly killing him in the other, and talk shop with fellow lawyers, or taste the frivolous pleasures of Bombay society. But it was not to be. By now, he was a mere shadow of the man who had, single-handedly, brought Pakistan into being. When a Parsi friend from Bombay, Jamshed Petit, visited him in Karachi, he found him asleep in a chair in the garden of the modest Government House. Jinnah awoke, and whispered, 'I am so tired, Jamshed, so tired.' He looked like a skeleton.

In June, accompanied by Fatima, he flew to Quetta to ease his lungs by breathing the cool mountain air of Baluchistan. His coughing stopped, and he was able to sleep and eat well for the first time in months. Indeed, Fatima recorded that 'For the first time in years, he seemed relaxed.'[10] On 1 July, he was due to speak at the opening ceremony of the State Bank of Pakistan in Karachi. Fatima tried to persuade him not to go, but he insisted. The trip totally exhausted him, and on 6 July his doctors advised him to return to the mountains, this time to Ziarat, which was several thousand feet higher than Quetta. But his condition got worse. Lieutenant-Colonel Ilahi Bakhsh of the Pakistan Medical Service flew from his home in Lahore to examine him. He diagnosed lung cancer. Other doctors confirmed his diagnosis. Mirza Abol Hassan Ispahani, head of the Calcutta financial empire, flew in from the USA to offer the services of an American consultant if Dr Bakhsh thought fit. Dr Bakhsh did not: everything that could be done was being done.

The doctors moved Jinnah back down the mountains to Quetta. By then his weight was down to less than 80 pounds and he was diagnosed with pneumonia as well as tuberculosis and cancer of the lung. He needed oxygen to help him breathe. On 11 September he was flown back to Karachi. His stretcher was placed in a military ambulance at the airport, which then set off for the city, but after a few miles the ambulance broke down. Fatima later recalled: 'There was no breeze, and the humid heat was oppressive. To add to his discomfort, scores of flies buzzed around his face, and he did not have the strength to brush them away.' It took over an hour for a replacement ambulance to arrive. They finally reached Government House at 6.10 p.m. Jinnah slept for two hours, then opened his eyes. The last word he spoke was his sister's name. He died at 10.20 p.m.

The following day, Pakistan's Quaid-i-Azam was buried in Karachi, a few hundred yards from the place where he was born. It was just seven and a half months after Gandhi's body had been cremated at Raj Ghat in Delhi, on the bank of the river Jumna. Gandhi's ashes were consigned to the waters at Triveni, the confluence of the rivers Ganges, Jumna and the underground Saraswati at

Allahabad, where nearly four years earlier the ashes of his wife, Kasturbai, had been scattered to begin their journey to the ocean. Today, Jinnah lies in a magnificent pink marble mausoleum, still a potent icon for the citizens of the country he created.

What of the remaining major players in the independence drama? Vallabhbhai Patel, the eldest at 73, became home minister and deputy prime minister under Nehru, but the differences between them increased. In March 1948, he suffered a major heart attack, brought on, it is said, by accusations surrounding the police failure to round up Gandhi's would-be assassins before the murder. He recovered, however, and resumed his posts in time to direct the 'police action' against Hyderabad, before dying of a second heart attack on 15 December 1950.

Liaquat Ali Khan was a sick man, suffering from stomach ulcers, but remained prime minister of Pakistan while the chief minister of East Pakistan, Khwaja Nazimuddin, became Pakistan's second governor-general. On 16 October 1951, Liaquat was gunned down at Rawalpindi. The assassin, an Afghan, was himself immediately shot. No one was ever charged with Liaquat's murder. Liaquat had been described by Jinnah as 'mediocre' but he was one of the few men the Quaid completely trusted. He was always a decent, honest and honourable man – after his death, it was discovered that he was virtually penniless, having always rejected bribes, lived on his salary and, as long as other refugees were still suffering financial hardship, refused to claim the compensation due to him for his lost family lands back in the UP.

Nehru died from a stroke on 27 May 1964, at his home in Delhi, aged 74. He had been prime minister for nearly 17 years, had become a world statesman, a figure of international importance and the undisputed leader of the non-aligned nations. 'When Nehru left the scene,' wrote S.S. Gill in his recent book *The Dynasty*, 'idealism and greatness walked out of Indian politics.' That may or may not be true, but he had left India a great legacy, the legacy of a stable democracy, a secular republic with no state religion and full protection under the constitution for all minorities. He was largely responsible for defeating the efforts of Hindu nationalists to eject the 30 million Muslims who chose to remain in India after partition – with the ironic result that there are now more Muslims in India than in Pakistan. In the years since his death, he has been followed by 10 prime ministers, each of whom has assumed and relinquished office peacefully and constitutionally with the exception of his own family: his daughter, Indira, was gunned down by her Sikh bodyguards in 1984; her son, Rajiv, succeeded her, but having been voted out of power in the general election of November 1989, was himself assassinated 18 months later while campaigning for re-election.

Mountbatten left India in May 1948, handing over to the first Indian governor-general, Chakravarti Rajagopalachari. He was back in the navy in June,

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as planned, and resumed his interrupted career with conspicuous success, starting with command of the 1st Cruiser Squadron. In due course, he achieved his lifetime's ambition by filling his father's old post as first sea lord, and then went one better by becoming supremo over all three armed services as chief of the defence staff, retiring as an admiral of the fleet. He was assassinated on 27 August 1979, not by anyone connected with India or Pakistan but by IRA terrorists at Mullaghmore harbour in County Sligo, Ireland, where he holidayed each year with his family in Classiebawn Castle, a neo-gothic pile inherited by Edwina from her father's family, the Ashleys. At about 11.30 a.m. that morning, Mountbatten climbed down the harbour steps and boarded his 29-foot fishing boat, *Shadow V*. The boat had just cleared the harbour wall when it was torn apart by a massive 50-pound bomb, killing Mountbatten and three of his passengers, including his 14-year-old grandson Nicholas Knatchbull, and seriously injuring three others.

Having spent the previous few years planning his state funeral in great detail – an interest that had replaced the family tree as his principal hobby – he was buried with all the pomp and circumstance he had wished for. In New Delhi, every shop and office closed, and a week's state mourning was declared. For a while, India remembered the joys of independence, and forgot the sorrows of partition.

There is, the authors of this book have been gratified and astonished to discover, a vast residue of goodwill and even affection in India and Pakistan not only for the British but even for the relatively unlamented British Raj. Gandhi once told a viceroy to leave India to anarchy or to God. Largely because they could not do otherwise, the British did just that – and it has almost worked.

Annex BR4

A. Von Tunzelmann, *Indian Summer: The Secret History of the End of an Empire* (2007)

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Indian Summer

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Alex von Tunzelmann

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The Battle for Delhi

"ONE MILLION DEAD": THIS IS THE MOST CONVENIENT NUMber to have come out of the wildly varying estimates of how many people may have been killed following partition. Mountbatten preferred the lowest available estimate, which was two hundred thousand, and has been widely condemned for it; the denial of holocausts is always a sticky business, and yet more so when one may be implicated personally.[1] Indian estimates have ranged as high as two million. Many historians have settled for a figure of somewhere between half a million and a million. The figure of one million dead has now been repeated so often that it is accepted as historical fact. "What is the basis for this acceptance?" asked the historian Gyanendra Pandey. "That it appears like something of a median?"[2] Unfortunately so, for the truth is that no one knows how many people were killed, nor how many were raped, mutilated or traumatized. The numbers anyone chooses say more about their political inclination than about the facts. Fewer than four hundred thousand suggests an apologia for British rule; four hundred thousand to one million moderation; a million or more usually indicates that the person intends to blame the deaths on a specific party, the most usual culprits being one or more of Mountbatten, Patel, Jinnah or the Sikhs.

Beyond the dead, there were more numbers, too, plucked from the extrapolations and imaginations of regional officials, army, police and historians. Refugees on the move by the beginning of September: five

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hundred thousand, or perhaps one million. Women abducted and raped: 75,000, or perhaps 125,000. Total who would migrate from one dominion to the other between 1947 and 1948: ten million, or perhaps twelve million, or perhaps fifteen million. The Indian National Archives contain sheaves of charts scribbled by British and Indian officials, recording eighty-seven killed in Bengal here, forty-three injured in Madras there. "The figures make no pretence to accuracy," admitted the Home Department. The Punjab government reported that its casualty estimates were "increasing daily as investigation uncovers further tragedies"; the North-West Frontier Province government referred to "stray murders," which were not counted.[3] Usually it was impossible to count the number of victims amid the "confused heap of rubble & corpses" that was left behind after riots.[4] Sir Francis Mudie, governor of the West Punjab, remembered, "[I had to] ignore any report of a riot unless it alleged that there were at least a thousand dead. If there were, I asked for a further report, but I cannot remember any case in which I was able to do anything."[5]

In Stalin's famous words, one death is a tragedy; one million deaths is a statistic. In this case, it is not even a particularly good statistic. The very incomprehensibility of what a million horrible and violent deaths might mean, and the impossibility of producing an appropriate response, is perhaps the reason that the events following partition have yielded such a great and moving body of fictional literature and such an inadequate and flimsy factual history. What does it matter to the readers of history today whether there were two hundred thousand deaths, or a million, or two million? On that scale, is it possible to feel proportional revulsion, to be five times more upset at a million deaths than at two hundred thousand? Few can grasp the awfulness of how it might feel to have their fathers barricaded in their houses and burned alive, their mothers beaten and thrown off speeding trains, their daughters torn away, raped and branded, their sons held down in full view, screaming and pleading, while a mob armed with rough knives hacked off their hands and feet. All these things happened, and many more like them; not just once but perhaps a million times. It is not possible to feel sufficient emotion to appreciate this monstrous savagery and suffering. That is the true horror of the events in the Punjab in 1947: one of the vilest episodes in the whole of history, a devastating illustration of the worst excesses to which human beings can succumb. The death toll is just a number.

Amid these dark tales came one remarkable sign of hope. In Bengal, Gandhi had been faced with the collapse of his hard-won peace. Once again, packs of armed *goondas* (gangsters) ruled the streets of Calcutta. The years had not been kind to Gandhi. The Salt March had been the apogee of his power and influence; the 1930s a struggle, bitter and increasingly opposed, culminating in a private breakdown; the early 1940s a calamity, with the ill-judged Quit India campaign and mass departure of Muslims from Congress; the later 1940s a wilderness, with his presence treated as an irritation. And yet, despite intense personal disaffection and marginalization by his colleagues, the Mahatma would rally for a final, spectacular swan song. With Calcutta detonating around him, he decided to fast.

Used against the British raj during the war, Gandhi's fasts had become useless as a political weapon. The British government had decided to let Gandhi die, concluding that the short-term consequences of Gandhi's death might be easier to manage than the long-term consequences of Gandhi's life. But as a moral weapon the fasts had power, and now a moral weapon was required. Against the *goondas* of Calcutta, Gandhi's fast would prove astonishingly successful.

On 2 September, the Mahatma renounced all food and sustenance except sips of water and reclined on a cot in a public room at the house in Belliaghatta. The effect was unprecedented. Over the course of little more than a day, the city calmed, and the processions to his house changed their temper from angry mob to penitent pilgrimage. From all parties and all faiths, leaders came to beg with him to give up his fast and save his life. He replied that it was not a question of saving his life. The fast was "intended to stir the conscience and remove mental sluggishness"; if the people's consciences were stirred, there might be the side effect that he would live. The hours passed, with burly *goondas* turning up to weep contritely by the Mahatma's bedside. Finally, on the evening of 4 September, when all the city leaders had signed a pledge that there would be no further trouble in

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Calcutta, Gandhi broke his fast with a drink of fruit juice.[6] "In the Punjab we have 55,000 soldiers and large scale rioting on our hands," an awestruck Mountbatten wrote to him. "In Bengal our forces consist of one man, and there is no rioting."[7] To the wonder of all observers, Gandhi's achievement would endure beyond his presence in the city. Aside from a few isolated incidents—no more than in normal times of peace—Calcutta remained orderly for months.

Recovering quickly, the seventy-seven-year-old Mahatma left Calcutta and headed for the place where the need for his moral power was greatest: the Punjab. On the way, he planned to break his journey briefly at Delhi. But by the time he got there, the capital itself would become the new focus of communal fury.

At the end of August the Mountbattens had gone back up to Simla. The day after they arrived, they had held a farewell party for an aide-de-camp who was returning to England. His train was hijacked, and all one hundred Muslims on board murdered—except his own bearer, who hid under a seat. The day after that, the Mountbattens heard that their treasurer and his wife had been killed in another train massacre.[8] In Delhi, panic began. From the city center, smoke could be seen unfurling from nearby villages and the town of Gurgaon. Three hundred Muslims fled to Palam airfield, where they had to be protected by Indian army troops.[9]

Appalled, Edwina told Dickie she was going back to the capital.[10] On 4 September, he was summoned back, too. The Mountbattens arrived the following day, along with Lord Ismay, recalled from his holiday in Kashmir.[11] By that time, Delhi was in turmoil. Blood-chilling reports landed hourly on the desks of government officials. A bomb exploded in the Fatehpuri Masjid, a seventeenth-century mosque at the western end of Chandni Chowk. The police arrived to find a mob throwing bricks at it while troops fired on them. Two Hindus were shot dead.[12] In Karol Bagh, between New and Old Delhi, children of all faiths were taking their matriculation examinations in a local high school, when *goondas* stormed in and demanded that the Muslim boys be separated from the rest. The boys were taken into another room and slaughtered like animals.[13]

Mountbatten set up an emergency committee, which met for the first time that afternoon. Patel was full of rage, while Nehru sat at the table with an expression of all-consuming sorrow on his face.[14] "If we go down in Delhi," Mountbatten told them firmly, "we are finished."[15] He immediately set up a large and splendid map room in Government House, fitted out with lots of charts, graphs and telephones. His staff stayed up for two nights getting all the little flags into the correct places to represent the Punjab boundary. So exhausted was the lieutenant colonel in charge of this effort that he fainted while showing the committee around the room on 8 September.[16] Mountbatten devoted much of his own time to concerns such as whether visitors ought to come through a special entrance and be given a special pass.[17]

At the suggestion of Nehru, Edwina Mountbatten was put in charge of the emergency committee's refugee group. While Dickie was still fiddling with his map room, Edwina established and chaired the United Council for Relief and Welfare. It was a swift, effective and hands-on attempt to deal with the reality of the situation. Edwina coordinated fifteen separate relief organizations, two government ministries and one Mahatma into a single targeted team with clear instructions and purpose.[18] She began touring the worst areas of trouble, mobilizing volunteers and personally directing the Red Cross effort to improve water, sanitation and medical supplies. Through the United Council, she suggested initiatives ranging from the establishment of a sister organization in Pakistan, all the way down to the setting up of Girl Guide knitting circles to provide pullovers for refugees.[19] A sure sign of her effectiveness was that the governor-general's aides-de-camp began to try to avoid being on her staff. Anyone required to serve with Edwina would have to help with a variety of gruesome tasks in unpleasant locations. She stopped her car when she saw injured or dead people, got out, dodged bullets and retrieved their bodies to take them to hospitals or morgues. She also ordered her husband's personal bodyguards to forget about him and patrol the hospitals, following a number of unspeakable attacks on helpless patients as they lay in the wards.[20] In Edwina's wake, the

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main emergency committee also got into its swing, canceling all holidays—including Sundays—to keep the economy going, punishing errant officials and arranging a volunteer police force.

The battle to bring Delhi back under control was prolonged and vicious. On 6 September, a bomb was thrown into New Delhi's packed railway station, aimed at fleeing Muslims. The police arrived and fired into a massed Hindu crowd. By this point, 450 were reckoned to have been killed in the previous forty-eight hours of rioting alone. But the worst was still to come. The following day, outbursts of violence erupted all across Delhi, so simultaneously and so brutally that many thought it must have been planned. Looters descended on Connaught Circus, the huge central plaza of New Delhi, built by the proud British as concentric circles of graceful neoclassical arcades. This forum was filled with a baying mob, which began to smash up Muslim-owned shops. The army arrived and attempted unsuccessfully to disperse the crowd with bullets and tear gas. Nehru himself arrived a little later armed with a stick, plunged into the crowd and chased looters away from outside the Odeon Cinema. The orgy of destruction was not confined to *goondas*. The writer Nirad Chaudhuri, who was present, described middle-class couples strolling away from the scene, loaded down with stolen handbags, cosmetics and bottles of scent. He also saw tongas, the light horse-drawn taxis mainly driven by Muslims, left burning by the sides of the road. Their drivers had been dragged from them and murdered. When he returned to his house, he looked back on a view of the city colonnaded with pillars of smoke from arson attacks, and soundtracked by the screams of fire engines and bursts of gunfire. That evening, six thousand Muslims fled from their homes in the middle-class Lodi Colony to the Pak Transfer Office in Connaught Place.[21]

The rest of 7 September was punctuated by repeated blasts of fire from Sten guns.[22] Serious rioting was simultaneously under way in the princely state of Mysore in the south. In Bangalore shops were looted, apparently by police as well as civilians, and congressmen arrested for lawbreaking.[23] In Karachi that day, Jinnah was holding a garden party for the Emir of Kuwait, which was gate-crashed by five hundred government workers demanding the rescue of their families from Delhi. Karachi itself had seen a slew of train attacks, bombings and assaults.[24]

By this point, thousands of Muslims had clustered in any part of Delhi that offered sanctuary: the Jama Masjid; the Purana Qila (Old Fort); Muslim graveyards and Mogul ruins; the Pakistani High Commission; the houses and gardens of well-known Muslims, including Nehru's two Muslim cabinet ministers, Abul Kalam Azad and Rafi Ahmed Kidwai; and even Humayun's Tomb, the same gorgeous marble mausoleum that had briefly sheltered the fleeing Mogul emperor Bahadur Shah II ninety years before.

Outside the camps, things kept getting worse. On 8 September at Sabzimandi, north of Old Delhi, a confrontation between troops and rioters lasted for twelve hours, leaving the roads "littered with bodies," and the town "burnt to ashes," according to the British high commissioner.[25] Paharganj, just north of Connaught Circus, was reported to be "like a battle-field," its streets filled with dead animals, its buildings ablaze, and the constant pattering of machine-gun fire in the air.[26] All flights from Bombay and other cities into Delhi were canceled. Reports suggested that six hundred thousand were involved in rioting in the city, and Muslim estimates put their death toll at ten thousand. The telephone, telegraph and mail systems shut down, as did all public transport.[27] A shoot-to-kill order was issued to Delhi police and armed forces. Patel called the Sikh leaders to a meeting and threatened to set up "concentration camps" and put all Sikhs in them unless the leaders appealed for an end to the violence. They duly did.[28] All weapons were banned except, to Jinnah's fury, Sikh *kirpans*, which had to be sheathed.[29] In conjunction with Pakistan's prime minister, Liaquat Ali Khan, Nehru organized an airdrop of more than one hundred thousand leaflets over the Punjab, saying that lawbreakers would be hunted down without mercy or hesitation. By the end of the day, the number of Muslims in the Pak Transfer Office in Connaught Place had doubled to twelve thousand.

The following day, the riot spread to Bara Hindu Rao, on the north side of Old Delhi. Insurgents had equipped themselves with hand grenades and firearms, and the police and troops had great

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difficulty in regaining order. More than five thousand residents had to be evacuated the following morning.[30] The Pakistani high commissioner, who had no means of communicating with his government and had long run out of food, absconded to the airfield with the intention of escaping to Karachi. Mountbatten heard in time and sent a member of his staff to go and pull the man off the plane. The governor-general was acutely aware that the arrival of a hysterical diplomat "would have sent Mr. Jinnah through the roof."[31] Such was the confusion that the Pakistani government received the impression that its high commissioner had been murdered, and a diplomatic incident was only narrowly avoided.[32] The high commissioner was persuaded to delay his departure for two days and allow Lord Ismay to accompany him, but once they got to Pakistan, Ismay was unable to force the terrified man to return to Delhi.[33]

Filled with aggrieved Sikhs, Hindus and Muslims, the capital had become a crucible for the rages that had boiled up across the Punjab. Large-scale riots were no longer a daily but an hourly threat. In terror, the citizens of Delhi began to mark themselves out with visible signs that they were not Muslim. Hindus shaved their hair to leave a traditional *shikha* tuft on the crown and left shirts unbuttoned to show the white sacred thread worn across the chest. Indian Christians began to sew large red crosses onto their shirts. All the shops in central Delhi displayed placards saying "Hindu Shop," regardless of their ownership. These public displays of religious identity only made the conflict more tribal.[34]

"We are dealing with a situation which is analogous to war," announced Nehru on All-India Radio, "and we are going to deal with it on a war basis in every sense of the word."[35] But his tough stance isolated him from many in Congress, who conspicuously refrained from condemning Hindu atrocities in the fear that they would lose the support of the Hindu majority. Nehru reminded the party's president, Rajendra Prasad, that under Gandhi's leadership Congress had always condemned even minor acts of violence. Now its politicians refused to criticize murder, rape and communal hatred. "I have no stomach for this leadership," Nehru wrote in disgust. "Unless we keep to some standards, freedom has little meaning."[36] All hopes were now pinned on the small, khadi-draped figure who arrived in the capital by train that day.

Gandhi arrived back to great acclaim and expectations. "Delhi will now be saved," Muslims told each other. "Muslims will now be saved."[37] It was not just Muslims who would be saved, but Nehru, too. Gandhi returned from his triumph in Calcutta with his reputation at a new high and immediately made his support public for Nehru's unpopular policies of protecting Muslims, maintaining full religious tolerance and avoiding war with Pakistan. His arrival had come at a time of desperate need. For those who had survived the riots so far, conditions in Delhi were grim. Communal feeling was so ingrained that, despite Nehru's efforts, Indian government aid had only found its way to Hindu and Sikh refugees. Muslim refugees had been left to the Pakistani High Commission and nongovernmental peace committees. Gandhi insisted that the government take responsibility for all faiths.[38] Finding that the Untouchable settlement at the Bhangi Colony was now a refugee camp, Gandhi roomed in the grand New Delhi mansion of his sponsor, G. D. Birla. He visited dangerous sites, though with difficulty. When he visited Hindu camps, so uncontrollable was the "rush for *darshan*," according to the *Times of India*, that he did not get a chance to speak.[39] One of the first people to visit him was Edwina Mountbatten. Through her efforts for the refugees she formed a working bond with Gandhi that was even closer than her friendship with him in the months before partition.

In response to the crises of September, Nehru flourished. One of his oldest friends, Sri Prakasa, remembered sitting in sickened silence at the thought of the crisis when Nehru came and sat by his side. "There are only two things left for us now, Prakasa," Nehru said with affection. "To go under or overcome our difficulties. And we are not going under."[40] He devoted himself to his constant work with courage and diligence. "Almost alone in the turmoil of communalism," noted Alan Campbell-Johnson, "he speaks with the voice of reason and charity."[41] He set up a city of tents in his garden and filled that and his house with refugees, including two Muslim children he had personally rescued from a roof in Old Delhi while a riot raged below.[42] Every day, he walked in the streets and listened to people tell him their sorrows. "I know, I know, mere bhai [my brother], it is my sorrow too," he replied.[43] The old Nehru temper flared up frequently. Jawahar was being driven in his official car when he noticed a Hindu passerby with a cart full of loot from a Muslim neighborhood. Immediately, he leaped out and told the thief to take it back. "They have their Pakistan, we will have our Hindustan," replied the man, at which Jawahar flew into a rage, grabbed him by the throat and shook him. "If I must die it is an honour to do so at your hands, Panditji," gasped the man. Jawahar dropped him in disgust and returned to his car.[44]

During that first September fortnight, Jawahar's friendship with Dickie Mountbatten strengthened. "He has come suddenly to see me alone on more than one occasion—simply and solely for company in his misery; to unburden his soul; and to obtain what comfort I have to give," Dickie wrote to the king.[45] But Jawahar's relationship with Edwina Mountbatten became more important still. While Dickie chaired committees, both Jawahar and Edwina fearlessly went out into the streets of Delhi to deal with the rioters. Edwina was with her friend, the health minister Amrit Kaur, when they heard that Jawahar had gone out alone. They went out and found him attempting to stop a crowd of armed men. "Brought him back!" Edwina wrote.[46] Another evening, Jawahar heard of an attack planned on the Jamia Millia Islamia, a Muslim college outside Delhi. The college was in the middle of riot-torn countryside. At night, the students, fearing for their lives, turned off their lamps and stood guard. They could hear splashes as Muslims from nearby villages were chased into the Jumna River, pursued by mobs intent on drowning them. Without waiting to organize a bodyguard for himself, Jawahar got into a taxi and drove alone through the treacherous countryside straight there—only to find Edwina already on the site, without guards, trying to pacify the would-be raiders.[47] "Did we get our freedom so that you could kill each other?" Jawahar shouted at the mob. "He was," noted one observer, "a man who had no fear."[48]

Again and again, events brought the two together. Richard Symonds, a friend of Edwina's who was working alongside her in Delhi and the Punjab, noted the value of her friendship with Jawahar for the relief effort. "If we had problems where the prime minister's attention was needed," he remembered, "she'd got it."[49] At eleven o'clock one evening, Jawahar's sister Betty was in her brother's house at York Road, when a telephone call came through from Edwina. Jawahar was not in, so she took the call—noting with interest that the governor-general's wife had telephoned her brother personally, rather than having an aide-de-camp ring up. "Haven't you heard that there is fighting between a Hindu and a Muslim camp?" Edwina asked. "The rumor is that a Muslim from his camp shot a Hindu woman in their camp. So now the Hindus are up in arms throwing stones at the Muslims who are unable to protect themselves; and there aren't enough guards. So I am going down there and I called to see if your brother would like to come with me, but of course . . ."

Without hesitation, Betty offered to come in Jawahar's place. Edwina at first demurred. "I can't have you hurt or dead on my hands," she said; but eventually she agreed that Betty might be helpful. Shortly afterward, she arrived in a jeep, escorted by another in front and one behind, with discreetly armed guards. Together, the women drove out of the city to the Muslim camp in question. It was surrounded by an enormous and agitated crowd of Hindus and Sikhs, who were attempting to set it on fire. The few guards present could do little and had been backed against the wall. The man whose wife had been shot was leading the arsonists, screaming, "Nehru is protecting the Muslims and this is what they do!"

Edwina climbed out of the jeep, pushed past her guards and positioned herself between the mob and the camp gate. She turned to face the crowd, bricks and stones whizzing over her head, "as calmly as though she were at a garden party in the Moghul Gardens," remembered Betty. Edwina started to address the mob, but her command of Hindustani was inadequate. Betty took over, jumping on top of the jeep and shouting for the crowd to stand down. She told them that her brother was away but would be back the next day and would be sure to find the murderer.

Some of the protesters calmed down at her words, but the widowed man still attempted to incite them further. "All right," Edwina said to Betty. "Now tell them that if they continue this way we will

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order the guards to shoot down the agitators, it doesn't matter which side they are on."

Betty realized immediately that calling the mob's bluff was a risky strategy. Even with their guards, she and Edwina were massively outnumbered by the rioters. If it came to a fight, they would probably be torn to pieces. But, lacking other options, she shouted out the message. To her great relief, it worked. The shouting stopped, and the crowd dispersed.

When the panic had subsided, Edwina and Betty went into the camp to talk to the terrified Muslims, who pleaded their innocence and said they had no guns. Betty was inclined to believe them. Most were half naked, and none had many possessions. An hour later, they headed back to York Road, to find Jawahar just returned. Edwina told him the story. "Poor Bhai was so tired and distressed that he flew into one of his fine rages, angry at both sides," Betty remembered. He started an investigation the very next morning. It found that the dead woman had long been ill with tuberculosis. Worn out by caring for her, her husband had shot her himself—and blamed it on a Muslim. Unlike most of those involved in the partition war, who escaped prosecution, he was later convicted of murder.[50]

At the beginning of September 1947, Edwina noted in her diary her surprise at how deeply fond of Jawahar she had become.[51] The feeling was obviously mutual. In at least one photograph of the two of them visiting a refugee camp, Jawahar's hand can be seen clasped protectively around Edwina's. Jawahar's niece Nayantara Pandit came to live with him in October and observed the relationship firsthand. "It was a very deep emotional attachment, there's no doubt about that," she remembered. "I think it had all the poignance of the lateness of the hour . . . that terrible cut-off-ness from the world, and anxieties about India, where are we going, all the rest of it. And then to find this—and for her, apparently, also a great and unique love."[52]

Dickie would subtly facilitate Edwina's relationship with Jawahar, just as he had with her other lovers; more so, in fact, for he liked Jawahar. But stoicism comes at a cost, and there is a glimpse of it in a letter Dickie wrote to Noël Coward in October. The film at Govern-

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ment House had been Coward's masterpiece, *Brief Encounter*, released two years previously and recommended to Dickie by Noël at the time.[53] In it, a woman married to a kind but undemonstrative man falls in love with a passionate doctor. She goes through a spectrum of feelings, from exhilaration to despair; her husband simply keeps doing the crossword. Dickie, too, was firmly entrenched in the role of the accepting husband, though he preferred genealogy to crosswords. The congruence between the film and his own situation can only have been enhanced by the fact that Coward had based scripts on the Mountbattens before; and that Celia Johnson, the Edwina-look-alike actress in the lead role, had appeared in Coward and Mountbatten's *In Which We Serve* as the wife of the Mountbatten character.

"I have just seen 'Brief Encounter' in our private cinema, and cannot refrain from writing to tell you how deeply it moved me," wrote Dickie to Noël.[54] The two men had drifted apart somewhat in recent years, but something about *Brief Encounter* had affected Dickie on an intimate level. It is almost the only instance among all his papers in which he can be seen to respond emotionally to any piece of art.[55]

So GREAT had been the drama inside Delhi that it would have been possible to forget that the Punjab had not yet calmed. Richard Symonds drove up the Grand Trunk Road in late September and observed fresh Muslim corpses by the side of the road. At a railway station, he saw a band of one thousand Sikhs, armed with spears and *kirpans*, awaiting the arrival of the Pakistan Express with its consignment of Muslim refugees. When he arrived at the huge Kurukshetra refugee camp, it was to a scene of total disaster: cut off by monsoon rains and flooding, the camp had little food, no clothing, no blankets, no lighting, no medical supplies and twice the number of people that it could accommodate in its tents.[56]

On 21 September, the Mountbattens took Nehru, Patel and a few others on a round-trip in Dickie's plane to view the Punjab migrations. Near Ferozepur, they found the first caravan—and followed it for over fifty miles against the stream of refugees without finding its source.[57] The refugees moved slowly, in bullock carts or on foot, carrying children, the elderly and the infirm on their backs. Vultures followed the convoys, waiting for deaths which came frequently. Exhausted families would sometimes be forced to abandon their invalid relatives by the roadside rather than carry them along.[58] Suffering pushed the communities further apart. Punjabi Hindu women entering Delhi openly rejoiced at the sight of streets filled with Muslim corpses. According to Nirad Chaudhuri, "the group of corpses which drew forth the strongest expression of delight from the ladies was that of a mother lying dead with her dead baby clasped in her arms."[59]

That night, the party returned to Government House, where the Sunday film was *A Matter of Life and Death*, and the Sunday dinner was austere. The severe rations in Government House became severer still under Edwina's watchful eye. When Lord Listowel, the former secretary of state for India and now the secretary of state for Burma, came to visit, the Mountbattens threw a full ceremonial banquet with all the state pomp—and served a first course of cabbage water, followed by a main course of one slice of spam with a potato, and finished off with a solitary biscuit and a small piece of cheese.[60] "The ADCs are mad with rage at me," Edwina wrote with satisfaction, "as they think food can be spirited out of the skies."[61]

Even after Delhi was subdued, the situation outside Government House remained dire. The camps had not been prepared; there was no water, no food, no sanitation, no security. Anees Kidwai, the widow of a murdered government official and sister-in-law of Communications Minister Rafi Ahmed Kidwai, went to work in the camp at the Purana Qila. She described a jumbled mass of tents among which "naked children, unkempt women, girls without their heads covered and men overcome with anger wandered up and down endlessly."[62] Still no one kept count of how many Muslim refugees there were. By the middle of September, around 60 percent of the Muslims of Old Delhi and 90 percent of the Muslims of New Delhi were thought to have left their homes. There were thousands clustered into each of the biggest camps, at the Purana Qila and Humayun's Tomb: perhaps 60,000 in each, perhaps 80,000, perhaps even 100,000. Thousands more had been killed. Was it 20,000 now? Or

30,000? No one knew.[63] Someone had counted 137 mosques damaged, a few of which had been forcibly converted into Hindu temples, looted for their libraries and hung with flags of the fundamentalist Hindu Mahasabha. Gandhi mourned and condemned the desecration as "a blot on Hinduism and Sikhism."[64]

To THE north and east, Pakistan fared ill. Like India, it suffered riots; trains full of dead bodies turned up in its stations; rich Hindu merchants streamed out of its cities, despite efforts by the Pakistani government to persuade them to stay.[65] Grim conditions prevailed at West Pakistan's refugee camps. Richard Symonds remembered gaunt women with half-starved babies throwing themselves at his feet, their ration in some camps just two ounces of flour a day—enough to make one single chapati.[66] Unlike India, Pakistan had to deal with these problems on an empty treasury. The Punjab, its only profitable region, had collapsed. As a result of the migrations, Pakistan had lost four million people who had been settled, established and productive, and gained five million destitute refugees.[67] British India had not been poor, but the dominions had not yet agreed on the details by which its assets would be divided between them. In the meantime, India held on to the lot, while Pakistan struggled to cope. Even at the most basic level, the logistics of setting up the new government had proven impossible. When Ghulam Mohammed, the finance minister, had turned up in his Karachi office on 15 August for his first day's work, he had found it bare except for one table. Everything else had been sent on a train from Delhi and looted en route.[68]

Jinnah was livid at what he saw as a deliberate sabotaging of Pakistan. In early September, Ismay had visited him in Karachi and, according to Alan Campbell-Johnson, found the Quaid-e-Azam seething on the brink of "precipitate action."[69] He wrote irate letters to Attlee, demanding the help of the Commonwealth; but Attlee had no intention of wading into a fight between two dominions.[70] Jinnah appealed to all the other Commonwealth governments directly, and Ismay began to suspect his aim was to push India out of the Commonwealth altogether.[71] At the beginning of October, Jinnah sent another long letter to Attlee. By then, the strain was making him ill. Jinnah's writing was full of spelling mistakes and repetition. "I regret to say that every effort is being made to put difficulties in our way by our enemies in order to paralyse or cripple our State and bring about its collapse," he began. "It is amazing that the top-most Hindu leaders repeatedly say that Pakistan will have to submit to the Union of India. Pakistan will never surrender."[72] At the bottom, the usually sharp "M. A. Jinnah" was signed with a tremulous hand.

Under the circumstances, Jinnah saw that he would have to cultivate international allies. On 7 September, he had told a cabinet meeting that communism could "not flourish in the soil of Islam," and that Pakistan's interests would best be served by friendship with "the two great democratic countries, namely, the U.K. and the U.S.A., rather than with Russia."[73] Jinnah sought to present his new nation as a crucial strategic ally: a buffer zone between Communist Russia and dubious India, and a vantage point between China and the Middle East. For most of the nineteenth century, Britain and Russia had played the "Great Game" for primacy in central Asia. Now a new Great Game was beginning, and elements in the U.S. government were already beginning to realize that Pakistan—though they had opposed its creation—presented a more amenable prospect than India. From Jinnah's point of view, this had one great advantage: money. The Pakistani finance minister had already brought up the question of possible financial aid with the American embassy in Karachi. Pakistan now asked the United States for a massive $2-billion loan, for the purposes of development and defense. In December, to the great disappointment of the Pakistani government, the Americans would offer a more realistic $10 million. But the Cold War was only just beginning; Pakistan's argument that it should be supported for being anti-Russian would be taken more seriously by the late 1950s, with happy results for its treasury.[74]

In the meantime, Jinnah was forced to go begging. He sent a letter to the Nizam of Hyderabad on 15 October, reminding him of the "special claim" Pakistan had on his state, and that "the resources of the Dominion of India are very vast whereas Pakistan is starting from scratch." He concluded: "Please do not think that I am trying to get more money. God is great, and we shall go through this dire calamity which has overtaken us."[75] Three months later, he would ask the nizam directly for a large loan.[76]

The status of Hyderabad troubled India, too. To Patel's embarrassment, Nehru put Mountbatten rather than him in charge of negotiation. Patel's relationship with Nehru, never great, was rapidly souring. Patel made it clear that he thought Nehru was too soft on Muslims. Nehru made it clear that he disliked Patel's Hindu-chauvinist tone. With almost half of his cabinet tending toward the establishment of India as a Hindu nation, Nehru had to fight an increasingly hard battle against the swell of fundamentalist feeling.[77] "As long as I am at the helm of affairs India will not become a Hindu state," Nehru announced in a public speech, with a deliberate dig at the orthodox members of his government. "The very idea of a theocratic state is not only medieval but also stupid."[78] Lord Addison visited Delhi and Karachi in October and reported back to Attlee his fears about Patel. If Nehru's government fell, he warned, Patel would probably take over and install "an iron-handed system," openly hostile to Pakistan.[79]

While the bigger problem of Hyderabad fermented, the Indian and Pakistani governments had their opening skirmish over another princely state. Junagadh was a small state wedged firmly amid Indian territory in Kathiawar. The Nawab of Junagadh was a Muslim, ruling over a population that was over four-fifths Hindu. Accession to Pakistan, while tricky, was not impossible: Junagadh had a port on the Arabian Sea, within reach of Karachi.[80] The nawab wavered before, on 16 September, his Muslim League government acceded to Pakistan.

Coming so soon after the great insurrection in Delhi had been quelled, the petty affair of Junagadh provoked a far more serious reaction than it warranted. Patel wanted to send troops in immediately. Nehru was more circumspect. Mountbatten suggested to Nehru and Liaquat that both India and Pakistan should abide by the results of a plebiscite, a procedure he hoped they would follow for any state. Nehru nodded dejectedly, but Liaquat's eyes lit up. Mountbatten noted that "there is no doubt that the same thought was in each of their minds—'Kashmir!' "[81] Shortly afterward, the nawab packed up his beloved dogs—of which there were eight hundred, each with its own keeper—and absconded to Pakistan, leaving his government and his subjects in some confusion.[82] At the beginning of November, India sent troops in at the invitation of the Junagadh administration, to the fury of Pakistan. The promised plebiscite, held in February 1948, would count only 91 votes for Pakistan, against 190,779 for India.[83]

Lord Addison's assessment of the situation between India and Pakistan made uncomfortable reading for those back in London. Jinnah was in such a weak position financially, militarily and administratively "that he would be quite unable to take any action against India even if he wanted." Rather, Addison believed, the Quaid-e-Azam was anxious to maintain, and possibly even increase, British involvement in Pakistan. "I think it cannot be doubted that the danger to the British connection, and to the eventual success of our policy for the establishment of a progressive Indian democracy, comes much more from India than from Pakistan," he concluded.[84] As far as the government in London was concerned, Mountbatten might well be on the wrong side.

By October, there were thought to be around four hundred thousand Hindu and Sikh refugees from the Punjab in Delhi. Thousands could not even fit into the tent city that Nehru had set up outside the capital, a sad and grimy echo of the gorgeous campsite that had been pitched there for his wedding, thirty-one years before. Delhi's own population had been devastated: 330,000 Muslims had left, representing around one third of the city's population.[85] Many refugees were obliged to camp out on Delhi streets, and courtyards, doorways and gutters were filled with their huddled bodies. The death toll continued to rise, not only from the epidemics of cholera, typhus and smallpox that issued forth from the unsanitary camps, but also from traffic accidents. Dozens of refugees who had collapsed, worn out, to sleep on the streets were run over each night.

"At times I could not believe my eyes or ears," remembered Edwina a year later. "All I can tell you is that the people I was privileged to work with did a superhuman job and I would like to say that they were of all religions, of all nationalities, and of all beliefs. I worked with Hindus, Muslims, Christians, Sikhs, Parsees, with people from India, Pakistan, Canada, China and America."[86] She and Amrit Kaur continued to coordinate the relief effort, ensuring that vaccines were flown in from Bombay, Madras and Calcutta, and organizing campaigns to inoculate the migrants before they reached Delhi. Edwina also kept Betty Hutheesing on call to visit hospitals, clinics and camps. "It was amazing to see her in those terrible places," remembered Betty, "neither patronizing, nor oversympathetic, but just talking naturally to the inmates. This is the hardest thing of all to do when people are destitute, hopeless or dying."[87]

Edwina coped well, but the stress was exacting a terrible toll on Jawahar. "Ever since I assumed charge of my office, I have done nothing but tried to keep people from killing each other or visited refugee camps and hospitals," he said. "All the plans which I had drawn up for making India a prosperous and progressive country have had to be relegated to the background."[88] Speaking at the end of September, he did not yet know that arguably the greatest challenge of all was just about to begin.

Annex BR5

“New Moore isle no more, expert blames warming”, *Times of India*, 25 March 2010, (available at < http://articles.timesofindia.indiatimes.com/2010-03-25/global-warming/28119002_1_ghoramara-global-warming-rise-in-sea-levels>)

New Moore isle no more, expert blames warming

TNN Mar 25, 2010, 01.31am IST

Tags: Bay of Bengal

KOLKATA: The New Moore island near the Bay of Bengal is being swallowed by the rising sea, making it one of the earliest instances of a patch of territory ceasing to exist because of global warming.

New Moore Island, also known as Purbasha island, is at the confluence of Ichhamati and Rai Mangal rivers near the Bay of Bengal. But it remains almost perpetually submerged, peeping out only in the event of a very low tide. The startling fact about its submergence emerged from satellite images in 2009. These were studied by a team led by Sugato Hazra, director of Jadavpur University's school of oceanography studies. "There's no trace of the island anymore. After studying satellite images, I reconfirmed this from fishermen," Hazra said on Tuesday.

Till the early 1980s, New Moore Island was claimed by both India and Bangladesh. Dhaka called it South Talpatti island. With the 3-km long and 3.5-km wide island disappearing, an irritant in Indo-Bangladeshi ties may have gone.

Although many environmentalists are yet to endorse the view that global warming is pushing up sea levels, rising temperatures are definitely responsible for the phenomenon, said Hazra. "Nobody lives on the island now. Coastal erosion and rising temperature in the Bay of Bengal between 2000 and 2009 led to the Purbasha island getting submerged. Temperature in the region has been rising at an annual rate of 0.4 degree celsius," he said.

Four super cyclones — Aila, Cedar, Bijli and Nargis — hit the southern parts of the Sunderbans between 2007 and 2009. In 1996, Lohachara Island, too, in the Hooghly estuary had disappeared under water. "It had 4,000 inhabitants then. They were all compelled to relocate," said Hazra. Lohachara later resurfaced. But no studies were conducted to prove the island submerged due to global warming and a consequent rise in sea levels.

According to Hazra, the islands of Ghoramara in the Hooghly estuary and Jambudeep near the Bay of Bengal, too, are slowly sinking. Ghoramara is inhabited. On islands like Bulcheri, Bhangaduani and Dalhousie facing threat from the rising sea, the tigers risk getting wiped out. Besides, there are other inhabited islands which face erosion, flooding due to storms and rising salinity of water," said Hazra, who conducted the research along with Anirban Mukherjee and Anirban Akhand of the university's school of oceanography studies.

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N. Najib and S. Ali Bernama, “Oil Blocks ‘Giveaway’ to Brunei”, *The Malay Mail* (30 April 2010) (available at <http://stage2.mmail.com.my/node/35121>)

Published on *The Malay Mail* (http://stage2.mmail.com.my)

Oil blocks 'giveaway' to Brunei

Thursday, May 06, 2010 - 10:31
yeap [1]

PETALING JAYA: Democratic Action Party (DAP) adviser Lim Kit Siang has called on former prime minister Tun Abdullah Ahmad Badawi to explain the 'release' of oil producing offshore areas in South China Sea as claimed by former premier Tun Dr Mahathir Mohamad in his blog yesterday.

Lim told *The Malay Mail* this morning that Pak Lah must clarify Dr Mahathir's claims.

"As a matter of grace and national interest, Pak Lah must respond. We have to establish the facts of the matter first.

"If what Dr M says is true, issues like this should never be hidden. Pak Lah must speak. If not, people would be jumping to conclusions," he told *The Paper That Cares*.

Yesterday, Dr Mahathir in his blog www.chedet.com [2], claimed that Abdullah, during the latter's tenure as PM, had agreed to surrender two blocks of oil producing offshore areas in the South China Sea — Block L and Block M — to Brunei in return for Limbang in Sarawak.

He had written that Block L and Block M had been claimed by Malaysia based on historical facts. The two blocks were awarded to Petronas Carigali Sdn Bhd in 2003 and entered into a production sharing contract with Murphy Oil Corporation to start drilling.

It was estimated that the reserves amounted to almost 1 billion barrels.

"Abdullah has caused Malaysia to lose at least US100 billion dollars (about RM320 billion) of Malaysia's oil in this agreement," Dr Mahathir wrote.

He had claimed that when Abdullah negotiated with Sultan of Brunei Sultan Hassanal Bolkiah, no Petronas representatives were present but only foreign office staff and the foreign affairs adviser to the PM were present.

Dr Mahathir has called for Wisma Putra to explain why it did not stop Abdullah. A Wisma Putra spokesman said they are still investigating the matter.

Abdullah says Cabinet approved boundary pact with Brunei

KUALA LUMPUR: (Bernama) -- Tun Abdullah Ahmad Badawi said he signed a land and sea boundary agreement with Brunei in March 2009 in which two overlapping offshore exploration fields came under Brunei after it was approved by the Malaysian Cabinet a month earlier.

In a statement on Friday, the former prime minister confirmed that Block L and Block M concessions now belonged to Brunei but the agreement provided that Malaysia would be allowed to participate in joint development of oil and gas on a commercial basis in the two areas for a period of 40 years.

"The financial and operational modalities for giving effect to this arrangement will be further discussed by the two sides. This means that in so far as the oil and gas resources are concerned, the agreement is not a loss for Malaysia," said Abdullah who had visited Bandar Seri Begawan for a two-day working visit on March 15 and 16 last year before he stepped down as prime minister two weeks later on April 3.

Abdullah was responding to questions raised by his predecessor, Tun Dr Mahathir Mohamad, who said Abdullah had surrendered the two blocks in negotiations with the Sultan of Brunei in exchange for Limbang which straddles the Sarawak-Brunei border.

Dr Mahathir said the loss of the two blocks cost Malaysia at least US$100 billion dollars (RM320 billion) from an estimated reserves of almost one billion barrels of oil.

Dr Mahathir also said Brunei had disclaimed that it had agreed to give up Limbang and Abdullah had made no mention of the two blocks when he announced that he had settled the Limbang claim.

Last week, United States-based Murphy Oil Corp said Malaysia's Petroliam Nasional Bhd (Petronas) had terminated the production sharing contracts for Blocks L and M as they "are no longer a part of Malaysia".

Abdullah, revealing details of the agreement for the first time, said he had signed the Exchange of Letters with the Sultan of Brunei on March 16 last year in specific steps to finally establish a permanent land and sea boundary between the two countries.

"In my capacity as the Prime Minister of Malaysia, I signed the Exchange of Letters with the Sultan of Brunei after the Malaysian Cabinet approved the deal on 11 February 2009," he said.

The two sides agreed to undertake a joint survey to demarcate the land boundary in two ways.

Firstly, the joint survey would confirm the ground boundary in five sectors which had already been established by previous agreements in 1920, 1931, 1933 (two separate agreements) and 1939.

Secondly, in the sectors where there were no agreements yet, the joint survey shall determine the land boundary on the basis of the watershed principle.

"When the entire land boundary demarcation exercise is completed, there will be established a final and permanent boundary between Sarawak on the Malaysian side and Brunei on the other side.

"When this is accomplished, there will no longer be any land boundary dispute between Brunei and Malaysia as a whole. This long standing issue, which had existed in the past as an irritant in the relations between Malaysia and Brunei, will be settled without any disadvantage for Malaysia," Abdullah said.

On the maritime area, he said the two countries agreed to establish a final and permanent sea boundary.

"This agreement serves to settle certain overlapping claims which existed in the past which included the area of the concession blocks known before as Block L and Block M.

"Sovereign rights to the resources in this area now belongs to Brunei.

However, for this area the agreement includes a commercial arrangement under which Malaysia will be allowed to participate, on a commercial basis, to jointly develop the oil and gas resources in this area for a period of 40 years," he said.

Details of this would be further discussed and thus, in so far as oil and gas resources, the agreement was not a loss for Malaysia, he added.

Petronas invited by Brunei to develop Block L and M

KUALA LUMPUR: The national oil corporation, Petronas, said today it has been invited by Brunei to develop two offshore exploration areas formerly designated as Blocks L and M on a commercial arrangement basis.

In a statement, Petronas said it had set up a team and had begun negotiations with Brunei to work out the terms for the development of the two areas now known as Blocks CA1 and CA2.

"Both parties are committed to arriving at a mutually beneficial arrangement as soon as possible," Petronas said.

In the four-paragraph statement, the national oil company said the arrangement was made following the Exchange of Letters between Malaysia and Brunei on March 16, last year.

"This Exchange of Letters was a culmination of a long-standing issue between the two countries to arrive at a mutually beneficial arrangement, which allowed Petronas to enter into new production sharing contracts for both blocks," it said.

It also said that following the Exchange of Letters, the production sharing contracts covering Blocks L and M, which were awarded in 2003 to Petronas Carigali Sdn Bhd and Murphy Sabah Oil Co Ltd, were formally terminated on April 7 this year as these blocks were no longer a part of Malaysia.

Blocks L and M were redesignated as Blocks CA1 and CA2 respectively, it said.

Former prime minister Tun Dr Mahathir Mohamad, in a blog posting on Thursday, had questioned why the two blocks were no longer belonged to Malaysia and said that the loss could cost Malaysia at least US$100 million (RM320 million).

Dr Mahathir claimed that his successor Tun Abdullah Ahmad Badawi had surrendered the two blocks in exchange for Limbang.

Abdullah, who signed the Exchange of Letters, clarified that the land and sea agreement with Brunei was approved by the Malaysian cabinet and that Malaysia would be allowed to participate in joint development of oil and gas on commercial basis in the two areas for a period of 40 years.

MORE: Oil blocks deals - Govt must explain, says Tian Chua [3]

MORE: Parliament: Oil blocks handover would not be discussed [4]

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Annex BR7

S. Bandyopadhyay, "Natural Environmental Hazards and their Management: A Case Study of Sagar Island, India", *Singapore Journal of Tropical Geography,* Vol. 18, No. 1 (1997)

NATURAL ENVIRONMENTAL HAZARDS AND THEIR MANAGEMENT: A CASE STUDY OF SAGAR ISLAND, INDIA

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ABSTRACT

The reclamation of Sagar island from the Sundarban mangrove wetlands of the western Ganga Brahmaputra delta was initiated in 1811. At present the island is almost wholly settled. The major natural environmental hazards (NEH) that affect the island are tropical cyclones, coastal erosion, tidal ingression and dunal encroachment. Human adjustments to these problems include acceptance, technological control, relocation, regulation and emergency measures. Seven different agencies manage the existing NEH-prevention projects of the island, often with little coordination. Important schemes managed by these agencies include coastal and interior embankments, mangrove plantations, storm refuges, resettlement projects and vegetation wind-breaks. Their efficiency ranges from excellent to very poor. Since a large outlay is inconceivable, the island's hazard prevention projects should mobilise existing resources in a more rational and coordinated manner. The long-term solution to the problems, however, lies in an accelerated socio-economic development of the region.

INTRODUCTION

An environmental hazard is generally defined as an extreme and uncommon physical event that inflicts some kind of damage on humans and their physical surroundings. A natural environmental hazard (NEH) is distinguished from a human environmental disturbance by the fact that while humans are fully responsible for generating the latter, they usually have no control over the origin of the former (Burton, 1989). However, the effect of an NEH can often be exacerbated by human activities that modify the physical setting of an area. Humans may also expose themselves to an NEH, knowingly or unknowingly, by simply occupying a hazard-prone region. Over the years, two distinct schools of thought in NEH research have emerged. The deterministic *behavioural hazard paradigm*, developed from the classical works of Gilbert White (1936; 1974) constitutes the dominant view (Smith, 1992:42). This focuses on the physical nature of the NEH events, human responses and mitigation aspects. The more recent socio-centric *structural hazard paradigm*, reflected in the works of O'Keefe *et al.* (1976), Susman *et al.* (1983) and Drabek (1989), in contrast, emphasises the effects of socio-economic and political parameters on NEH. It argues that in the poorer regions of the world like India, underdevelopment - in

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turn leading to marginalisation and lack of resources - may literally force the choice of locating in an NEH-prone area. An NEH, therefore, cannot always be seen as a purely natural event. The geomorphic components of the NEH (for example, coastal erosion) often tend to be more pervasive and dispersed in nature rather than rare and extreme occurrences (Gares *et al.*, 1994). Considering these views, a working definition of an NEH may be a natural event which is harmful to humans and cannot be considered by them to be part of the normal state or condition of the environment; its potential for harm varies with the physical parameters of the event as well as the socio-economic conditions and political situation of the place of its impact.

In 1781, while describing the Sundarban mangrove wetlands of the lower Ganga Brahmaputra delta, Rennell (1788: 259) observed that "this tract ... is so completely enveloped in woods, and infested with tygers (*sic*) that if any attempts have ever been made to clear it ... they have hitherto miscarried". A new phase of reclamation, however, was soon to follow and, a couple of centuries later, some 5,366 km^2 (about 56 per cent) of the former tidal wetlands were converted to rice farms in the Indian districts of South and North 24-Parganas, West Bengal State (Mandal, 1992).[1] This reclaimed area now constitutes one of the most NEH-prone and least developed regions of the country.

The present work, using Sagar island (213.83 km^2; 21°37'-57'N, 88°02'-11'E) (Plate 1) as a representative of the sea-board sections of this region, is a comprehensive study of the nature and management of the NEHs that affect it. While natural hazards research is now developing an emphatic bias towards the social sciences (Gares *et al.*, 1994), this paper is written mainly from the standpoint of physical geography and mostly within the framework of the original natural hazards paradigm. However, it does acknowledge the significance of the human system as an important influence on NEHs.

[1] The total area of the existing Sundarban mangroves, still the largest in the world (Collins*et al.*, 1991:95), is 7,180 km^2 (Richards, 1990). Of this, some 4,264 km^2 form the Indian sector (Mandal, 1992) and the rest is in the Bangladeshi districts of Khulna, Satkshira and Bagerhat.

RECLAMATION OF SAGAR ISLAND

Causes and consequences

Although a number of archaeological evidences indicating former human inhabitation were reported from Sagar (Princep, 1831; Anon, 1859; Haldar, 1983), the island was completely covered with mangroves in 1811 when a project of clearing the area was conceptualised by the British colonial State government (Chapman, 1869; Pargiter, 1934:115). The usual reclamation procedures in Sagar island, like everywhere else in the Sundarban, was to embank the coastline and the major tidal channels with mud, completely blocking the smaller tidal creeks (to prevent flooding by the highest high tides) and subsequent deforestation (see Westland (1874:106-10) for a graphic description of this arduous labour-intensive process). One major problem associated with this practice is that, by keeping out sediment-laden tidal water, the reclaimed region remains forever lower than the highest high tide and/ or storm surge levels and therefore prone to NEHs like tidal ingression and flooding due to breaching or overtopping of the low-tech earthen embankments.

Prevention of tidal spilling also throws a macro-tidal resonant estuary like the Hugli out of morphological equilibrium by reducing its inter-tidal area and thereby increasing its mean depth. The estuary then tries to restore the equilibrium by actively eroding its embanked channel-margins and by increasing rates of in-channel sedimentation, both to decrease its mean depth (Pethick, 1994). These conditions

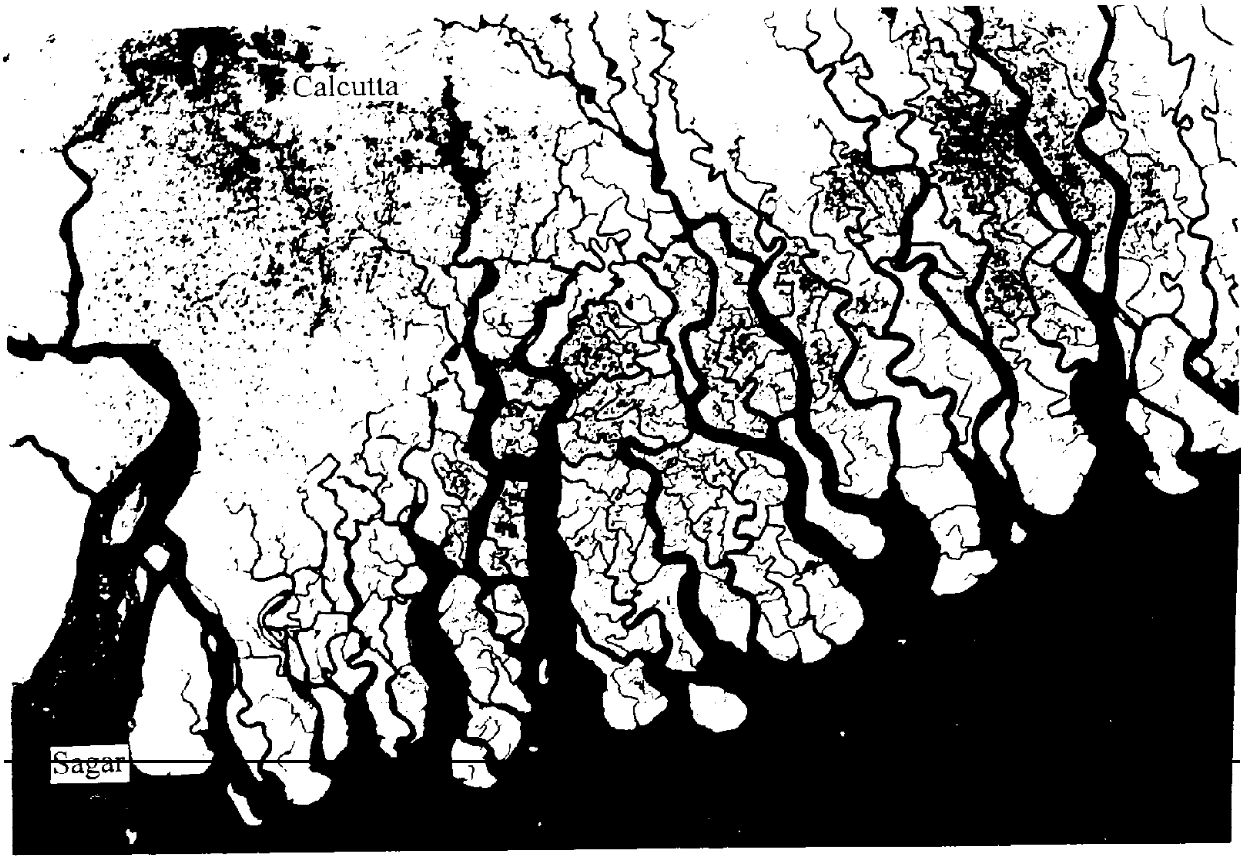
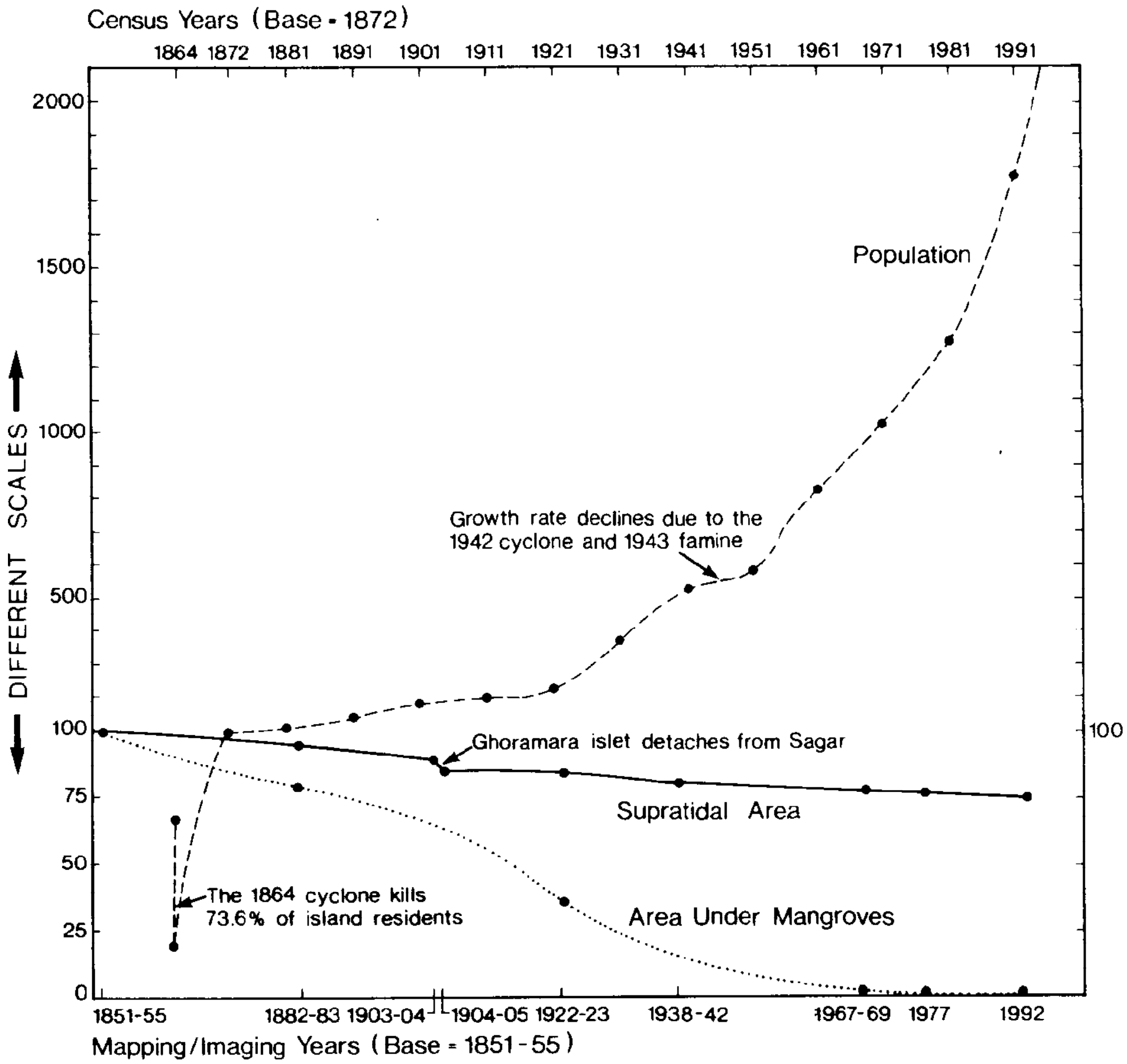


Plate 1. Western part of the coastal Ganga Brahmaputra delta showing the position of Sagar island at the mouth of the Hugli estuary. The light grey tint of the tidal islands indicates the extent of the Sundarban mangroves (Landsat-1 MSS FCC, 21 February 1973).

are now being replicated in the Hugli, requiring enormous dredging operations to keep its navigational channels open and constant repair or reconstruction of the damaged marginal embankments (Bandyopadhyay, 1997). Apart from this, some other probable contributors to the problem of coastal erosion include the decrease in sediment input from the Hugli due to abandonment of the western Ganga-Brahmaputra delta caused by a Late Holocene eastward tilt (Morgan & McIntire, 1959); sediment sinks at the Swatch of No Ground submarine canyon (Kuehl *et al.*, 1989) and at the post-independence (1947) river valley projects (Bandyopadhyay & Bandyopadhyay, 1996); and subsidence of the coastal delta (Das & Bhattacharya, 1994).

Despite Chapman's (1869:7) observation that "Sagar island is more valuable ... as a break-water to save the main land from the full destructive force of storm waves than a precarious field for agriculture" and Addams-Williums' (1918:159) suggestion that heavy embankments "should be avoided in Sundarban until the height of the land is a sufficient protection against the highest tides", the island gradually became almost wholly deforested and settled (Figure 1). As traced in detail by Ascoli (1921:76-79), Pargiter (1934:115-18) and Lahiri (1936:118-20), the reclamation activity was slow at the beginning and gathered sufficient momentum only from the later half of the 19th century. This was achieved mainly due to different policies of the colonial State government, reflecting the general contemporary attitude towards mangrove wetlands that simply considered them as wastelands waiting to be reclaimed for agriculture and fuel (Richards, 1990). Other contributory factors include the lack of alternative opportunities elsewhere and



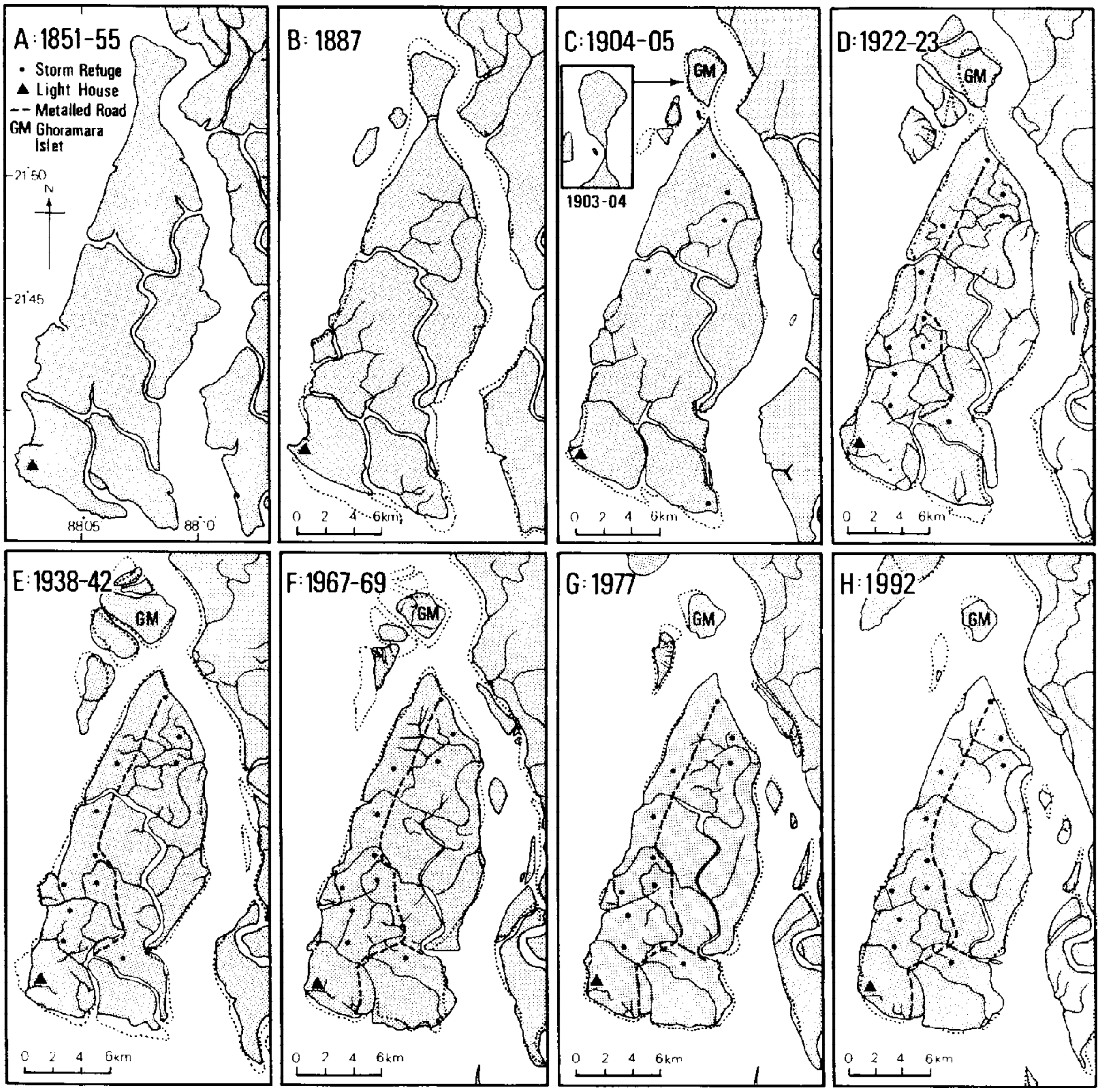
Map Sources:	Calcutta Port Commissioners (CPC) (1948) *Chart of the Hooghly Estuary*, Scale: 1:145,728; Indian Remote Sensing Satellite-1B, Linear Imaging Self Scanner-2 False Colour Composite (IRS-1B LISS-2 FCC) (1992) *Geometrically Rectified Standard FCC*, Path: 18, Row: 53, Date of Pass: 14 February 1992, Scale: 1:100,000; River Survey Department (RSD) (1903-04) *River Hugli: Kulpi to Lower Gasper Light Vessel*, Scale: 1:72,625; RSD (1904-05) *River Hooghly: Calcutta to Saugore*, Scale: 1:80,724; Survey of India (SoI) (1851-55) 'Map no. 121, District 24 Pergunnahs', *Atlas of India*, Scale: 1:253,440; SoI (1882-83) *Map No. 482-S.00, District Midnapore Including Saugore Island*, Scale: 1:253,440; SoI (1922-23) *Map Nos. 79C/1 and 79C/2, District Twentyfour Parganas*, 1st ed., Scale: 1:63,360; SoI (1942) *Map No. 79C/2, District Twentyfour Parganas*, 2nd ed., Scale: 1:63,360; SoI (1967-69) *Map Nos. 79C/1 and 79C/2, Districts Twentyfour Parganas and Medinipur*, 3rd (1st metric) ed., Scale: 1:50,000; SoI (1977) *Controlled Aerial Photomosiac*, 47 photos, 5 runs, Scale: 1:50,000.
Other Sources:	Chapman (1869: 4); Mitra (1954: XIV & 440); Ray (1963: 291); Ghosh (1978: 352); Ghosh (1982: 467); DCO-WBC (1992: 50).

Figure 1. Changes in area, forest cover and population size of Sagar island, India.

perceived high ratios of reserve to potential loss by the settling peasant farmers. At present, Sagar's population of 149,222 represents a density of 698 persons/km^2 and is naturally growing by four per cent every year (1991 estimates). The pressure it causes on the carrying capacity of the island is further aggravated by a diminishing island area (Figure 2).

Management possibilities

The suggestions for improving the elevation of the prematurely reclaimed part of the Indian Sundarban are mostly based on opening of the reclaimed areas to the sediment-laden tidal spill in a phased manner until they are sufficiently accreted to rise over the highest high tide level (Bose *et al.*, 1957; Gupta, 1957; Dutt, 1966; Ray, 1966; Mukherjee, 1969, 1976). Although Brammer (1990) described indigenous applications of similar methods in a very isolated example from Bangladesh, little can be predicted of the practical applicability of the schemes. Temporary free spilling may take decades to raise the level of the land above the highest high tides. On the other hand, *permanent* opening of the marginally reclaimed areas is required to restore the



Source: Refer to Figure 1.

Figure 2. Evolution of Sagar island: 1851-55 to 1992.

disturbed estuarine equilibrium (Pethick, 1994). According to Maddrell (1993), regional removal of the embankments did show marked improvement in depths of the previously silted tidal channels in southeastern Bangladesh. Moreover, due to the high population pressure of the region, any such plan would obviously have to address the immense problem of relocation. But, among the different proposals, only that of Mukherjee's (1976) considered the resident population as a part of the plan.

NATURAL ENVIRONMENTAL HAZARDS AFFECTING SAGAR ISLAND

The NEHs that affect the resident population of Sagar island are identified and described in Table 1, mostly on the basis of qualitative parameters of the events emphasised by Burton *et al.* (1974). The types and levels of human adjustments to these hazards are listed in Table 2.

The hazard calendar

The rhythm of the seasons, reflected in the typical yearly cycles of wind, precipitation and tidal regimes, has a major influence on the hazard calendar of the island. The highest pre-monsoon wind velocities (southerly and southwesterly: 27-30 km/h) are observed during the dry months of April and May, which, together with the hottest period of the year (30°C), bring about dunal encroachment in the agricultural areas. The high velocity winds (southwesterly: 20-25 km/h) continue all through the rainy monsoon season (June-September) when, becoming moist with precipitation, the sand movement stops. However, a significant rise in the local sea level, together with wind-beaten waves and tropical cyclones, result in an increase in the intensity of coastal erosion and tidal ingression. From October onwards, the winds start to reverse their direction and speed (northerly: 11-12 km/h), the wave climate also changes and depositional processes take over the beaches (Bandyopadhyay *et al.*, 1993). However, marked deviation from this pattern can often be caused by tropical cyclones, especially the severe ones, landfalling in May, October and November (Figure 3). Generally, the late post-monsoon period (December-January) is most suitable for construction and repair of various management-related structures.

Tropical cyclones

The destructive action of a tropical cyclone is mostly felt on the right of its track (northern hemisphere) and on the shores that face an advancing system perpendicularly (Coch, 1994). It is an adverse combination of factors like lowest pressure attained by a storm, local sea level and tidal conditions at the time of its landfall that determines the surge level at a particular locality (Flather & Khandker, 1993). Thus, while the storm frequency diagrams (Figure 3) and recurrence intervals (Table 1) do provide an approximate guide for frequency of the events, they do not necessarily mean recurrence of similar levels of destruction. This was well borne out on 16 May 1995 when even a low-magnitude system (maximum wind speed at Sagar: 66 km/h) caused most widespread damage to the coastal areas of the Indian Sundarban in the last five years simply because its landfall coincided with the spring tides. Three of the most destructive tropical storms that ever affected Sagar island occurred on 21 May 1833 (nearly 7,000 people died), 5 October 1864 (4,137 people killed) and 17 October 1942. While materials providing some new information on the extent of damage or level of storm surge abound on the first two events (Martin, 1836:84, 151; Chapman, 1869; Hunter, 1875:259-60; Blanford, 1877; Beadle, 1903; O'Malley, 1914:135; Pargiter, 1934:116), hardly any authentic literature exists on the 1942 event although it is still fresh in the memory of the elderly islanders who remember hundreds perishing in the storm surge and the famine that ensued (Figure 1). Adverse socio-political conditions often suppress NEH reporting (Smith, 1992:34) as in the case of the 1942 Bengal event (Mitra, 1991:110-13).

HAZARD CLASS	HAZARD TYPE (with relative importance: 5-point scale, A-E)[1]	SEASON OF ACTIVITY/ FREQUENCY/RATE	IMPACT ON CULTURAL LANDSCAPE	REGIONS AFFECTED
Climatic and meteorological	Tropical cyclone (A-D)	Between May and November (rarely in December) with maximum frequency in August. *Average recurrence intervals* (in years) within 100 km of Sagar are: 0.6 for depressions (Beaufort force 7 or lower), 2.9 for cyclonic storms (Beaufort force 8 and 9), 3.3 for severe cyclonic storms (Beaufort force 10, 11 and 12) and 0.4 for any storm.	Episodic storm surges related to high-magnitude events are capable of inundating the entire island. Storm surges and high-speed winds cause accelerated coastal erosion by wave stacking. Incessant rain and high-speed winds damage the earthen structures and standing crops. Actual extent of damage depends on severity of a given event.	Coastal areas in general, but interior areas may also get affected in high-magnitude events.
Geologic	Earthquake (E)	Approximately once in a century.	May cause tsunami, and subsidence resulting in transgression. Can harm rural homesteads.	Whole island.
Geomorphic	Coastal erosion (A)	During the monsoon season (June-September) or during tropical cyclones. Between 1851-55 and 1992, the average erosion rate was 0.51 km^2/yr. This caused a 24.9 per cent reduction in island area.	Damages or destroys coastal embankments. Erodes away marginal farmlands and settlements. Causes tidal ingression.	Coastal areas: 29 per cent of the 62-km coastline is affected at present, 8.7 per cent severely.
	Tidal ingression (B)	Occurrence same as above.	Inundates marginal farmlands, may render agriculture impossible.	Same as above.
	Sand encroachment (dune progradation) (C)	During late pre-monsoon season (April-May). Between 1990 and 1994, the average yearly encroachment varied between 0 and 14.1 m, rendering 40 ha of farmland unusable.	Covers farmland with wind-blown sands. Sands are also carried into coastal settlements.	Interior areas in the south-central, adjacent to coastal dune belts.

TABLE 2. LEVEL OF ADJUSTMENTS TO THE NATURAL ENVIRONMENTAL HAZARDS, SAGAR ISLAND

ADJUSTMENT TYPES (after Burton, 1989)	LEVEL OF IMPORTANCE (5-point scale: A-E)[1]	EXPLANATION/REMARKS
Acceptance	A	Some of the greatest losses in human terms, such as destruction of homesteads or farmlands by coastal erosion are regular yearly occurrences and are almost stoically accepted as part of life.
Technological control	B	Present in the form of low-tech embankments and recent mangrove regeneration programmes. Individual structures are very basic but are quite extensive and need recurring maintenance.
Regulation	D	Mainly exists on paper. For example, law even prohibits presence of grazing animals over embankments (Harrison, 1909). Regulations such as these should be implemented if some of the management schemes are to survive anthropogenic pressure.
Relocation	C	Present in the form of three resettlement colonies. Relocating the coastal people out of Sagar may soon become an important issue in event of a greenhouse warming-induced accelerated rise in the sea level.
Emergency measures	D	Present in the form of 13 storm refuges, all but one of which have become degraded due to disuse and neglect.

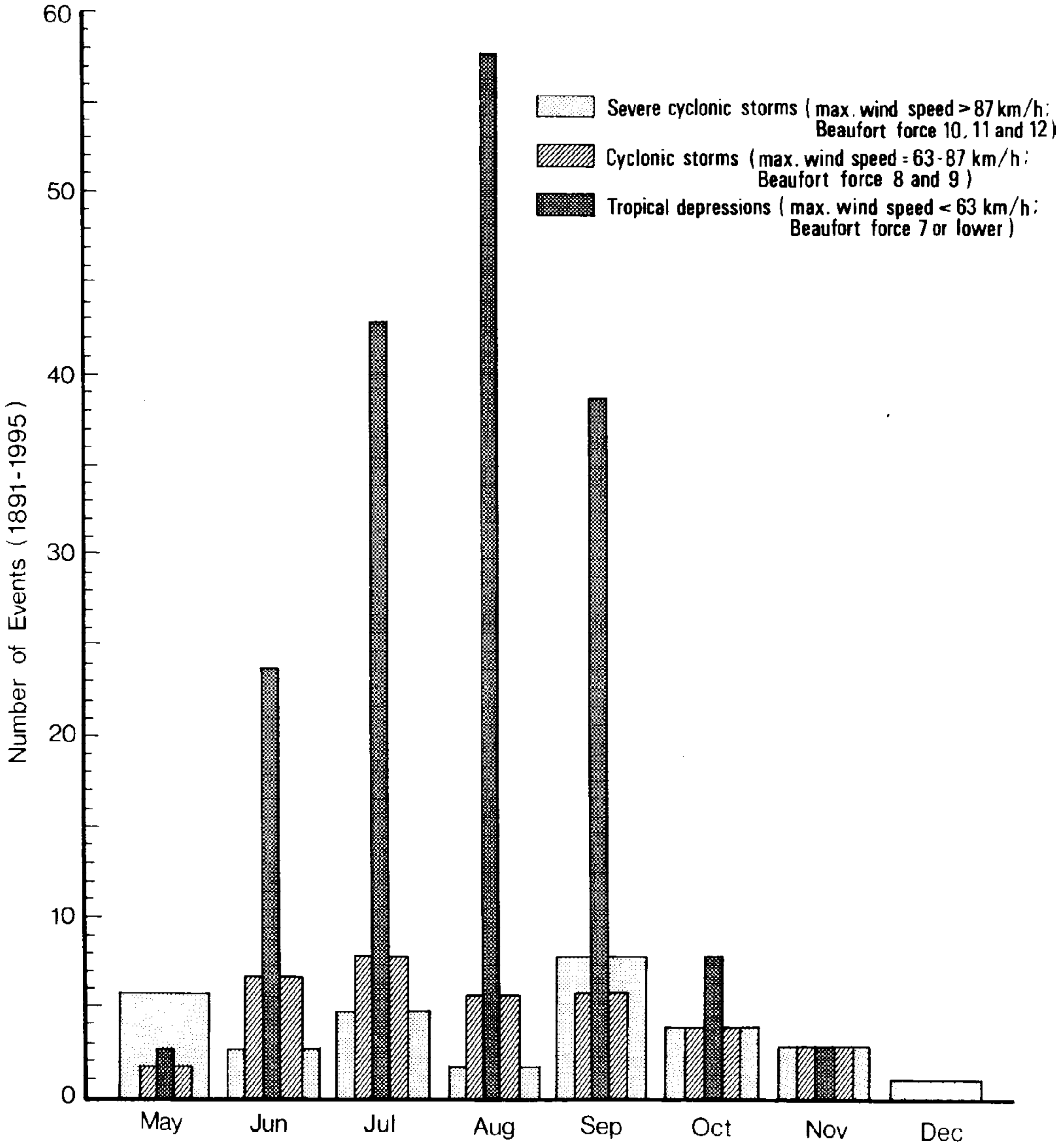
[1]A = emphatic presence; E = emphatic absence.

Earthquakes

Although it is widely believed that an earthquake and a simultaneous oceanic surge (tsunami) killed some 300,000 people in the area around the Hugli estuary on 2 October 1737 (Dunbar *et al.*, 1992:175), its authenticity has long been questioned (Anon., 1859). Another report, unconfirmed by any other source, made an earthquake responsible for subsidence and transgression of a part of the southern Sagar in 1897 (Dutt, 1950). Despite the absence of any destructive earthquake in the area for years, threats from earthquakes and tsunamis cannot be ruled out in view of the recent reviews by Maddrell (1993) and Nandy (1994). Its comparative risks (measured as probability times amount of loss), however, must be rated quite low.

Coastal erosion

The evolution of Sagar island since the mid-nineteenth century clearly shows predominance of erosion that was unevenly distributed over space although it has progressed more or less steadily through time (Figure 2). Overall, its area decreased by 25 per cent between 1851-55 (284.55 km^2) and 1992 (213.83 km^2). One important fact revealed from the 140-year chronological study is that coastal erosion of the island took place irrespective of its forested or deforested reaches. During the latter half of this interval

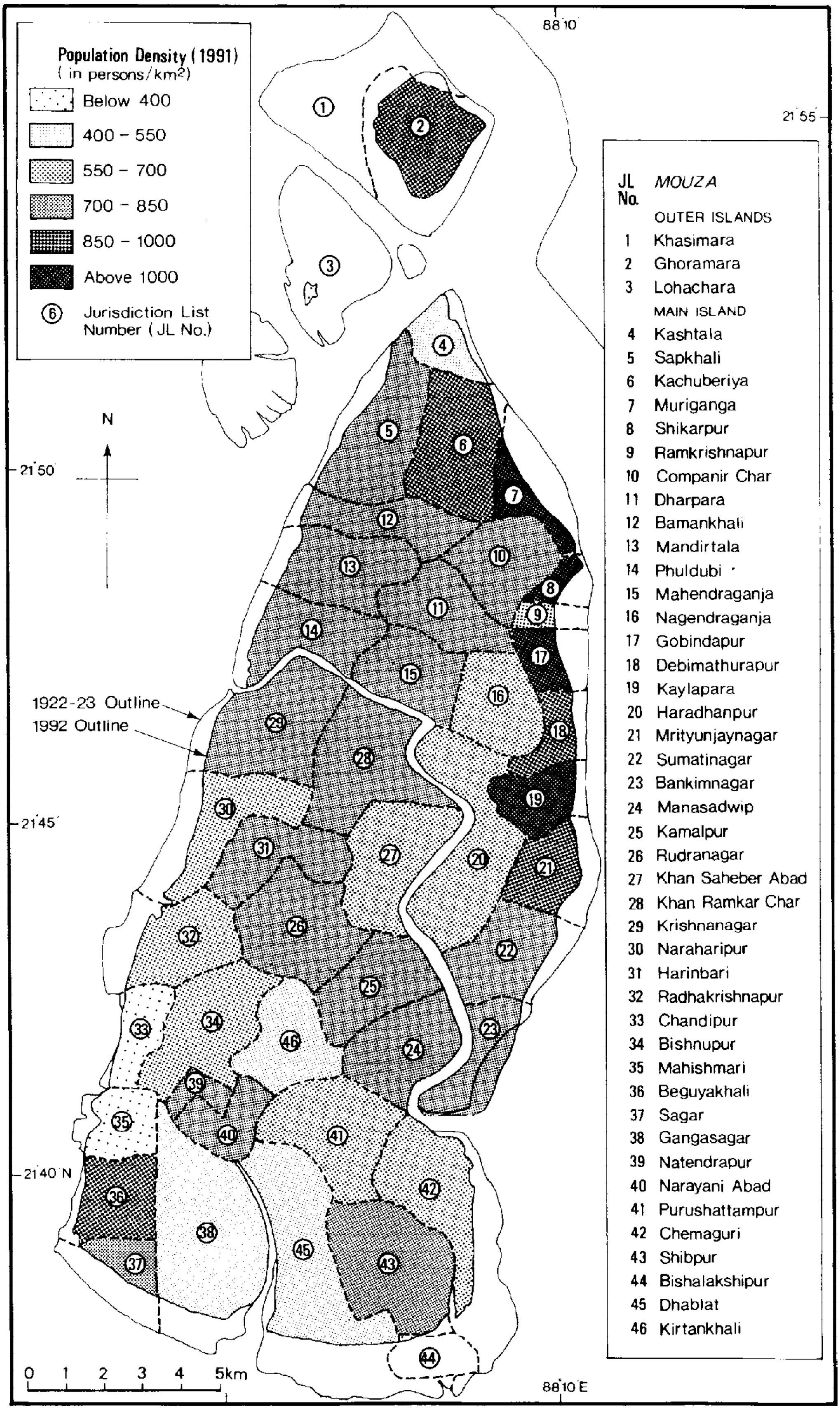


Source : IMD (1979) (data up to 1970) & India Meteorological Department (post-1970 data).

Figure 3. Tropical cyclones passing through 100 km of Sagar island, 1891-1995. (There is no recorded occurrence of cyclones in this locality from January to April).

(that is, the last 70 years), all except two of the 27 coastal *mouzas*[2] were affected by erosion and nine lost more than 25 per cent of their original extension (Figure 4). The *mouzas* particularly affected were: Bishalakshipur (area eroded: 96.1 per cent), Sagar (67.0 per cent), Muriganga (60.9 per cent), Ramkrishnapur (57.1 per cent) and Shikarpur (55.7 per cent). The northeastern river-board *mouzas* were the main corridor through which peopling of the island progressed and were major population centres right from its early reclamation years. Erosion of these *mouzas*

[2] A *mouza*, comprising one to a few villages, is the smallest administrative-cum-revenue unit of the Indian union.



Sources: DCO-WBC (1992:50); refer to Figure 1.

Figure 4. 'Mouza'-wise distribution of coastal erosion (1922-23 to 1992) and population density (1991) of Sagar island.

increased the concentration of this population even more (Figure 4).

Tidal ingression

In Sagar, nearly all coastal embankments are double and compartmented. Any breach in them results in intrusion of salt water into the compartmented area (measuring between 2.5 and 10 ha), rendering agriculture difficult if not impossible. Breaches are quite common along the erosion-affected coast of the island (Figure 5) and, on an average, amounted to one for every 10.2 km of the outer embankment per year during 1990-95.

Sand encroachment

The NEH caused by the landward migration of the coastal dunes does cause extreme difficulty for the residents of southern hamlets of the island who even need to hoist fine fishing nets to prevent wind-blown sands from entering their houses. However, its effect is localised and cannot be compared, for example, to the damage caused by tidal flooding.

EVALUATION OF THE PRESENT HAZARD MANAGEMENT SCHEMES

As many as seven different loosely coordinated organisations are involved in the management of NEHs on the island (Table 3). Although the local residents (selected by local *panchayets*[3]) form the labour force required to implement and maintain the different management projects, as in other underdeveloped areas, they have little role to play in priority selection or decision-making affairs. Generally they also do not have any clear perception of the efficiency of the projects being undertaken or the agencies responsible for their implementation (Bandyopadhyay, forthcoming).

The coastal embankments

Earthen structures: About 80 per cent of the existing 71.5 km of marginal embankments of the island are earthen (Figure 5) and require constant maintenance. These 2.4 m high dykes, with a water-face gradient of 1:2, are clearly inadequate for the sustained high-energy waves of the erosive monsoons, let alone the cyclonic surges. Traces of old and abandoned marginal embankments are ubiquitous sights. At the end of the monsoons, damage is inflicted on practically the entire stretch of the mud embankments all around the island. By digging pits in front of the damaged sections of the embankment and by dumping the dug-up material onto them, these walls are commonly repaired only when the monsoons of the subsequent year approach. Emergency protection is generally provided by makeshift bamboo palisades driven into the dykes and occasional sand bag piles (Plates 2 & 3). Many less-damaged stretches of the embankments are often left unmended due to a shortage of funds and time. Priority is also given to repairs in certain areas based on socio-political considerations.

Brick-lined structures: In contrast to the earthen embankments, the brick-lined ones have proven to be much better in checking marginal erosion in the eastern and western river banks and beach-bank transitional areas of the island (Plate 4). However, in the eroding stretches of the southern coastline, these embankments too are easily penetrated by the breaking sea waves which wash away the earthfill supporting the cemented brick-lining and cause the entire structure to collapse.

In Sagar, it requires approximately Rs 2,200 (US$62.90)[4] to build a metre of brick-lined embankment if local kilns are used. By comparison, earthen embankments are

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[3] *Panchayets* are the lowest tier of democratically elected bodies of the Indian union and consist of a number of *mouzas*, that have administrative and judicial power. Sagar has nine independently elected *panchayets*, comprising 43 *mouzas* in all.

[4] Based on the early 1996 exchange rate.

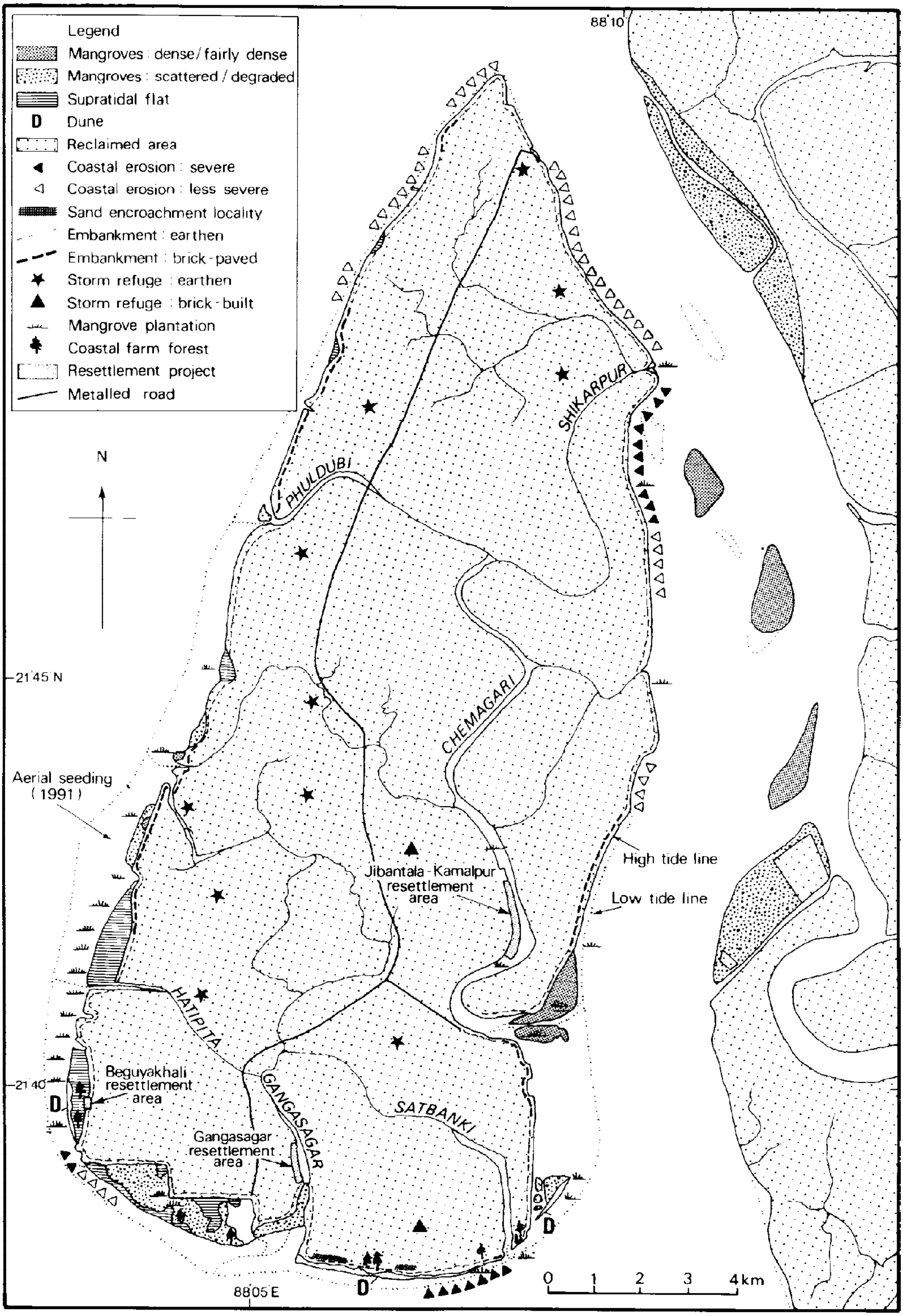


Figure 5. Locations of major hazard affected parts and management projects, Sagar island.

TABLE 3. MANAGEMENT OF THE NATURAL ENVIRONMENTAL HAZARDS AFFECTING SAGAR ISLAND

HAZARD TYPE	EXISTING MANAGEMENT SCHEMES	AGENCIES INVOLVED[1]	ADEQUACY RATING OF THE EXISTING MANAGEMENT SCHEMES (5-point scale: A-E)[2]	SUGGESTED ALTERATIONS IN THE EXISTING MANAGEMENT SCHEMES (see Table 5 for details)
Tropical cyclones	(1a) Coastal embank-ments: 74.5 km (19.4 per cent brick-paved) (1b) Interior embank-ments: 222 km.	DoIW; District council; Village *panchayets*; CPT; Subcontractors.	B-D (low to medium-magnitude events) D-E (high-magnitude events).	Brick paving of the existing earthen reaches of the coastal embankments and hoping for the best.
	(2) Mangrove plantation on coastal inter-tidal flats mainly using *Avicennia sp.*: 579 ha in 11 localities.	DoF; SFD-SDB	C-E (open coast) A-C (around tidal inlets)	To be extended all along the inter-tidal coast on a priority basis. Anthropogenic manipulation should be restricted.
	(3) Storm shelters: 11 earthen, 2 brick-built.	None	D-E	The existing shelters should be renovated and new ones added.
	(4) Resettlement pro-jects: 3 colonies.	District council; Village *panchayets*.	A-B	Not to be located on the coasts.
Earthquake	None	None	-	None - in view of the rarity of the events and dominance of 1 cost non-permanent structures on the island.
Coastal erosion & Tidal ingression	Same as (1a), (2) and (4) above.	Same as (1a) and (2) above.	Earthen embankments: C-D (open coast), A-C (mangrove-fringed coast). Brick-paved embankments: B-C (river-facing coast), D-E (sea-facing coast).	Same as (1), (2) and (4) above.
Sand encroach-ment	(5) Farm foresty on dune belts using *Casuarina equisetifolia*: 300 ha in 5 localities.	SFD-SDB; Village communities; Individual initiative.	A-B	Natural dune colonisers should be promoted on the dune itself and the farm forests should be used as the last line of defence. Anthropogenic manipulation/grazing over dunes should be stopped.
	(6) Strip plantation along sand-covered embankments.	Village *panchayets* in addition to (5), above.	D-B	

[1]CPT: Calcutta Port Trust; DoIW: Department of Irrigation and Waterways, West Bengal Government; DoF: Department of Forest, West Bengal Government; SFD-SDB: Social Forestry Division, Sundarban Development Board.
[2]A = most adequate; E = least adequate.

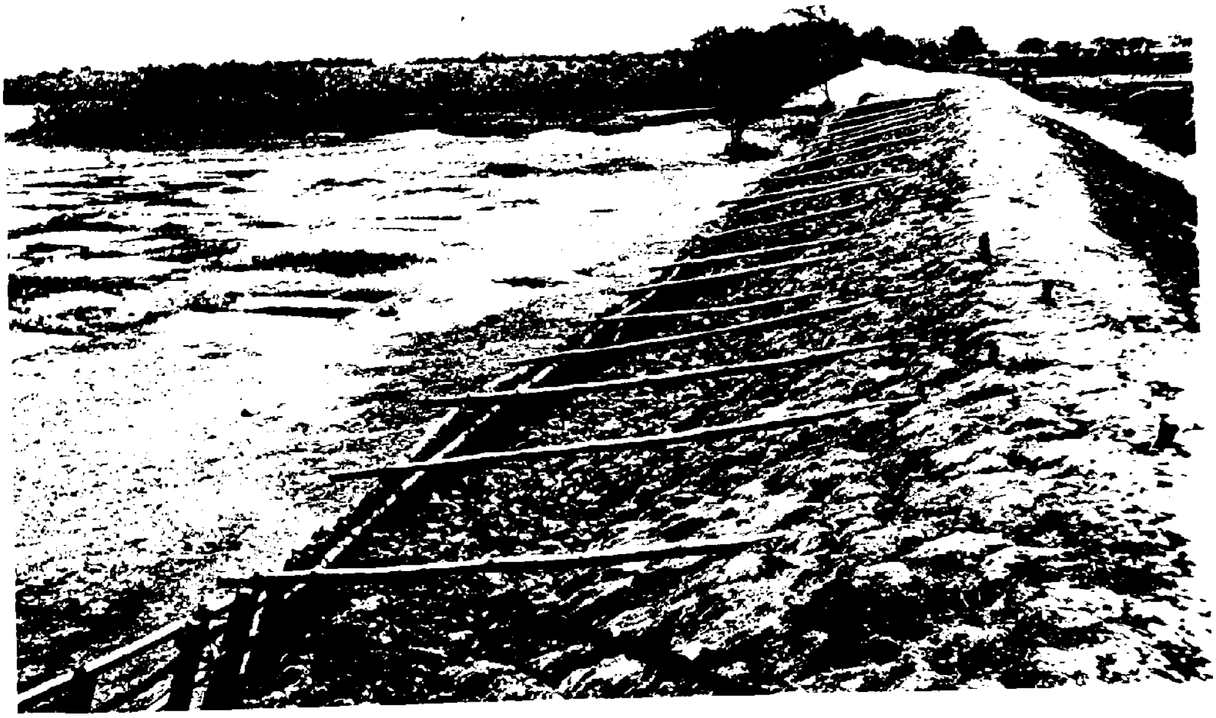


Plate 2. An eroding stretch of the marginal earthen embankment (foreground) in Bankimnagar 'mouza' of southeastern Sagar. The bamboo palisades are placed to temporarily reinforce the structure during the monsoons. Mangrove patches (background), however, offer a better and more permanent solution.

Plate 3. Repair of a damaged sea-facing section of the earthen marginal embankment, Shibpur 'mouza' of southern Sagar, by replacing the eroded materials with chunks of clay dug from the intertidal mudflat.

Plate 4. Brick paving over earthen embankments in exposed sections of the coast, e.g. in the Kachuberiya 'mouza' of northern Sagar, can successfully prevent seasonal erosion in most cases but, once damaged, their repair may take a considerable time.

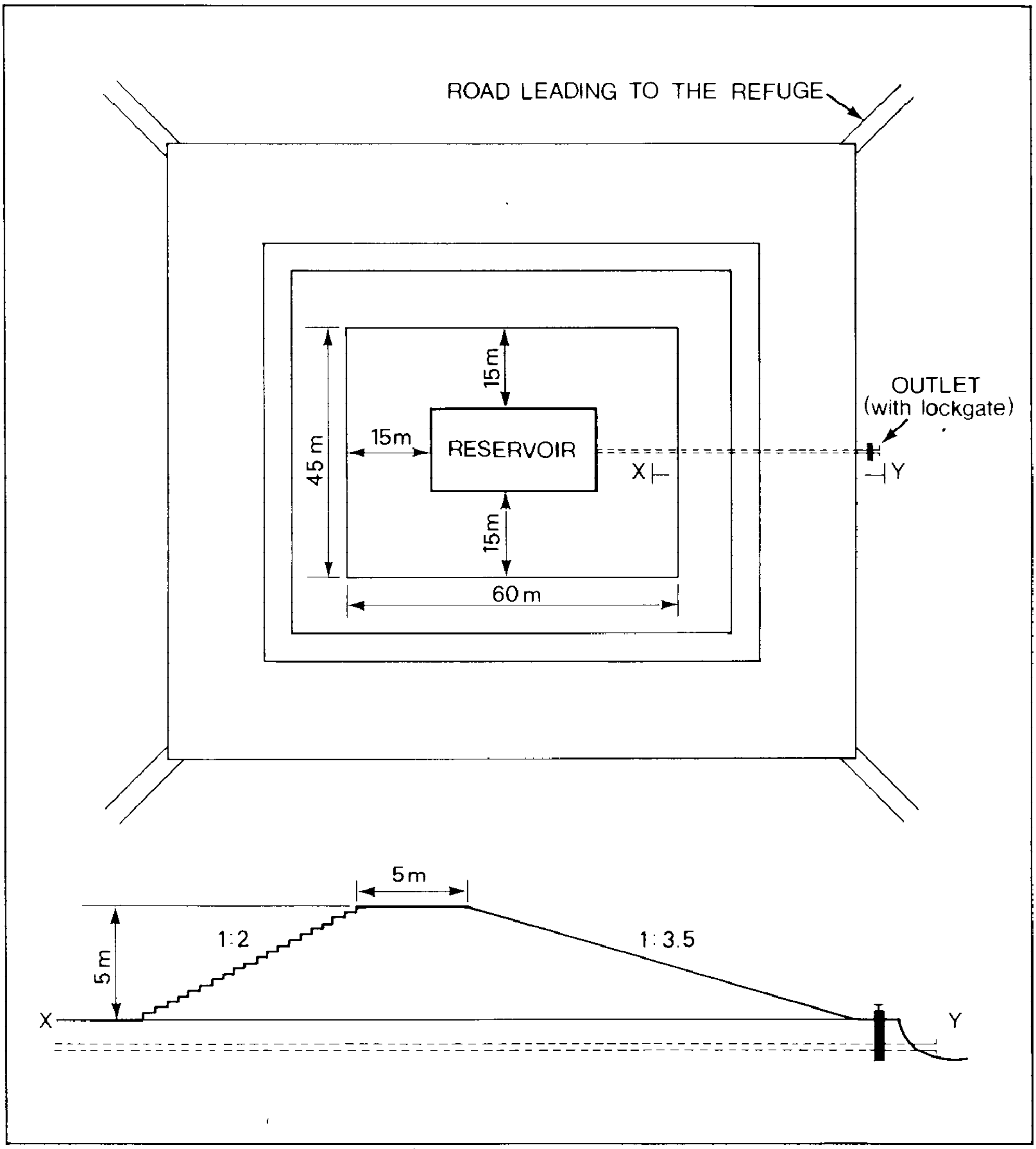
cheaper at Rs 252 (US$7.20) per metre (1995-96 prices). However, the former are unquestionably more durable and cost-effective in the long run if properly constructed, but they require specialised maintenance skills not available locally. Even emergency repairs may take considerable time due to procedural formalities and red tape. Corrupt practices among the non-resident contractors responsible for the brick paving often lead to faulty construction.

The storm refuges

Earthen structures: Following the extremely destructive cyclonic storm of 1864, the State government made it mandatory in 1871 for the landlords[5] of the island (called "grantees") to construct storm refuges for the settling peasant farmers according to certain pre-laid specifications (Figure 6).

Conceptualised by R.B. Chapman, the then Divisional Commissioner of Sundarban, these earthern structures were meant to supply fresh uncontaminated drinking water and shelter on its embankments in an eventuality of total inundation of the island by a storm surge (Chapman, 1869; Pargiter, 1934:118). Some enterprising grantees also constructed bell-towers on the refuges to disseminate emergency warnings. Excellent examples of the purposeful use of indigenous technology and raw materials, these refuges were last used during the 1942 cyclone. Since then, no major flooding has taken place and the shelters, falling into disuse, have completely been

[5] The landlordship or *zamindari* system was abolished from West Bengal in 1962. The peasants now pay taxes directly to the State government.



Note: The shallow central reservoir was meant for storage of fresh rain water only during a cyclone. The inner slopes of the protective embankments were intended for use as temporary shelter from storm surge.

Sources: Pargiter (1934:118) and location surveys.

Figure 6. Plan and section of a typical late nineteenth-century earthen storm refuge of Sagar island.

modified or damaged by the villagers. Consequently, if a storm surge-induced inundation does take place now, only a few of these refuges would be able to provide safe drinking water, as originally planned. The fact that no highly destructive tropical cyclone has lashed Sagar island since 1942 simply increases the probability of such an event in the near future.

Brick-built structures: Apart from the earthen structures, two storm shelters, built by brick and mortar in the early twentieth century, are also in existence on the island at Bishalakshi Bazar (Shibpur *mouza*) and at Kamalpur (Kamalpur *mouza*). The former is still in perfect working condition with a wide staircase and spacious living spaces. Shelters like these saved numerous lives in Bangladesh during the disastrous cyclone of 29-30 April 1991 (Cobb, 1993).

Afforestation

Unlike coastal embankments and storm refuges, afforestation projects for protection from the NEHs were initiated in Sagar only in the last few years. A majority of these projects were undertaken under the Social Forestry Programme of the Sundarban Development Board (MED-SDB, 1992), an organisation under the State government.

Strip plantation: Strip plantation means planting of trees (mainly *Acacia nilotica* and *Eucalyptus hybrid*) on the sides of the roads, canals and embankments. The scheme, however, had little influence in controlling NEHs like shifting sands.

Farm forestry: In this programme, certain seedlings are distributed (about 1,800 per ha) free of cost among the village communities to raise "social forests" in their own lands or on coastal dune belts. The mature trees are sold as timber. The five *Casuarina equisetifolia* green belts that were created in the southern Sagar under this scheme emerged as excellent wind breaks, halting sand movement altogether (Plate 5). However, one important drawback of *Casuarina equisetifolia* is that these tall trees, unlike surface-hugging dune herbs and sedges (the growth of which they inhibit), cannot withstand strong winds if planted on sands and are easily uprooted during cyclonic storms (Chakrabarti, 1995). Experience from Sagar island shows that, in regions sheltered from a high degree of anthropogenic pressure and grazing activity, growth of natural dune colonisers like *Ipomoea pes-carpae*, *Launaea sarmentosa*, *Cyperus exaltatus* and *Opuntia dillenii* stabilise coastal dunes quite satisfactorily. In other parts, human intervention notably reduce their effectiveness - one bald patch often acting as a nucleus of a blowout.

As was proved during the 1864 cyclone in the Medinipur coast, west of the Hugli estuary (Gastrell, 1868:28), dunes work as efficient natural barriers against storm surges. Therefore, it probably makes more sense if the landward migration of dune belts that keep pace with the retrograding coastline are left undisturbed. In Sagar, a *Casuarina equisetifolia* farm forest contributed significantly to the complete obliteration of a dune belt in the retrograding southeastern (Shibpur) coast by checking its landward movement altogether. The coastal areas affected by sand encroachment (Figure 5), however, have been stable for the last two decades.

Mangrove regeneration: Ranwell (1979:515) observed that "at the individual site level management strategies tend to be conservative and frequently do not take account of known trends such as the rate of silting in estuaries". In view of this, it should be noted that, as stated earlier, the role of mangroves in preventing past coastal erosion of Sagar was insignificant. Therefore, while mangroves may slow the pace of coastal erosion, they are not capable of stopping it altogether.

To protect against storm wave erosion, mangrove cover along the coasts of Sagar began to be re-established from 1985. The most frequently used plants were *Avicennia sp.* and *Excoecaria agallocha*. It was observed that, in general, mangroves prospered only in the regions close to the tidal inlets where they were sheltered from erosive storm waves and

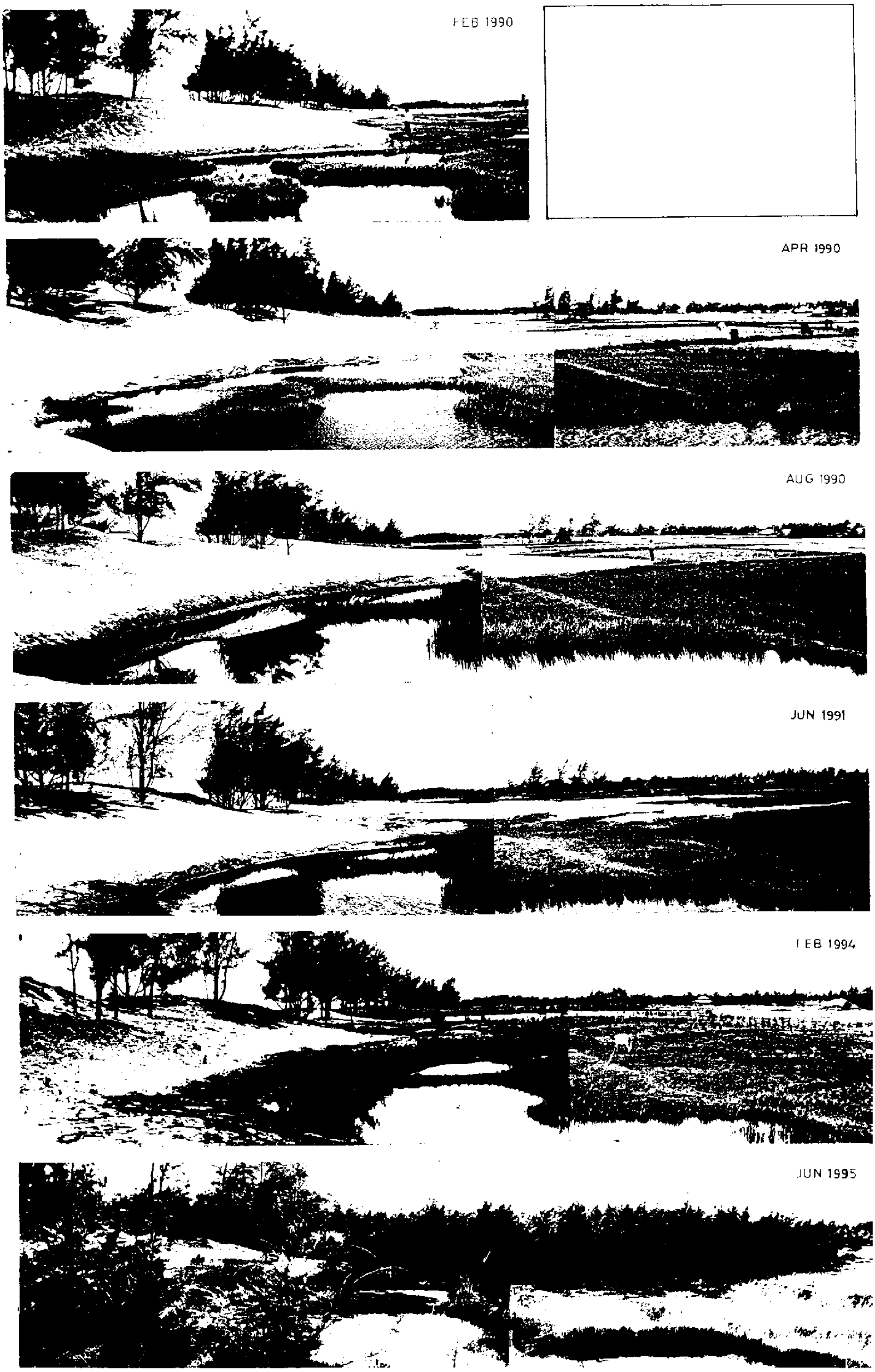


Plate 5. An example of gradual encroachment of coastal dunes on agricultural areas (Dhabtat 'mouza') and use of 'Casuarina equisetifolia' farm forests to successfully stabilise them.

aided by suitable sediment character and a wide inter-tidal area that distributed the anthropogenic pressure evenly. It must be emphasised here that pressure from human activities along almost all of the 65 km coastal stretch of Sagar is enormous. The inter-tidal marshes (mainly *Proteresia coarctata*) are routinely grazed by the cattle or exploited for fodder. In addition, the high population growth rate and continuous loss of marginal farmlands forced a large number of islanders into dragnet fishing, especially prawn-seed collection. The lucrative Southeast Asian market has provided a major boost to the prawn farms of West Bengal in recent years and, in the present situation, it is almost impossible to isolate a large area from anthropogenic manipulation, to plant vulnerable mangrove seedlings (or to scatter mangrove seeds from air) and to expect that they would grow satisfactorily. Since 1985, the area with successful regeneration of coastal mangroves is only about 25 to 30 per cent of the total area covered in Sagar (611 ha). However, even this should be rated as a significant achievement in view of almost complete failure in a 300 ha aerial seeding programme attempted on the island's southwestern tidal flat in 1991 (Figure 5).

Resettlement projects

Fresh reclamation of still-available intertidal flats along the small intra-island creeks is the only way in which relatively less NEH-prone new land can be generated in the island at the cost of almost certain deterioration of the creeks concerned. Although such projects should never be undertaken along the coastal areas (where there is always a probablity of erosion), this was exactly where the Beguyakhali resettlement colony (10 houses), one of the recently launched (1994-95) subsidised resettlement projects, was located (Figure 5). Among others, the Jibantala-Kamalpur scheme, housing 100 families from the neighbouring Ghoramara island in 30.4 ha of freshly reclaimed intertidal flat, is by far the largest project of its kind in the Indian part of reclaimed Sundarban. It was implemented under a Central government-funded housing scheme at the cost of Rs 14,700 (US$420) for each of the one-room (12 m^2) cyclone-resistant houses.

CONCLUSIONS AND RECOMMENDATIONS

It is well known that while costly and elaborate management projects may become a necessity to protect fairly developed coastal cities or towns, affording similar levels of protection to an overwhelmingly rural and agricultural area is simply not a practical proposition. Therefore, it seems that a practical approach to the management problems of Sagar as well as the rest of the region would be to mobilise the existing resources in a more rational framework rather than hope for costly high technology defences in the foreseeable future.

NEH research and NEH-related holistic management planning for the reclaimed coastal wetlands are largely in their infancy in India. Even when certain management proposals were developed for the Indian Sundarban (Maitra, 1968; Pramanik & Sinha, 1972; Bose *et al*., 1989; Paul, 1991), they mostly remained unimplemented, if not unnoticed. Conversely, with liberal assistance from donor countries, significant strides in this direction have been made in neighbouring Bangladesh since the 1960s (see Bari Talukdar, 1993; Brammer, 1993a; and Hodgson & Whaites, 1993, for reviews). Because both these countries share the physical and economic conditions as well as the NEH-related problems of the reclaimed Sundarban, increased interaction and feedback both at government and non-government level would probably be helpful in reducing NEH-related problems in the Indian Sundarban. One important aspect of the problem is the absence of a central NEH-managing body in West Bengal, which greatly affects decision-making.

Table 4 shows the recommendations that can be made for the area under review for implementation within a time frame of 25

TABLE 4. GUIDELINES FOR AMELIORATING MANAGEMENT OF NATURAL ENVIRONMENTAL HAZARDS IN SAGAR ISLAND

1. Form an apex NEH-managing body at the Government level with participation from related managing agencies and research organisations. Empower it to finalise all management policies and priorities.

2. Renovate the existing storm refuges and/or construct new ones on a priority basis - their location and capacity depending upon the contemporary population size and distribution (Figure 4). Provide the shelters with tube-wells on their upper stories/surfaces and use them as public utility buildings to ensure regular maintenance. For fail-proof coordination during actual events, practise trial storm warning dissemination and evacuation drills at appropriate intervals.

3. Ensure that all rural houses constructed in future follow an adequately cyclone-resistant design and that the already existing thatch or tile-roofed mud houses gradually get converted. Savings in maintenance cost alone should prove economical in the long run even if no cyclone strikes in the near future.

4. Convert the existing earthen marginal embankments along the river banks to brick-paved ones where they are not (or cannot, by regeneration, be) protected by mangrove buffers, and design differently the embank ments bordering the sea-facing erosive sections (southeastern and southwestern corners of the island). Meanwhile, ensure timely unreluctant maintenance of the existing earthen embankments.

5. Give mangrove replantation due importance. Where the intertidal area is critically narrow for this purpose, consider possibility of wetland restoration by opening 100-150 m wide coast-adjacent reclaimed areas, already compartmented by interior embankments, running parallel to the marginal ones.

6. Reclaim only the already-deforested tidal flats along the interior creeks for the resettlement projects after carefully judging the benefits against the potential adverse consequences. Never undertake fresh reclamation along the coasts.

7. Use the farm forests as the last line of defence at the back of the dunes to check sand encroachment and promote natural dune colonisers on the dunes itself. In a given farm forest, ensure coexistence of trees of at least two generations so that the entire protective cover is never destroyed when they are cut down for timber. However, in the eroding stretches of the coastline, allow landward migration of dunes to keep pace with the coastal retrogradation.

8. Reduce anthropogenic manipulation by proper environmental education/restrictions and search for alternative arrangement of fodder if the management schemes involving vegetation are to succeed fully.

years. One of the principal components of management planning for the next 25 years should concern regulation of the ever increasing anthropogenic pressure on the fragile tidal flat and dune ecosystems of the island which is critically important for dampening storm surges and marginal erosion. Table 5 lists the management strategy options for these areas. These should also be applicable to any other reclaimed locality of the Indian Sundarban where the human-environment relationship operates at a similar level.

Looking beyond 25 years from now, it seems that the overall eroding trend of the island (Figure 2) and human-induced global greenhouse warming, resulting in future marine transgression (Milliman *et al.*, 1989; Broadus, 1993) and increased storm magnitude and frequency, may one day call for a gradual abandonment of the island[6]. As seen before, the reclamation and peopling of Sagar were initiated by certain government policies. While

[6] It must, however be emphasised that any accelerated rise in sea level could not be detected from the Ganga-Brahmaputra delta as yet (Brammer, 1990; 1993b).

TABLE 5. MANAGEMENT STRATEGY OPTIONS TO REGULATE ANTHROPOGENIC PRESSURE ON DUNE AND TIDAL FLAT ECOSYSTEMS, SAGAR ISLAND

POLICY OPTIONS	POSSIBLE REACTIONS	REMARKS
I. *Internal management*		
(a) Environmentally most ideal measure *Dunes*: Total ban on grazing and exploitation. *Tidal flats*: Total ban on grazing and exploitation.	General public dissent. Opposition from political and social pressure groups.	Impossible to transfer into reality unless complete alternative arrangement for fodder is made.
(b) Compromise measure *Dunes*: as in I(a) above (unchanged). *Tidal flats*: Regulated grazing and exploitation.	Some public dissent.	This can be contained at the political and social level if some alternative arrangement for a part of fodder requirement is made.
II. *External management*		
(a) Environmentally most ideal measure *Dunes*: Total stoppage of trampling, seasonal fishing settlements and recreation. *Tidal flats*: A ban on dragnet fishing in mangrove regeneration areas for the first four years after planting.	Negative responses from the part of the fishing communities and the residents of dune-fringed southern Sagar due to reduced access to the sea. Acceptance in other areas as the regeneration schemes generally occupy small areas at a time.	Fences generally have certain adverse aerodynamic effect on dunes. Fences may also be tampered with. These facts must be considered before putting them up.
(b) Compromise measure *Dunes*: Total stopping of trampling and recreation over the vulnerable surfaces by fencing if needed. Limited number of access corridors through the existing blowouts. Fishing settlements may be allowed over sandflats. *Tidal flats*: as in II(a) above (unchanged).	General acceptance.	

this may have brought temporary relief by absorbing extra population for some years, in the future, it may cause a far-reaching problem involving relocation of thousands of families into the already overcrowded interiors. The only plausible long term solution to this probably lies in a balanced socio-economic development of the entire Sundarban region. As suggested by O'Keefe *et al*. (1976) and Warrick and Rahman (1992), this alone can provide the most permanent solution to the future NEH-related problems of the region by cutting birth rates, elevating the standard of living and rationalising resource allocation, thereby reducing vulnerability to the NEHs to a great extent.

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REFERENCES

Addams-Williums, C. (1918) *History of Rivers in the Gangetic Delta: 1750-1918*, Calcutta: Bengal Secretariat Book Depot.

Anonymous (1859) 'The Gangetic delta' (a compilation from six articles, maps and mss), *The Calcutta Review*, 32(1), 1-25.

Ascoli, F.D. (1921) *A Revenue History of Sundarbans from 1870 to 1920*, Calcutta: Bengal Secretariat Book Depot.

Bandyopadhyay, S. (forthcoming) 'Human responses to natural environmental hazards in three coastal hamlets of Sagar island, South 24 Parganas, West Bengal', *Indian Journal of Landscape Systems and Ecological Studies.*

Bandyopadhyay, S. (1997) 'Managing coastal erosion in the perspective of long term evolution of an estuary: The case of Hugli, West Bengal, India' (Abstract), *Abstract Volume, International Seminar on Quaternary Sea Level Variation, Shoreline Displacement and Coastal Environment*, 20-26 January 1997, Thanjavur: Tamil University, 44-45.

Bandyopadhyay, S. & Bandyopadhyay, M.K. (1996) 'Retrogradation of the western Ganga-Brahmaputra delta : Possible reasons', *National Geographer*, 31(1&2), 105-28.

Bandyopadhyay, S., Paul, A.K. & Bandyopadhyay, M.K. (1993) 'Seasonal changes in beach configuration of Sagar island, West Bengal', *Indian Journal of Landscape Systems and Ecological Studies*, 16(2), 89-99.

Bari Talukdar, M.A. (1993) 'Current status of land reclamation and polder development in coastal lowlands of Bangladesh', in *Polders in Asia (Atlas of Urban Geology, Volume 6*), New York: United Nations Economic and Social Council for Asia and the Pacific, 1-22.

Beadle, J.P. (1903) 'Note on the progress of the late hurricane (dated 25th Oct., 1864)', *Papers from 1864 to 1873 Regarding the Cyclone Wave of 1864 and its Effect on the Hooghly Embankments etc.*, Calcutta: Bengal Secretariat Press, 2.

Blanford, H.F. (1877) 'Catalogue of the recorded cyclones in Bay of Bengal up to the end of 1876', *Journal of the Asiatic Society of Bengal*, 46(2), 328-38.

Bose, A.N., Dwibedi, S.N., Mukhopadhyay, D., Danda, A.K. & Bandyopadhyay, K.K. (1989) 'Summary of the recommend-ations', in A.N. Bose, S.N. Dwibedi, D. Mukhopadhyay, A.K. Danda & K.K. Bandyopadhyay (eds.), *Coast Zone Management of West Bengal*, Calcutta: Sea Explorer's Institute, X1-X7.

Bose, N.K., Ray P.B. & Sinha, G. (1957)

'Tidal rivers of Bengal and the problem of their maintenance', *Indian Journal of Power and River Valley Development*, 7(9), 111-15.

Brammer, H. (1990) 'Floods in Bangladesh: II. Flood mitigation and environmental aspects', *Geographical Journal*, 156(2), 158-65.

Brammer, H. (1993a) 'Protecting Bangladeshi communities against floods and cyclones', in P.A. Merriman & C.W.A. Browitt (eds.), *Natural Disasters: Protecting Vulnerable Communities*, London: Thomas Telford Services Ltd., 388-407.

Brammer, H. (1993b) 'Geographical complexities of detailed impact assessment for the Ganges-Brahmaputra-Meghna delta of Bangladesh', in R.A. Warrick, E.M. Barrow & T.M.L. Wigley (eds.), *Climate and Sea Level Changes: Observations, Projections and Implications*, Cambridge: Cambridge University Press, 246-62.

Broadus, J. M. (1993) 'Possible impacts of and adjustments to sea level rise: The cases of Bangladesh and Egypt', in R.A. Warrick, E.M. Barrow & T.M.L. Wigley (eds.), *Climate and Sea Level Changes: Observations, Projections and Implications*, Cambridge: Cambridge University Press, 263-75.

Burton, I. (1989) 'Natural environmental hazards', in J. Henry & G.W. Heinke (eds.), *Environmental Science and Monitoring*, Englewood Cliffs: Prentice Hall, 86-113.

Burton, I., Kates, R.W. & White, G.F. (1974) *The Environment as a Hazard*, New York: Oxford University Press.

Chakrabarti, P. (1995) 'Coastal zone management in Hooghly estuary: An operation approach', *Indian Journal of Earth Sciences*, 22(3), 125-34.

Chapman, R.B. (1869) 'Official paper no. 103Ct (dated 28th Dec. 1867)', *Correspondence Relating to the Settlement of Saugor Island for 1869*, Calcutta: Bengal Secretariat Book Depot, 1-9.

Cobb, Jr., C.H. (1993) 'Bangladesh: When the water comes', *National Geographic*, 183(6), 118-34.

Coch, N.K. (1994) 'Geologic effects of hurricanes', in M. Morisawa (ed.), *Geomorphology and Natural Hazards, Geomorphology*, 10, 37-63.

Collins, M.N., Sayer, J.A. & Whitmore, T.C. (eds.) (1991) *The Conservation Atlas of Tropical Forests: Asia and the Pacific*, London: Macmillan Press Ltd.

Das, G.K. & Bhattacharya, A.K. (1994) 'A piecemeal mechanism of bank erosion following subsidence: A case study from Thakuran river of deltaic Sundarban, West Bengal', *Journal, Indian Society for Coastal Agricultural Research*, 12(1&2), 231-34.

Directorate of Census Operations - West Bengal Circle (DCO-WBC) (1992) *Primary Population Census Abstracts - 1991, Volume 1: South 24-Parganas District*, unpublished report, Calcutta: Government of India.

Drabek, T.E. (1989) 'Disasters as nonroutine social problems', *International Journal of Mass Emergencies and Disasters*, 7, 253-64.

Dunbar, P.K., Lockridge, P.A. & Whiteride, L.S. (1992) *Catalog of Significant Earthquakes 2150 BC - 1991 AD including Quantitative Casualties and Damage*, National Geophysical Data Centre, Boulder: National Oceanographic & Atmospheric Administration.

Dutt, K. (1950) 'Western Sundarbans in ancient times' (in Bengali), *Prabasi*. Reprinted in *Souvenir, 24-Parganas Archaeological Conference (1983)*, Baruipur: Sundarban Regional Museum, 12-18.

Dutt, S. (1966) 'Drainage in the Sunderbans', *River Behaviour and Control: Journal, River Research Institute*, 1, 62-69.

Flather, R.A. & Khandker, H. (1993) 'The storm surge problem and possible effects of sea level changes on coastal flooding in the Bay of Bengal', in R.A. Warrick, E.M. Barrow & T.M.L. Wigley (eds.), *Climate and Sea Level Change: Observations, Projections and Implications*, Cambridge: Cambridge University Press, 229-45.

Gares, P.A., Sherman, D.J. & Nordstorm, K.F. (1994) 'Geomorphology and natural hazards', in M. Morisawa (ed.), *Geomorphology and Natural Hazards, Geomorphology*, 10, 1-18.

Gastrell, J.E. (1868) *Geographical and Statistical Report of the Districts Jessore, Fureedpur and Backergunge*, Calcutta: Office of Superintendent of Government Printing.

Ghosh, B. (1978) *District Census Handbook of Twentyfour Parganas, West Bengal, 1971*, Volume 22, Number 10-B, Calcutta: Government of India.

Ghosh, S.N. (1982) *District Census Handbook of 24-Parganas, 1981*, Volume 23, Number 13B, Calcutta: Government of India.

Gupta, A.C. (1957) 'The Sundarbans, its problems and its possibilities', *Indian Forester*, 83(8), 481-87.

Haldar, N. (1983) 'Archaeological treasures of Diamond Harbour sub-division' (in Bengali), in *Souvenir, 24-Parganas Archaeological Conference*, Baruipur: Sundarban Regional Museum, 55-57.

Harrison, H.L. (1909) *Bengal Embankment Manual*, Calcutta: Bengal Secretariat Press, xxxi-xxxvi.

Hodgson, R.L.P. & Whaites, A. (1993) 'The rehabilitation of housing after natural disasters in Bangladesh', in P.A. Merriman & C.W.A. Browitt (eds.), *Natural Disasters: Protecting Vulnerable Communities*, London: Thomas Telford Services Ltd., 374-87.

Hunter, W.W. (1875) *A Statistical Account of Bengal, Volume 1: District of 24 Parganas and Sundarbans*, London: Trubner and Co.

India Meteorological Department (IMD) (1979) *Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea, 1877-1970*, 2nd ed., Pune: Government of India.

Kuehl, S.A., Hariu, T.M. & Moore, W.S. (1989) 'Shelf sedimentation off the Ganges-Brahmaputra river system: Evidence for sediment bypassing to the Bengal fan', *Geology*, 17(12), 1132-135.

Lahiri, A.C. (1936) *Final Report on the Survey and Settlement Operations in the District of 24-Parganas for the Period 1924-1933*, Alipur: Bengal Goverment Press.

Maddrell, R.J. (1993) 'Alleviation of natural disasters in the southwestern area of Bangladesh', in P.A. Merriman & C.W.A. Browitt (eds.), *Natural Disasters: Protecting Vulnerable Communities*, London: Thomas Telford Services Ltd., 51-66.

Maitra, B. (1968) 'Sundarbans delta project and its potentialities', *River Behaviour and Control: Journal, River Research Institute*, 3(1), 29-31.

Mandal, G.S. (1992) 'Sundarban biosphere reserve - an action plan for conservation of Sundarban mangroves ecosystem', in Sundarban Development Board (ed.), *Role of Social Forestry in the Development of Sundarbans*, Calcutta: Sundarban Development Board, 14-23.

Martin, R. (1836) *Notes on the Medical Topography of Calcutta*, Calcutta: Bengal Military Orphan Press.

Milliman, J.D., Broadus, J.F. & Gable, F. (1989) 'Environmental and economic implications of rising sea level and subsiding deltas: The Nile and Bengal examples', *Ambio*, 18(6), 340-45.

Mitra, A. (1954) *District Census Handbook of 24-Parganas, West Bengal, 1951*, Calcutta: Government of India.

Mitra, A. (1991) *Towards Independence: 1940-1947, Memoirs of an Indian Civil Servant*, Bombay: Popular Prakashan.

Monitoring and Evaluation Division - Sundarban Development Board (MED-SDB) (1992) 'Social forestry programme under Sundarban Development Board', in Sundarban Development Board (ed.), *Role of Social Forestry in the Development of Sundarbans*, Calcutta: Sundarban Development Board, 3-13.

Morgan, J.P. & McIntire, W.G. (1959) 'Quaternary geology of the Bengal basin, East Pakistan and India', *Bulletin Geological Society of America*, 70(3), 319-42.

Mukherjee, K.N. (1969) 'Nature and problems of neo-reclamation in Sundarbans', *Geographical Review of India*, 31(4), 1-9.

Mukherjee, K.N. (1976) 'Harmonious solution of the basic problem of Sundarban reclamation', *Geographical Review of India*, 38(3), 311-15.

Nandy, D.R. (1994) 'Earthquake hazard potential of central and southern Bengal basin', *Indian Journal of Earth Science*, 21(2), 59-68.

O'Keefe, P., Westgate, K. & Wisner, B. (1976) 'Taking the naturalness out of natural disasters', *Nature*, 260, 566-67.

O'Malley, L.S.S. (1914) *Bengal District Gazetters: 24-Parganas*, Calcutta: Bengal Secretariat Book Depot.

Pargiter, F.E. (1934) *A Revenue History of the Sundarbans from 1765 to 1870*, Alipur: Bengal Government Press.

Paul, A.K. (1991) 'Effective management strategies for the coast of West Bengal', *Geographical Review of India*, 53(1), 60-74.

Pethick, J. (1994) 'Estuaries and wetlands: function and form' in R.A. Falconer & P. Goodwin (eds.), *Wetland Management*, London: Thomas Telford, 75-142.

Pramanik, H.R. & Sinha, G. (1972) Development of coastal areas in western Sundarbans, *Proceedings, Seminar on Geomorphology, Geohydrology, and Geotechnics of the Lower Ganga Basin*, 27-29 May 1972, Kharagpur: Indian Institute of Technology, C7-C15.

Princep, G.A. (1831) 'Sketch of the proceedings and present position of the Saugor island society and its lesees', extracted in W.H. Carey (1887), *The Good Old Days of Honorable John Company etc.*, Volume 2, Calcutta: Cambray and Co., 122-25.

Ranwell, D. S. (1979) 'Strategies for the management of coastal systems'. in R.L. Jefferies & A.J. Davy (eds.), *Ecological Processes in Coastal Environments*, London: Blackwell Scientific Publishers, 515-27.

Ray, B. (1963) *District Census Handbook of 24-Parganas*, West Bengal, 1981, Volume 2, Calcutta: Government of India.

Ray, P.B. (1966) 'Tidal rivers in the deltaic zone', *River Behaviour and Control: Journal, River Research Institute*, 1, 48-51.

Rennell, J. (1788) *Memoir of a Map of Hindoostan or the Mogal Empire*, London: M. Brown.

Richards, J.F. (1990) 'Agricultural impacts in tropical wetlands: rice paddies for mangroves in south and southeast Asia', in M. William (ed.), *Wetlands: A Threatened Landscape*, Oxford: Blackwell, 217-33.

Rundell, F.E. (1903) 'Note on the protective works constructed on either banks of the river at the mouth of the Hooghly (dated 26th Feb. 1868)', *Papers from 1864 to 1873 Regarding the Cyclone Wave of 1864 and its Effect on the Hooghly Embankments etc.*, Calcutta: Bengal Secretariat Press, 7.

Smith, K. (1992) *Environmental Hazards: Assessing Risk and Reducing Disaster*, London: Routledge.

Susman, P., O'Keefe, P. & Wisner, B. (1983) 'Global disasters, a radical interpretation', in K. Hewitt (ed.), *Interpretations of Calamity: From the View-point of Ecology*, London: Allen and Unwin, 263-83.

Warrick, R.A. & Rahman, A.A. (1992) 'Future sea level rise: Environmental and socio-political considerations', in I.M. Mintzer (ed.), *Confronting Climatic Change: Risks, Implications and Responses*, Cambridge: Cambridge University Press, 97-112.

Westland, J. (1874) *A Report on the District of Jessore: its Antiquities, its History and its Commerce*, 2nd ed., Calcutta: Bengal Secretariat Press.

White, G.F. (1936) 'The limit of economic justification for flood protection', *Journal of Land and Public Utility Economics*, 12, 133-48.

White, G.F. (1973) 'Natural hazards research', in R.J. Chorley (ed.), *Directions in Geography*, London: Methuen, 193- 216.

Annex BR8

D. Ganguly et al., "Geomorphological Study of Sundarban Deltaic Estuary", *Journal of the Indian Society of Remote Sensing,* Vol. 34, No. 4 (2006)

SHORT NOTE

Photonirvachak
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GEOMORPHOLOGICAL STUDY OF SUNDARBAN DELTAIC ESTUARY

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Sundarban delta is one of the most dynamic estuarine deltas of the world. Several rivers channels criss-crossed Sunderban delta and these water channels brings with them tons of sediments from terrestrial sources and they also play a major role in eroding nature of this deltaic estuary. Remote sensing has proved to be one of the important techniques for geomorphological studies (Ballester and Pietsch, 1998). It can be of immense help in inaccessible areas such as Sundarbans mangrove forest. The Sundarbans in India has total area of 9630 km^2 including a reserve forest cover of 4260 km^2 spread over 110 deltaic islands of which 54 have been reclaimed by human population in earlier periods and rest 56 are marked for reserved forests including the tiger reserve (Chakrabarti, 1987). The area is located between 21°10′ E and 22°30′ E latitude, and 88°15′ N and 89°40′ N longitude. In the present study, western part of Indian Sunderban, which includes entire South 24 Parganas and reserve forest, part up to Gosaba river mouth at the southeastern part was taken. The total land area of the study area is around 4471 km^2. The boundary of the Sunderban is spread over into two districts i.e. North 24-Parganas and South 24-Parganas, covering 19 blocks.

Satellite data has been acquired during low tide condition so that exposure of the land will be maximum. Reproductive cycle of coastal vegetation has also been taken into account for selection of data. Mangroves (Baidya and Choudhury, 1986) are evergreen but many other coastal types of vegetation are seasonal (occurs from October to February and senescence in April). So image of the month of March has been acquired, to avoid the interference of the coastal vegetation growth and helps in geomorphologic mapping. IRS P6 LISS-3 of the year 2004 has been used for the study of coastal landforms. Ground data collected from field survey in the month of October 2005.

The coastal zone mapping has been done based on Landsat-5 TM of 1989 (Murthy and Madhavan, 1986). A standard procedure has been used for image preprocessing. The satellite image has been

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interpreted from standard false color composite (FCC, 4[R] 3[G] 2[B]) using standard Interpretation key (SAC, 1992). A detailed analysis of the spectral signatures of terrain associated with important elements like geometric, tonal and textural characteristics of the coastal landforms, helped to identify different geomorphologic units. Fieldwork was carried out to cross check the features observed in the image interpretation. During geomorphologic mapping vegetation, sediments and landforms of different coastal geomorphologic units were analyzed.

For the study of accretion and erosion in coastal zone multi temporal satellite data were used. The multi spectral images of Landsat-TM (1989) and IRS P6, LISS-3 (2004) were used. Image acquired during low tide condition has been selected. Both the images were acquired in pre-monsoon season. Band 4 (near IR) was extracted from the false color composite (stacked image) of both images to determine shoreline changes and the areas of accretion and deposition. The change detection was carried out using digital classification.

The geomorphic classification of the study area was based on landforms, sediment patterns, some other factors, including geomorphologic processes and land cover was also considered. The whole study area was divided into four geomorphologic classes' like- A-alluvial, B-mixed or transitional, C-coastal and D-marine. The alluvial area is far from the shoreline, the geomorphologic units of this area are generated by riverine processes i.e. the area is dominated by fluvial processes. The alluvial plain extends up to the tidal limit, forming the floodplain of the freshwater parts of the river Ganges. The coastal zone is the most extensive of the three geomorphologic compartments. The major landforms observed in the coastal zone are- creek, mangrove swamp, mudflats, salt flat, beach, and dune complex. The lower delta plain is sensitive to change in the balance between hydrodynamics and riverine input and to change in relative sea level. The geomorphology map (Fig. 1) showing important geomorphic units of the study area. Mainly nine geomorphic classes are considered namely creeks, river channel, coastal alluvial plain, mud flat, alluvial plain, salt flat, mangrove swamp, dune complex, estuary and beach. These geomorphic units and their total area are given in Table 1. The district, located in the delta region of the state, is a part of one vast plane, sloping very gently towards the sea. The Sundarbans consists of low flat alluvial plains in the active delta region.

Table 1: Geomorphic Units with area of Indian Sundarbans

Geomorphological classes	Total area (km^2)
Creeks	443.75
River channel	143.15
Coastal alluvial plain	2017.75
Mud flat	13.97
Alluvial plain	1854.66
Salt flat	26.76
Mangrove swamp	1456.24
Dune complex	2.89
Estuary	1892.96
Beach	15.39

It is evident from the present study that a huge amount of land area of coastal Sundarbans is subjected to erosion. Especially the southern portions of many islands (namely Sagar, Namkhana, Jambu, Lothian, Dalhousie, Bhangaduani etc.) are highly prone to massive erosion. A thorough study of sea level rise, littoral current pattern, and sediment influx from different rivers is required to explain and prevent the current trend of erosion in this region. Depositional lands are only found in few places of the north eastern part of Sagar Island, western part of Nayachar Island and few places of different river banks in their upstream. Finally it is estimated that

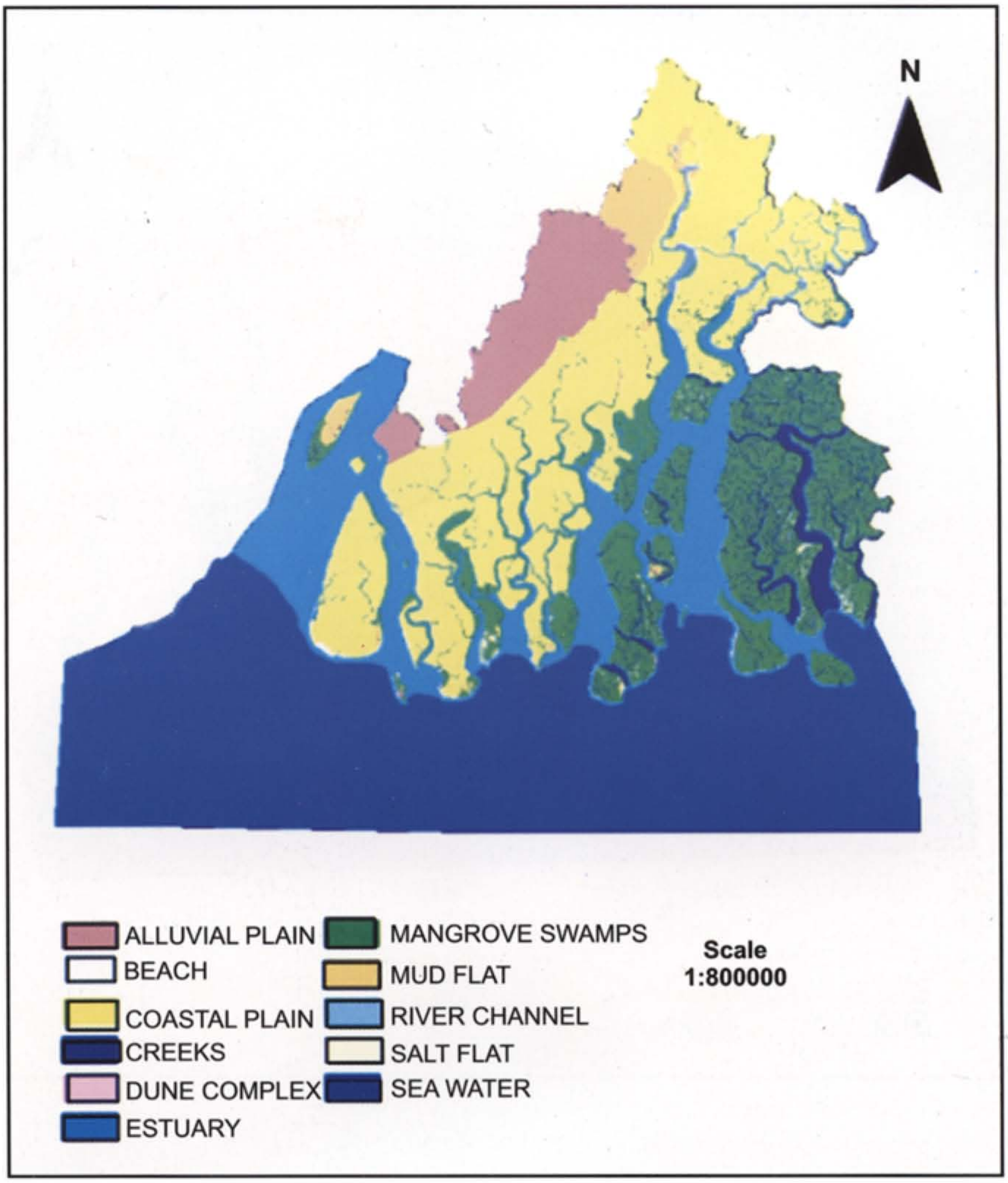

Fig. 1. Geomorphological map of Indian Sundarbans.

Total area of erosion is almost 283.58 km^2 whereas the total area of accretion is only 83.97 km^2. Map of erosion accretion of different parts of Indian Sundarbans from 1989 to 2004 is given in Fig. 2.

Summary

Study of landforms in Sundarbans deltaic estuary is necessary in regular basis due to its importance and impact on ecology, climate and economy. Remote sensing has proved as an important tool to study this. Multi-temporal satellite data helps to delineate the various geomorphic classes in different time domain and also provide inputs to study the coastal erosion and accretion. Finer spatial and better temporal resolution will be an added adventure for this kind of study.

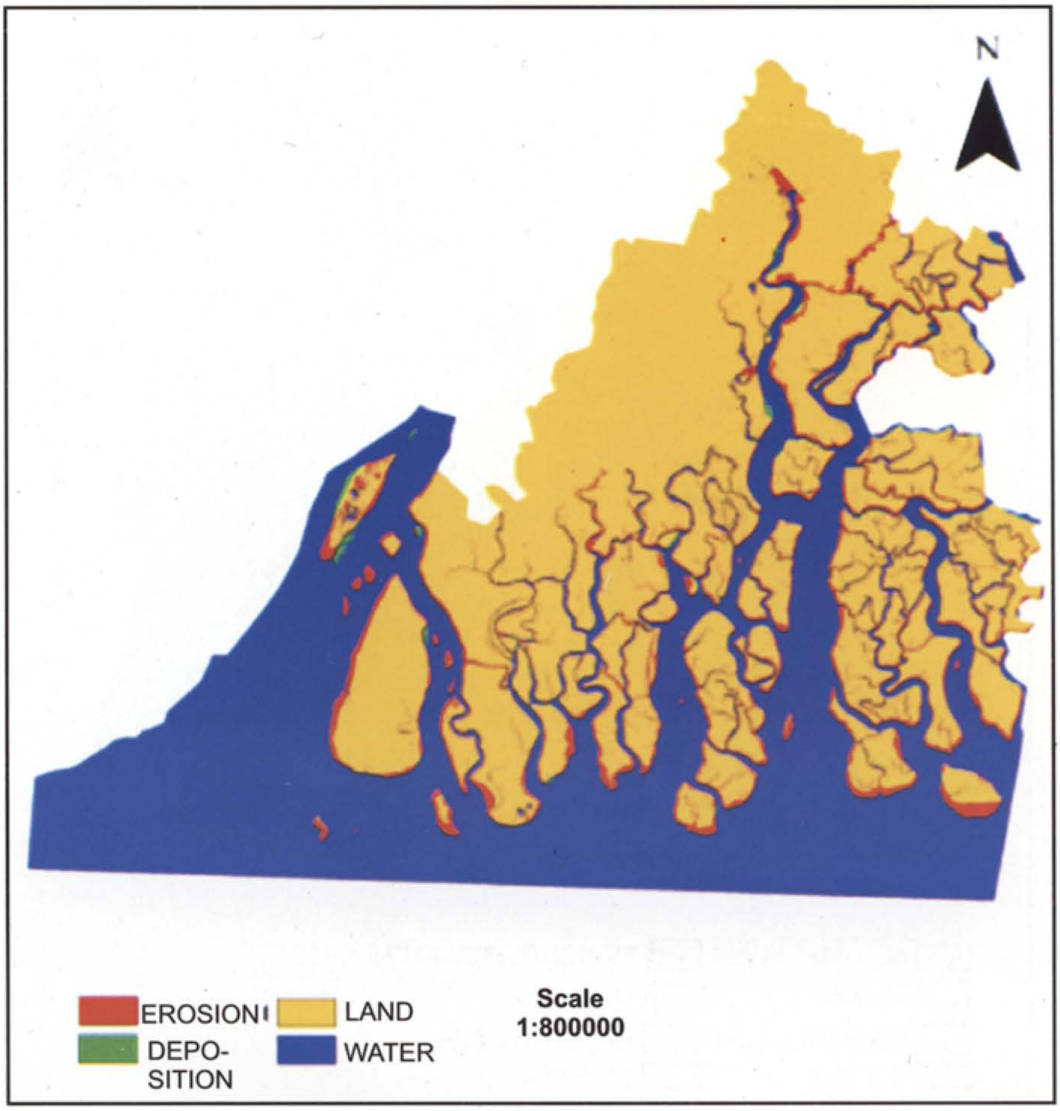

Fig. 2. Shore line change map.

References

Baidya, A. and Choudhury, A. (1986). The Mangroves (ed. Bhosale, L.J.), Shivaji University, Kholapur, pp. 132.

Ballester, M.V. and Pietsch, R.W. (1998). The Amazon floodplain through radar eyes: Lago grande de monte alegre case study. *Can. J. Remote Sensing*, **24**: 339-349.

Chakrabarti, K. (1987b). "Sundarbans mangroves of India - a study of conservation status". *The Indian Forester*, **113**: 352-358.

Chandramohan, P., Jena, B.K. and Sanil Kumar, V. (2001) "Littoral drift sources and sinks along the Indian coast". *Current Science*, **81(3)**: 292.

Gupta, R.D. (1987). "Save the Sundarbans" Sunday, Calcutta. 27 September - 3 October 1987, pp. 40.

Murthy Naidu, K.S. and Madhavan Unni, N.V. (1986). On sequential image analysis for estimation of land loss/accretion in Sundarbans. In: Kamat D.S. and Panwar, H.S. (Eds). Wildlife habitat evaluation using remote sensing techniques, Proc. seminar-cum-workshop organized by the Indian Institute of Remote Sensing and Wildlife Institute of India, from Oct. 22-23, 1986, pp. 248-257.

SAC (1992). Coastal Environment. Scientific Report No. RSAM/SAC/COM/SN/11/92.

Sanyal, P. Sundarbans Biosphere Reserve. Project Document – 1. Office of the Chief Conservator of Forests. Calcutta. pp. 32.

Williams, C. Addams. (1919). "History of the Rivers in the Gangetic Delta 1750-1918. NEDECO-Netherlands Engineering Consultants", The Hague, Holland. Bengal Secretariat Press: Calcutta Reprinted 1966, East Pakistan Inland Water Transport Authority. 96p.

Annex BR9

Chandra Giri, “Monitoring Mangrove Forest Dynamics of the Sundarbans in Bangladesh and India using Multi-Temporal Satellite Data from 1973 to 2000”, *Estuarine, Coastal and Shelf Science,* Vol. 73, No. 1 (2007)

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Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000☆

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Abstract

Mangrove forests in many parts of the world are declining at an alarming rate—possibly even more rapidly than inland tropical forests. The rate and causes of such changes are not known. The forests themselves are dynamic in nature and are undergoing constant changes due to both natural and anthropogenic forces. Our research objective was to monitor deforestation and degradation arising from both natural and anthropogenic forces. We analyzed multi-temporal satellite data from 1970s, 1990s, and 2000s using supervised classification approach. Our spatio-temporal analysis shows that despite having the highest population density in the world in its periphery, areal extent of the mangrove forest of the Sundarbans has not changed significantly (approximately 1.2%) in the last ∼25 years. The forest is however constantly changing due to erosion, aggradation, deforestation and mangrove rehabilitation programs. The net forest area increased by 1.4% from the 1970s to 1990 and decreased by 2.5% from 1990 to 2000. The change is insignificant in the context of classification errors and the dynamic nature of mangrove forests. This is an excellent example of the co-existence of humans with terrestrial and aquatic plant and animal life. The strong commitment of governments under various protection measures such as forest reserves, wildlife sanctuaries, national parks, and international designations, is believed to be responsible for keeping this forest relatively intact (at least in terms of area). While the measured net loss of mangrove forest is not that high, the change matrix shows that turnover due to erosion, aggradation, reforestation and deforestation was much greater than net change. The forest is under threat from natural and anthropogenic forces leading to forest degradation, primarily due to top-dying disease and over-exploitation of forest resources.

Keywords: mangroves; mapping; monitoring; remote sensing; Sundarbans; South Asia

1. Introduction

Mangrove forests, found in the inter-tidal zone in the tropics and subtropics, play an important role in stabilizing shorelines and in helping reduce the devastating impact of natural disasters such as tsunamis, and hurricanes. They also provide important ecological and societal goods and services including breeding and nursing grounds for marine and pelagic species, food, medicine, fuel, and building materials for local communities. These forests, however, are declining at an alarming rate, perhaps even more rapidly than inland tropical forests, and much of what remains is in degraded condition (Wilkie and Fortune, 2003). The rate and causes of such changes are not fully known. And, the remaining mangrove

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forests are under immense pressure from clear cutting, encroachment, hydrological alterations, chemical spills, and climate change (Blasco et al., 2001; McKee, 2005).

The Sundarbans offers coastal protection to millions of people in Bangladesh and India. The forests lie in a zone of cyclonic storms and tidal bores that originate in the Bay of Bengal and periodically devastate coastal areas. At the beginning of the colonial era (1757–1947) in India, the Sundarbans mangrove forest occupied approximately twice its current extent (Islam et al., 1997). Currently, the Sundarbans covers approximately 10,000 km^2, 40% of which is in India and the rest is in Bangladesh (WCMC, 2005).

Periodic forest inventories have been taken, recording the volume and condition of the timber resources of the Sundarbans at intervals of approximately 15 to 20 years. Through the 1900s inventories and management plans became more sophisticated and accurate, but remained focused on maximizing timber yield (Chaudhuri and Choudhury, 1994). However, in Bangladesh, for example, it has been 20 years since the Department for International Development of United Kingdom (formerly, Overseas Development Administration) conducted the last detailed inventory (Chaffey et al., 1985). Availability to up-to-date information on the status and conditions of this important ecosystem is critical for managing mangrove resources in a sustainable manner.

Remote sensing could play an important and effective role in the assessment and monitoring of mangrove forest cover dynamics. While remote-sensing data analysis does not replace field inventory, it provides supplementary information quickly and efficiently. The use of remotely sensed data offers many advantages including synoptic coverage, availability of low-cost or free satellite data, availability of historical satellite data, and repeated coverage. In addition, recent advances in the hardware and software used for processing a large volume of satellite data has helped increase the usefulness of remotely sensed data. Moreover, it is extremely difficult to get into vast swamps of mangrove forests, and conducting field inventory is time consuming and costly. A number of studies conducted in the Sundarbans have begun to develop and apply remote-sensing techniques mainly for mapping purposes (Islam et al., 1997; Dwivedi et al., 1999; Blasco et al., 2001; Nayak et al., 2001). These studies were conducted either in Bangladeshi or Indian parts of the Sundarbans at different times; thus, they lacked a holistic view of the whole Sundarbans mangrove forests. Monitoring of this important ecosystem in terms of both deforestation and forest degradation was urgently needed.

In this paper, we examine deforestation and degradation of the Sundarbans using multi-temporal Landsat data. More importantly, we investigate the dynamic nature of mangrove forests considering both net change and "turnover". We measure the extent and condition of the Sundarbans at three intervals between the 1970s and 2000s, using data from the newly compiled GeoCover data set. GeoCover is a collection of Landsat imagery from three decadal intervals: the 1970s, 1990s, and 2000s. Our specific objectives are to assess the current extent of the remaining forest, to measure change in the extent of the forest from the 1970s to 1990s, from 1990s to 2000s, and from the 1970s to 2000s, to identify localized areas of intensive change, and to identify changes in patterns of canopy density.

2. Study area

The Sundarbans mangrove spans the border between Bangladesh and India, extending from the Hooghly River in India to the Baleswar River in Bangladesh (Fig. 1). The forest lies on the delta of the Ganges, Brahmaputra, and Meghna Rivers on the Bay of Bengal. The area is intersected by a complex network of tidal waterways or channels, mudflats, and mangrove forests.

The Sundarbans support an exceptional biodiversity with a wide range of flora and fauna including more than 27 mangrove species, 40 species of mammals, 35 species of reptiles, and 260 bird species. Wildlife species found in the area include the man-eating Royal Bengal tiger, the Indian python, sharks, crocodiles, spotted deer, macaque monkey and wild boar. The forests are characterized two main tree species Sundri, and Gewa. Other species that make up the forest assemblage include *Avicenia, Xylocarpus, Sonneratia, Bruguiera, Rhizophora* and Nypa palm. The area experiences exceptional ecological processes such as monsoonal rains, flooding, delta formation, tidal influence and mangrove colonization. Rainfall in the area is as high as 2800 mm, mostly during the monsoon season lasting from June to October. Storms, cyclones and tidal surges are quite common throughout Sundarbans.

The forest is also a center for economic activities, such as the extraction of timber and fuel wood, fishing and collection honey and other forest products. Within the Sundarbans, there are three wildlife sanctuaries and one national park covering 27% of the area; all of these are listed as a World Heritage Site by the United Nations Educational, Scientific, and Cultural Organization (UNESCO). Over 2.5 million people live in villages surrounding the Sundarbans and depend for much of their subsistence on products from mangrove forests. The forest provides a livelihood for some 300,000 people, working seasonally as wood-cutters, palm collectors, fisherman, and honey hunters. Population density in the vicinity of Sundarbans is among the highest in the world.

3. Data and methodology

We used the recently compiled GeoCover data set, available freely through the Global Land Cover Facility (GLCF) (http://glcf.umd.edu) and the U.S. Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) (http://eros.usgs.gov). GeoCover is a collection of Landsat data that provides near global coverage with generally cloud-free images, collected for three eras: (1) the 1975 edition, with imagery collected from 1973 to 1983, (2) the 1990s edition, with imagery collected from 1989 to 1993, and (3) the 2000s edition, with imagery collected between 1997 and 2000s (referred to hereafter as the 1970s, 1990s, and 2000s data, respectively). Detailed description of GeoCover data can be found at: http://zulu.ssc.nasa.gov/mrsid/. A complete list of the Multi-spectral Scanner (MSS),

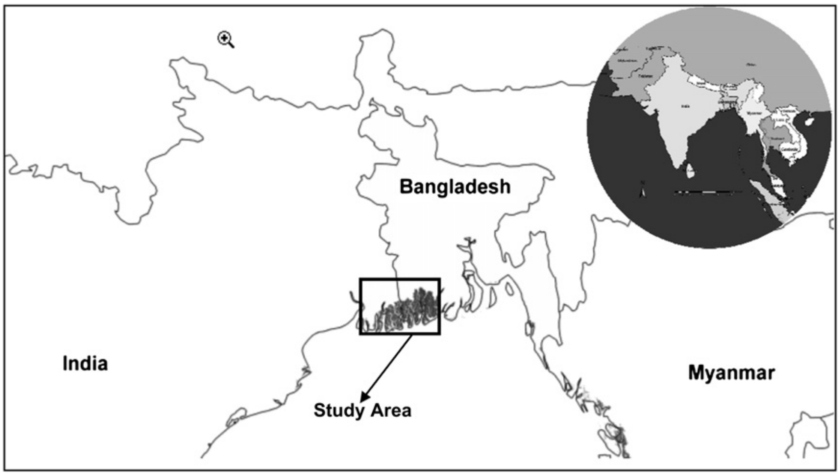

Fig. 1. Location map of the study area.

Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM^+) data used in this study is listed in Table 1. Despite our effort to acquire MSS data of the same month, we were not able to acquire it. Instead, data acquired within the period of three months were used. Because two Landsat MSS and ETM^+ scenes do not cover the entire area of Sundarbans, third scene was used to fill a small gap. The images are orthorectified and projected with an RMS error of less than 50 m (m) for the TM (1990s era) and ETM (2000s era) and to less than 100 m for the MSS (1970s era) (Tucker et al., 2004).

The use of multi-temporal satellite data at a large scale using MSS, TM and ETM^+ possesses a number of challenges including geometric correction error, noise arising from atmospheric effect, errors arising from changing illumination geometry, and instrument errors (Homer et al., 2004). Such errors can introduce biases in mangrove forest classification and change analyses.

Because the Sundarbans fall across two Universal Transverse Mercator (UTM) zones, each scene was reprojected to polyconic projection using 46 ground control points (GCP) distributed evenly throughout the study area. Re-projection was performed using cubic convolution re-sampling technique which provides superior spatial accuracy compared to nearest neighbor re-sampling technique (Park and Schowengerdt, 1982). GCPs were collected from 1:50,000 topographic maps. With additional GCPs, it was possible to decrease the root mean square (RMS) error to ±1/2 pixel. Additionally, the resolution of Landsat MSS data was re-sampled to 30 m to make it consistent with Landsat TM and ETM^+ data. This re-sampling, however, did not improve the spatial details of MSS data. Thermal band (band 6) was not used for both TM and ETM^+.

To reduce the noise due to influence of the atmospheric and illumination geometry, we used the techniques developed for the National Land Cover Database of the United States (Homer et al., 2004). Each image was normalized for variation in solar angle and Earth-sun distance by converting the digital number values to the top of the atmosphere reflectance (Chander and Markham, 2003). Considering the relative uncertainty of algorithms currently available, atmospheric correction was not performed. Only first-order normalization conversion to at-satellite reflectance was performed. This conversion algorithm is ''physically based, automated, and does not introduce significant errors to the data'' (Huang et al., 2002). Finally, mosaics were created for each decade with no further radiometric normalization. An example of the mosaic that was prepared is presented in Fig. 2.

Training samples were collected from these mosaics. Selecting training samples from these cloud-free mosaics was straightforward due to the very distinctive signature of mangrove forest. High contrast with open water in the south and croplands in the north helped in selecting the training data successfully. Same training samples with slight modifications in each mosaic (addition and removal of few training samples) were used for the classification of all three date images. Four major classes were delineated: Mangrove, Non-mangrove, Flooded, Barren lands, and Water bodies (Table 2). A supervised Maximum Likelihood Classification (MLC) method was used for the classification.

For change detection, we used post-classification techniques. This approach may have three sources of uncertainty: (1) semantic differences in class definitions between maps, (2) positional errors, and (3) classification errors. To minimize the semantic differences in class definitions, we used the same number of classes for all three dates. To minimize positional errors, additional GCPs were selected and RMS was reduced

Table 1
Landsat scenes used to create mosaics

Mosaic	Satellite	Date	Path and Row
MSS	Landsat 2	Jan. 3, 1977	p147r45
	Landsat 2	Feb. 9, 1977	p148r44
	Landsat 2	Dec. 5, 1977	p148r45
TM	Landsat 4	Jan. 12, 1989	p137r45
	Landsat 5	Jan. 3, 1989	p138r45
ETM^+	Landsat 7	Nov. 26, 2000	p137r45
	Landsat 7	Nov. 17, 2000	p138r44
	Landsat 7	Nov. 17, 2000	p138r45

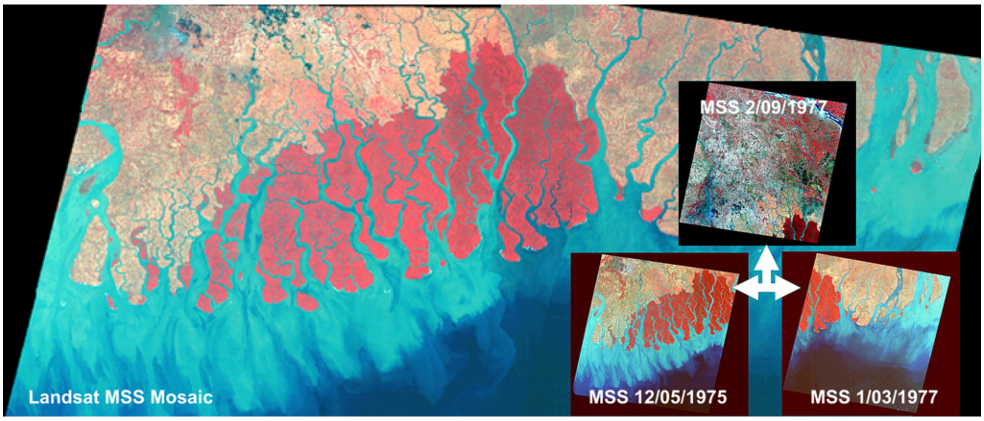

Fig. 2. Three sets of Landsat images from 1975–1977, 1989, and 2000 were used to create mosaics corresponding to the three decadal intervals of the study.

to ±1/2 pixel. Post classification editing using secondary data was used to minimize classification errors. However, there might still be errors associated with positional errors and classification errors. Civco et al. (2002) compared the results of for four land use and land cover change detection techniques: traditional post-classification cross-tabulation, cross-correlation analysis, neural networks, knowledge based expert system, and image segmentation and object-oriented classification. They concluded that each method assessed in the study has advantages and disadvantages and none of the method was able to solve the change detection problem. For example, change detection accuracy of all the methods was quire low.

A post-classification change matrix function was applied between 1970s–2000s, 1970s–1990s, and 1990s–2000s classification results. These change layers contained numerous areas of false alarms along and parallel to the many small streams of the Sundarbans. Much of this was caused by minor georeferencing errors in the data. Manual editing using secondary data was performed to remove those false alarms. Once the change areas were identified, further analysis was performed to examine net gain and loss due to deforestation, erosion, and aggradation. Changes observed in these analyses were compared to previous inventories (Chaffey, 1985) and other change detection studies (Islam et al., 1997) and were shared with local forestry experts for interpretation as to the validity and cause of these changes.

A second process was applied to the mosaic images to create a surface related to canopy closure. The normalized difference vegetation index (NDVI) has been shown to correlate very well with mangrove canopy closure: $r = 0.91$ (Jensen et al., 1991) using SPOT XS data. For our study, NDVI was calculated for each mosaic. A simple model explained by Gutman and Ignatov (1998) was used to scale NDVI to the green vegetation fraction per pixel. They used NDVIo (bare soil) and NDVI (dense vegetation) to estimate the green vegetation fraction from National Oceanic and Atmospheric Administration/ Advanced Very High Resolution Radiometer (NOAA/ AVHRR) data for use in numerical weather prediction models. We estimated $NDVI_{min}$ (0.2) and $NDVI_{max}$ (0.7) for open and closed mangrove forest. This estimation is based on our own analysis and findings from earlier studies. The NDVI range was then used to compute percent canopy closure from 0% to100%, where 0% corresponds to $NDVI_{min}$ and 100% corresponds to $NDVI_{max}$. Because of variation in season of collection, atmospheric conditions, tidal inundation, and the availability of only one pair of images for each era, calculation of absolute values for canopy closure were not expected to be reliable. However, within individual scenes, relative patterns of canopy closure were assumed valid.

Finally, confusion matrix was prepared using the training points collected from QuickBird images (8 scenes acquired in 2005 and available freely from http://glcf.umiacs.umd.edu/data/quickbird/sundarbans.shtml), aerial photographs (collected from national mapping agencies acquired in various dates), and mangrove forest classification maps (collected from forest departments of India and Bangladesh). Altogether 322 random sample points were used to compute overall accuracy and tau coefficient. Calculation of tau coefficient is necessary because the overall accuracy fails to take into account the correct allocation of pixels by chance.

Table 2
Class definitions

Classes	Supervised classification class definitions
Mangrove	Areas covered by both closed and open mangrove forests
Non-mangrove	Areas covered by croplands and other land uses
Flooded	Barren lands inundated at the time of image acquisition
Barren lands	Areas devoid of vegetation; e.g., sand dunes, sediments, or exposed soil
Water bodies	Areas of open water with no emergent vegetation; e.g., channels and waterways

4. Results

4.1. Forest cover change

From the 1970s to 2000s, mangrove forest in the Sundarbans decreased by 1.2%. The rate of change, however, was not uniform from the 1970s to 1990s and from 1990s to 2000s. From the 1970s to 1990s, mangrove forest area actually increased by 1.4%, and from 1990s to 2000s, the area decreased by 2.5%. These changes are non-significant in the context of errors associated with classification and the dynamic nature of mangrove ecosystems. In other words, these changes are well within the error margin. For example, because of the fluctuation of tide, selected areas in flooded areas, barren lands, and water bodies could easily be misclassified from one class to another. Areal extents of major land cover types for three time periods area presented in Table 3. Small changes less than 3 × 3 pixels were not detected from this study as this was the minimum mapping unit used. This is expected to minimize the errors arising from miss-registration of satellite imageries.

While the measured net loss of mangrove forest is not that high, the change matrix (Table 4) shows that turnover was much greater than net change. For example, 7% of the 1970s-era mangrove forest had changed to non-mangrove, Flooded, water bodies, or barren lands by 2000. The largest category of mangrove forest change was loss to Flooded (4.6%). The change matrix also revealed that during the same period approximately 37% of flooded areas, 21% of barren lands, 8.3% of non-mangrove, and 2.2% of water bodies were converted to forests. Similar patterns of change were observed from the 1970s to 1990s and from 1990s to 2000s (Table 4).

In all three classifications, 93—95% of mangrove forests, 93—96% of water bodies, and 69—79% of non-mangrove areas did not change. During the same period, the turnover for flooded areas and barren lands was, however, quite high, only 30—35% of flooded and 15—50% of barren lands remain unchanged. The large change between flooded and barren lands may possibly be due to variation in tidal inundation at the time of satellite data acquisition.

Non-mangrove areas are found in the outer periphery of the western and eastern parts of the Sundarbans (Fig. 3a—c). Major change areas were concentrated either in the outer periphery or near the shoreline (Fig. 3d), caused by anthropogenic and natural forces, respectively.

The high turnover between mangrove and non-mangrove is due primarily to encroachment, erosion, aggradation, and mangrove rehabilitation programs. The rate of erosion is highest at the southern edges of Mayadwip, Bulcherry Island, and Bhangaduni Island. For example, Bhangaduni Island lost one-fourth of its land area (25.1%) and just less than one-fourth of its mangrove area to erosion between the 1970s and 2000s. The majority of this loss in this island occurred between 1989 and 2000s, which is evident from the following illustrations (Fig. 4).

Table 3
Areal estimates of major land cover types

Class/Area (ha)	1970s	1990s	2000s
Mangrove	588,696.5	596,842.8	581,642.2
Non-mangrove	10,376.8	10,785.4	9,359.5
Flooded	73,190.9	55,622.4	66,564.5
Barren lands	2,921.0	11,651.7	6,366.9
Water bodies	270,664.8	270,947.7	281,916.9
Total	945,850.0	945,850.0	945,850.0

Table 4
Percent land cover changes from the 1970s to 2000s, from the 1970s to 1990s, and from 1990s to 2000s

	Mangrove	Non-Mangrove	Flooded	Water bodies	Barren
1970—2000					
Mangrove	92.9	0.1	4.6	2.0	0.4
Non-mangrove	8.3	69.2	22.0	0.5	0.0
Flooded	37.5	2.3	35.4	22.3	2.5
Water bodies	2.2	0.0	3.7	93.5	0.5
Barren lands	21.4	0.0	29.1	22.6	26.8
1970—1990					
Mangrove	95.4	0.1	3.1	0.9	0.6
Non-mangrove	4.1	78.6	17.1	0.1	0.0
Flooded	41.5	3.0	30.4	18.0	7.1
Water bodies	1.5	0.0	4.6	93.2	0.6
Barren lands	15.2	0.0	22.5	10.2	52.1
1990—2000					
Mangrove	93.1	0.1	5.1	1.3	0.4
Non-mangrove	7.3	66.6	25.0	1.1	0.0
Flooded	35.8	2.9	35.5	23.4	2.4
Water bodies	0.9	0.0	3.3	95.5	0.3
Barren lands	25.8	0.0	40.5	18.8	15.0

Due to aggradation, land continues to be made afresh in the Sundarbans, offsetting a large part of the loss to erosion. This process has increased the land and mangrove forest areas. Once the new land is formed, such lands are typically colonized by a sequence of plant communities, culminating in the establishment of mangrove forests. Examples of aggradation can be seen in Fig. 5.

Between 1970s and 1990s, mangrove forest gained from aggradation (2925 ha) nearly equals mangrove forest lost to erosion (3157 ha). From the 1990s to 2000s, however, the rate of erosion claimed seven times as much mangrove forest (4151 ha) as aggradation created (592 ha). Erosion was concentrated along the banks of major river channels and at the land-water interface with the Bay of Bengal. Approximately half of the mangrove forested land lost was at the extreme southern edge of the Sundarbans where almost no compensating aggradation took place.

While the most dramatic and indisputable areas of change were found along the major waterways and at the southern boundary with the Bay of Bengal, some inland areas showed evidence of change as well. For example, in Bangladesh forest compartment 30, the change matrix (Table 4) shows an area of mangrove forest lost partly to the flooded class and partly to barren lands. This finding is consistent with comparison of maps from Chaffey et al. (1985) and high-resolution QuickBird remote-sensing images from 2002.

On the India side of the Sundarbans, the most dramatic area of change is located approximately 14 km east of Kisoripur. In the 1970s image, 1085 ha of mangrove forest, interspersed with open flooded areas, extended approximately 4 km inland from the Matla/Bidya River. By 1990s, the classification shows that 13.27% of the mangrove forest had been lost, and the boundary between development and mangroves had receded approximately 1 km to the east. By 2000s (ETM^+),

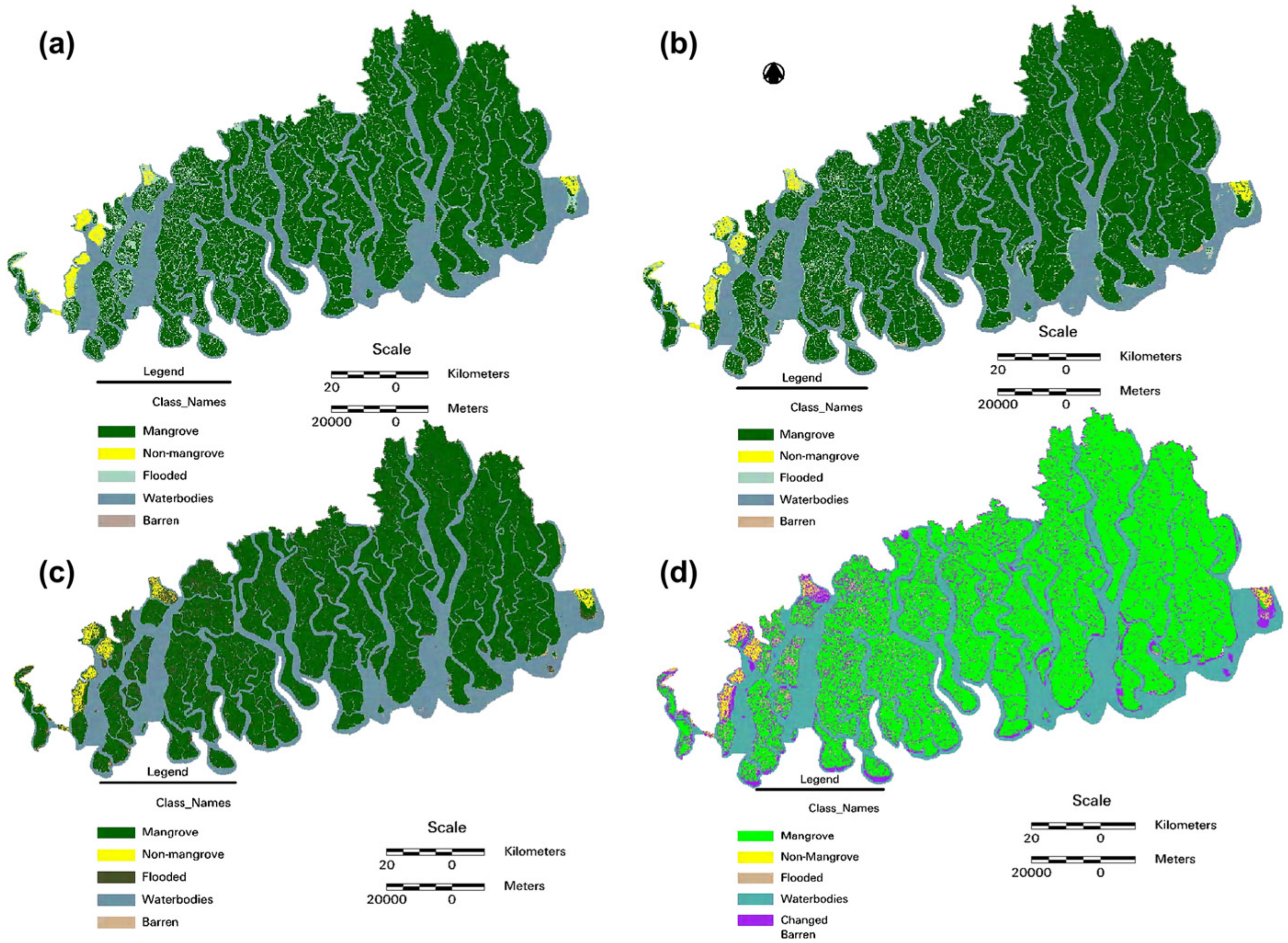

Fig. 3. Classification maps of (a) MSS, (b) TM, and (c) ETM^+ data, and (d) change maps from the 1970s to 2000s.

only 7.57% of the original 1085 ha of tree cover remained in a ring of mangrove at the shoreline. The evidence of development is apparent with the building of diked areas and canals as the forest was removed. This area falls outside of the managed forest reserves and contrasts sharply with the mangrove forested areas to the south and east, which remained generally unchanged during the same period.

Again, the net mangrove loss over the whole of the Sundarbans is about 1% as the numerous areas of loss are counterbalanced by areas of gain. Most of this gain is found in areas where new land formed through deposition has become vegetated. One of the exceptions is an area of afforestation located in the Jilla forest block on the northern forest boundary of the India side. This area of approximately 400 ha was completely degraded in 1975, but had been re-vegetated by 1989 and was generally indistinguishable from surrounding forested areas in a remote-sensing image by 2000s.

4.2. Accuracy assessment

Three confusion matrices were created to compute overall accuracy, users' accuracy, producers' accuracy, and tau coefficient. We assumed that the ground or reference data used in the study accurately represent the ground reality. The ground data may however represent another classification by the interpreter which may contain error, and moreover, such ground data did not correspond with the date of satellite data classified.

Overall accuracy of 86%, 85%, and 79% were achieved for 2000s, 1990s, and 1970s classification with the Tau coefficient of 0.85, 0.83, and 0.76, respectively. The tau coefficient for the year 2000, for example, indicates that our classification systems produce a map on which 85% more pixels were classified correctly than would be expected by random assignment. This means that for this classification, we were correct 85% of the time. Confusion arose in discriminating flooded and water bodies, and non-mangrove and barren lands classes. Mangrove class was relatively well classified.

4.3. Comparison of percent canopy closure

The canopy closure layers derived from NDVI measurements for the three mosaics show changing patterns of forest condition in the Sundarbans. The pattern of healthy upperstory vegetation is different in the different era classification results. Therefore, the least healthy areas in 2000s are different

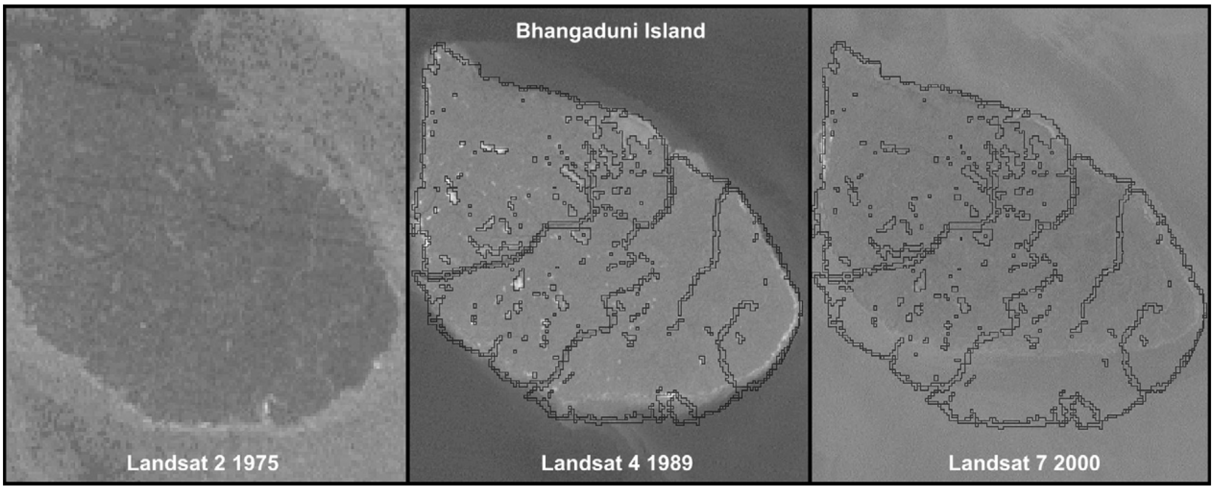

Fig. 4. Erosion claimed 25% of the land area and 24% of the mangrove forest of Bhangaduni Island between 1970s and 2000s.

from the least healthy areas of 1990s. Furthermore, the pattern of relatively unhealthy vegetation in 2000s corresponds to areas of reported top dying. As explained above, the lack of multiple images for each era, the different seasons of acquisition for images of different eras, and variation in the degree of tidal inundation in the various images prevents comparison of absolute values derived from each of the canopy closure layers. While the absolute values for canopy closure that the model is designed to generate are not reliable, patterns of relative canopy closure are confirmed as generally valid. Visual confirmation of the validity of the canopy closure layer comes from two sources—the 1985 (1983 data) Chaffey et al. inventory maps and QuickBird high-resolution remote-sensing images from 2002. The Chaffey et al. (1985) maps from 1983 aerial photography, while compiled approximately 6 years later, support the validity of the 1970s-era canopy closure layer. The 1983 maps show roughly two-thirds of this area as having canopy closure above 70% and little or none of this area to be below 30% canopy coverage. These areas correspond well to the high and low canopy closure areas in the 1970s-era canopy closure layer. The largest change in the pattern of canopy closure is between the TM and ETM$^+$ eras, when a large corridor of reduced canopy closure appears between the Bal and Sibsa Rivers (Fig. 6). This corresponds to forest compartments that have high rates of top dying (Canonizado and Hossain, 1998, in Iftekhar and Islam, 2004).

5. Discussion

Despite having one of the highest population densities in the world in its immediate vicinity, mangrove forest areas of the Sundarbans have not changed significantly from the 1970s to 2000s. Our multi-temporal analysis of Landsat data revealed that the decrease in forest area from the 1970s to 2000s was 1.2% of the total mangrove area. The decrease in area was higher (2.5%) from 1990s to 2000s, and forest area increased by 1.4% from the 1970s to 1990s. Measurement of change on the order of 1–2% has to be taken in the context of variability in the area measurements of this study and the studies reported in the literature. Mangrove forest areas estimated in Bangladesh and India vary considerably depending on the source data, methods, definition of mangrove forest,

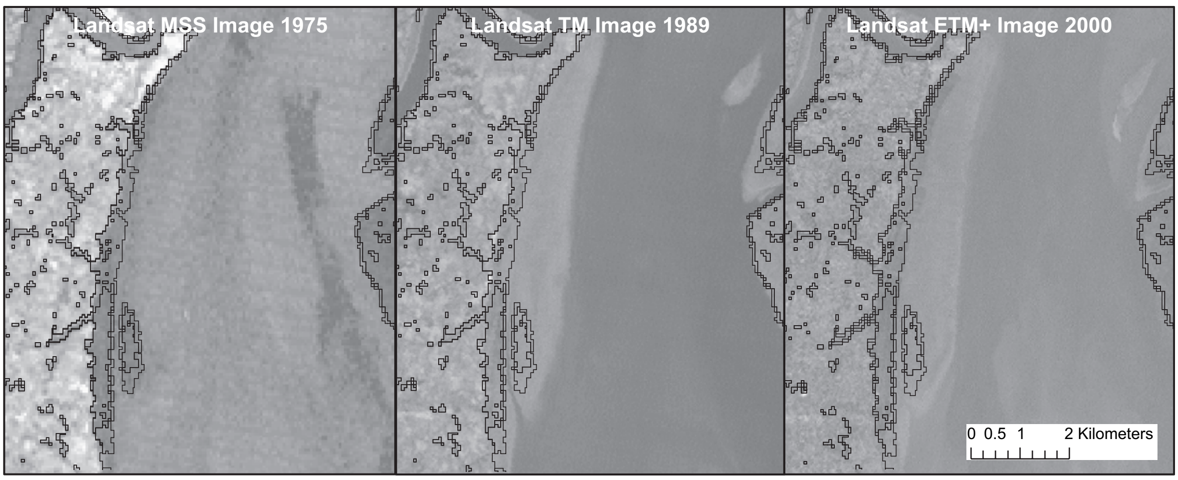

Fig. 5. Example of aggradation in which the extent of mangrove forest areas represented by red has increased from 1970s to 2000s.

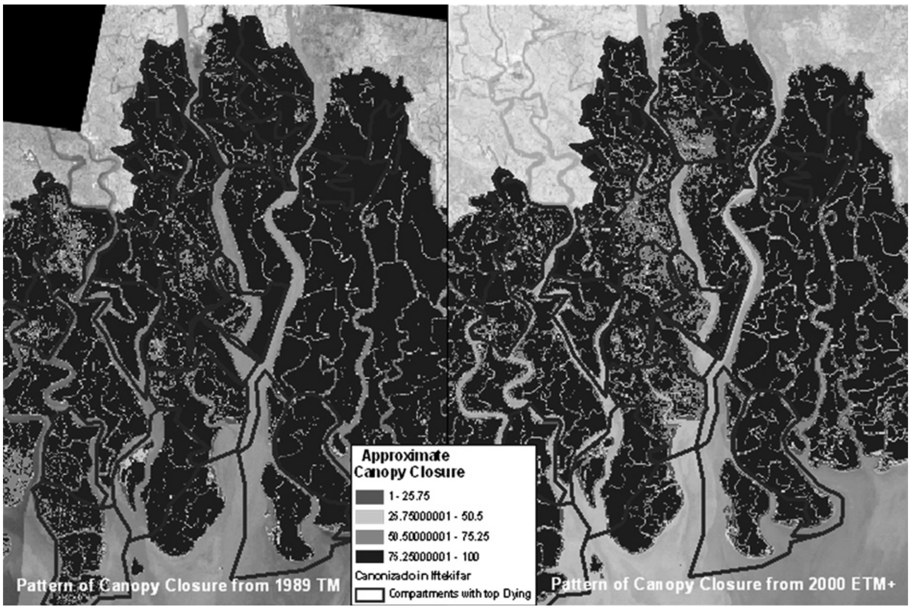

Fig. 6. Change in the pattern of canopy closure from 1989 to 2000 corresponds to areas of the greatest occurrence of Sundri top dying.

and the boundaries used. An estimate of the entire Sundarbans was not available. Our study estimated a total of 653,000 ± 9795 ha. This estimate includes mangrove, flooded, and barren classes. Including water bodies, the total area of the Sundarbans is 945,850 ha (Table 3).

Our estimates of mangrove on the Bangladesh side are within 4% of the published estimates. In addition, our rate of change for the Bangladesh side is consistent with the difference in change between the Chaffey et al. (1985) inventory (1983 data) and the estimates of Revilla et al. in 1998 (1996 data) (reported in Iftekhar and Islam, 2004), equaling 1.4% loss in area from 1983 to 1996 for Bangladesh.

On the India side, however, both of our estimates of forested area are roughly 20% lower than those of either Banerjee (1964) (from Blasco, 1975) or Naskar et al. (2004). These figures were found in secondary sources with no explanation of the methods or definitions. A calculation of the entire land area, forested or not, within our delineated Sundarbans study area matches quite well with these figures. Based on this fact, it is assumed that these estimates (Banerjee, 1964; Naskar et al., 2004) were for all land area within a boundary delineating the Indian Sundarbans. Therefore, these two estimates do not provide a good basis for comparison on the India side.

The apparent acceleration of erosion relative to accretion of new land during the second decade of the study seems to suggest that upstream hydrological changes, most notably the building of the Farakka barrage in India, have disrupted the balance of land creation and land loss that existed prior to human alteration of the local hydrology. While this may be the case, the geomorphology of this area is extremely dynamic. Large areas of erosion have been recorded for more than a century (Mitra, 1914), and large new islands are currently forming at the mouth of the Baleshwar River and elsewhere (Hoque, pers. commun.). Ongoing study over a more extended period of time would likely be needed to separate any anthropogenic influence from the background of dynamic change that is natural in this environment.

This study suggests that some of the mangrove forest is being lost within the Sundarbans boundaries. While this is not sustainable over the long term, it is a relatively modest rate of loss considering the intense population density in the area surrounding the Sundarbans (Fig. 2). Under various protections from forest reserves, wildlife sanctuaries, national parks, and international designations, the area of the Sundarbans mangrove forest seems to be holding relatively stable. Unfortunately, this only tells part of the story.

The consensus in the literature regarding the Sundarbans is that increasing salinity, over-harvesting of timber, and other human influences are degrading the condition of the Sundarbans mangroves (Iftekhar and Islam, 2004). The detailed inventories of forest in 1959 and as reported by Chaffey et al. (1985) show a dramatic decline in the density of desirable lumber species between their respective inventories (Islam et al., 1997). The Sundri tree (*Heritiera fomes*) is generally believed to be the namesake of the Sundarbans (Iftekhar and Islam, 2004) and is also the most commercially valuable species in the Sundarbans, contributing more than 60% of the forest's merchantable timber (Rahman et al., 1990). Average stand density of Sundri has declined by 95% since Curtis's inventory, which was taken between 1926 and 1928 (Iftekhar and Islam, 2004), presumably due to over-harvesting, both legal and illegal. In addition, since around the 1970s, the Sundri trees have been increasingly affected by a phenomenon commonly called "top dying disease" (Rahman, 1990). Our study found a pattern of reduced canopy closure coinciding with the Bangladesh forest compartments that had the greatest occurrence of top dying (Canonizado and Hossain in Iftekhar and Islam, 2004). Further validation is needed to confirm this relationship. If relative canopy closure were demonstrated to provide a good indication of Sundri top dying, this would provide an extremely valuable tool for understanding and managing this devastating phenomenon.

6. Conclusions

Our measure of extent for the Sundarbans mangrove forest shows little change in net area (approximately 1% loss) in the last 25 years. This finding is consistent with other recent remote-sensing studies at the local level (Islam et al., 1997; Dwivedi et al., 1999; Blasco et al., 2001; Nayak et al., 2001). This small change was generally expected based on the management and protection status of the Sundarbans, including the ban on clear cutting and forest encroachment. The relative stability of the forest's extent hides an equally significant change in the condition of the forest. The forest is undergoing constant change due to erosion, aggradation, deforestation, reforestation/afforestation, and forest degradation. Selective timber harvest, both legal and illegal, and more diffuse environmental pressures such as decreased freshwater flow, decreased sediment supply, water contamination, and disease have degraded the forest's condition. These pressures have led to decreased canopy closure in several areas of the forest. The patterns of changing canopy closure have been captured in remote-sensing data from the past 25 years. Correlation of NDVI data with canopy closure (Jensen et al., 1991) is generally borne out by our study. However, we conclude that this measure is not robust enough to transcend variation in the three data formats, slight variations in seasonal phenology, and limited samples from each epoch to provide reliable measure of absolute canopy closure. Nevertheless, the relative canopy closure within the mosaicked image for each decade was found to relate quite well to areas of degraded forest. With adequate validation and calibration, canopy closure layers, even ones derived from single date images as were the ones in this study, may provide valuable information about patterns of change in the forest's density and condition.

Early recognition of the value of the Sundarbans mangrove forest led to adoption of management practices designed for maximum sustainable yield of a limited number of timber species. This has been a crucial factor in preserving what remains of the Sundarbans. Recent emphasis on managing the entire ecosystem (Iftekhar and Islam, 2004) may be able to sustain this valuable resource well into the future. To do this, reliable and frequent measures of several dimensions of the forest's health will be required. Continued development and use of remote-sensing technology for this application could provide valuable and spatially explicit information about deforestation and degradation as well as a means of linking smaller-scale studies to a holistic appraisal of the state of the mangrove forests of the Sundarbans.

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References

Banerjee, A.K., 1964. Forests of Sundarbans. West Bengal Forests. Centenary Commemoration volume. Planning and Statistical Cell, West Bengal, Calcutta, India, pp. 166–175.

Blasco, F., 1975. The Mangroves of India. Institut Francais De Pondichéry, Pondichéry, India, 175 pp.

Blasco, F., Aizpuru, M., Gers, C., 2001. Depletion of the mangroves of Continental Asia. Wetlands Ecology and Management 9, 245–256.

Canonizado, J.A., Hossain, M.A., 1998. Integrated Forest Management Plan for the Sundarbans Reserved Forest. Mandala Agricultural Development Corporation and Forest Department and Ministry of Environment and Forest, Dhaka, Bangladesh, 234 pp.

Chaffey, D.R., Miller, F.R., Sandom, J.H., 1985. A Forest Inventory of the Sundarbans. Bangladesh. Overseas Development Administration, Land Resources Development Centre, Surrey, England, 187 pp.

Chander, G., Markham, B., 2003. Revised Landsat-5 TM radiometric calibration procedures and post-calibration dynamic ranges. IEEE Transactions on Geoscience and Remote Sensing 41 (11), 2674–2677.

Chaudhuri, A.B., Choudhury, A., 1994. Mangroves of the Sundarbans. Volume One: India. IUCN Wetland Programme, Bangkok, Thailand, 247 pp.

Civco, D.L., Hurd, J.D., Wilson, E.H., Song, M., Zhang, Z., 2002. A Comparison of Land Use and Land Cover Change Detection Methods. ASPRS-ACSM Annual Conference and FIG XXII Congress, April 22–26, 2002.

Dwivedi, R.S., Rao, B.R.M., Bhattacharya, S., 1999. Mapping wetlands of the Sundarban delta and its environs using ERS-1 SAR data. International Journal of Remote Sensing 20, 2235–2247.

Gutman, G., Ignatov, A., 1998. The Derivation of the Green Vegetation Fraction from NOAA/AVHRR Data for use in Numerical Weather Prediction Models. International Journal of Remote Sensing 19, 1533–1543.

Homer, C., Huang, C., Yang, L., Wylie, B., Coan, M., 2004. Development of a 2001 National Land Cover Database for the United States. Photogrammetric Engineering and Remote Sensing 70, 829–840.

Huang, C., Wylie, B., Homer, C., Yang, L., Zylstra, G., 2002. Derivation of a Tasseled cap transformation based on Landsat 7 at-satellite reflectance. International Journal of Remote Sensing 23, 1741–1748.

Iftekhar, M.S., Islam, M.R., 2004. Degeneration of Bangladesh's Sundarbans mangroves: a management issue. International Forestry Review 6, 123–135.

Islam, M.J., Alam, M.S., Elahi, K.M., 1997. Remote Sensing for Change Detection in the Sundarbans, Bangladesh. Geocarto International 12, 91–100.

Jensen, J.R., Lin, H., Yang, X., Ramsey, E., Davis, B.A., Thoemke, C.W., 1991. The measurement of mangrove characteristics in southwest Florida using SPOT multi-spectral data. Geocarto International 2, 13–21.

McKee, K.L., 2005. Global change impacts on mangrove ecosystems. Available from http://www.nwrc.usgs.gov/factshts/2004-3125.pdf. United States Geological Survey (USGS), USA.

Mitra, S., 1914. Jessore-Khulna Itihas. Dasgupta and Company Pvt. Ltd., 54/3, College Street, Calcutta-12, India, pp. 18–28 (in Bengali).

Naskar, K., Sarkar, N.S., Ghosh, A., Dasgupta, M., Sengupta, B., 2004. Status of the mangroves and mangrove ecosystem of Sundarbans in West Bengal: its impact on estuarine wetland fisheries. Bulletin of the Central Inland Fisheries Research Institute, Barrackpore, Central Inland Fisheries Research Institute, Barrackpore, 53 pp.

Nayak, S., Sarangi, R.K., Rajawat, A.S., 2001. Application of IRS P4 OCM data to study the impact of cyclone on coastal environment of Orissa. Current Science 80, 1208–1213.

Park, S.K., Schowengerdt, R.A., 1982. Image reconstruction by parametric cubic convolution. Computer Vision, Graphics and Image Processing 23, 258–272.

Rahman, M.A., 1990. A comprehensive report on sundry (*Heritiera fomes*) trees with particular reference to top dying in the Sundarbans. In:

Rahman, M.A., Khandakar, M.A., Ahmed, F.U., Ali, M.O. (Eds.), Proceedings of the Seminar on Top Dying of Sundri (*Heritiera fomes*) Trees. Bangladesh Agricultural Research Council, Dhaka, Bangladesh, 256 pp.

Rahman, M.A., Khandakar, K., Ahmed, F.U., Ali, M.O., 1990. Introduction. In: Rahman, M.A., Khandakar, M.A., Ahmed, F.U., Ali, M.O. (Eds.), Proceedings of the Seminar on Top Dying of Sundri (*Heritiera fomes*) Trees. Bangladesh Agricultural Research Council, Dhaka, Bangladesh.

Tucker, J., Grant, D.M., Dykstra, J.D., 2004. NASA's global orthorectified Landsat data set. Photogrammetric Engineering and Remote Sensing 70, 313−322.

WCMC (UNEP World Conservation Monitoring Centre), 2005. Protected Areas Database. Available from http://www.wcmc.org.uk/data/database/un_combo.html.

Wilkie, M.L., Fortune, S., 2003. Status and trends of mangrove extent worldwide. Available from http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/007/j1533e/J1533E41.htm.

Annex BR10

K. Kathiresan, “Threats to Mangroves: Degradation and Destruction of Mangroves”, United Nations University Institute for Water, Environment and Health, Training Course on Mangroves and Biodiversity - Module 5.1 (2008) (available at <http://ocw.unu.edu/international-network-on-water-environment-and-health/unu-inweh-course-1-mangroves/Degradation-and-destruction-of-mangroves.pdf>)

5. Threats to Mangroves

5.1 Degradation and Destruction of Mangroves

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Mangrove forests continue to disappear all over the world. They were estimated to cover 18.1 million km^2 worldwide (Spalding, l997) but a more recent estimate indicates that the figure may now be below 15 million km^2 (www.fao.org/forestry/mangroves). About 90% of the global mangroves are growing in developing countries and they are under the condition of critically endangered and nearing extinction in 26 countries. The world mangrove experts are of the opinion that the long term survival of mangroves is at great risk due to fragmentation of the habitats and that the services offered by the mangroves may likely be totally lost within 100 years (Duke *et al*., 2007).

In general, the mangrove areas are under heavy human pressure especially in the best developed mangroves that grow along humid sheltered tropical coastlines such as delta areas of Ganges-Brahmaputra, Irrawaddy and Niger as well in the coastlines of the Malacca Straits, Borneo and Madagascar. Besides man-made pressures, the mangroves are degraded by environmental stress factors. Some estimates put global loss rates annually at one million ha, with some regions in dangers of complete collapse (*e.g.* Kathiresan and Bingham, 2001). Habitat destruction through human encroachment has been the primary cause of mangrove loss. The destruction is caused by man either knowingly or unknowingly of values of mangroves, but certainly ignoring the consequence of the loss. The loss of mangrove habitats has declined fishery resources, livelihood, and biodiversity loss. Besides over-hunting and accidental death in fishing nets, loss of mangrove and seagrass habitats are considered to be a major cause for the serious decline in the populations of marine mammals such as Manatees and Dugongs (Alvarez-Leon, 2001).

The rate of loss in the recent past has reached alarmingly high rates (Table 3; Mastaller, 1996). To cite two examples, the Philippines lost 3155 km^2 of mangroves from 1968 to 1990 that was 70.4% of the initial stand, at a rate of 143 km^2 a year or 39 ha per day. The average annual destruction rate was calculated at 5.4% a year for the whole period. In Thailand the mangrove areas were lost by 1934 km^2 from 1961 to 1991 and the reduction was 53% within 30 years. The average annual reduction was 65 km^2 or 18 ha per day and the average loss rate was 2.5% a year. These rates of mangroves loss are much higher than other tropical forests and coral reefs. The global loss of mangroves is 7 million hectares a year, which is equal to 2 years of global loss of all forest systems (Dieter Uthoff, 1996).

Numerous case studies describe mangrove losses over time, but information on the status and trends of mangrove area extent at the global level is scarce. The first attempt at estimating the total mangrove area in the world was undertaken as part of the FAO/UNEP Tropical Forest Resources Assessment in 1980, where the world total was estimated as15.6 million hectares (FAO, 1981a,b,c). More recent estimates range from 12 to 20 million ha. For many of these studies, countries with small areas of mangroves were excluded due to lack of information and because their combined area of mangroves would not significantly affect the world total. However, access to comprehensive information on the status and trends of mangrove areas at the global level has been limited. Collecting more than 2800 national and sub-national data sets, covering 121 countries where mangroves are known to exist, and comparing with the earliest estimates dating back to 1918, the Food and Agriculture Organization of the United Nations (FAO, 2001) has compiled an updated list of the most recent, reliable estimate for each country.

The results of the study suggest that the current mangrove area worldwide has now fallen below 15 million ha, down from 19.8 million ha in 1980. The world has thus lost 5 million ha of mangroves over the last twenty years, or 25 percent of the extent found in 1980. It also indicates that mangrove deforestation continues, on a slightly lower rate in the 1990s (1.1 percent per annum) than in the 1980s (1.9 percent per annum), reflecting the fact that most countries have now banned the conversion of mangroves for aquaculture purposes and require environmental impact assessments prior to large-scale conversion of mangroves for other uses. The study concludes that better information on both the extent and the condition of mangroves is needed as an aid to policy and decision making aimed at the conservation, management and sustainable use of the world's remaining mangrove ecosystems.

Table 3. Examples of the estimated world-wide decline of mangrove forests in recent times (Mastaller, 1996)

Country	Period of Record	Estimated original mangrove area (ha)	Estimated present mangrove area (ha)	Percentage
Cuba	1969-1989	476000	448000	94
Bangladesh	1963-1990	685000	587000	86
Guatemala	1965-1978	58000	50000	86
Peninsular Malaysia	1979-1986	113000	89000	79
Ecuador	1966-1989	235000	177500	76
Thailand	1961-1993	300000	219200	73
Vietnam	1969-1990	425000	286400	67
U.S.A	1958-1983	260000	175000	67
Colombia	1976-1989	480000	307000	64
Indonesia	1969-1986	4220000	2176000	52
Philippines	1968-1995	448000	140000	31
Singapore	1922-1989	700	180	26
Puerto Rico	1930-1985	26300	3000	11
South India (Kerala)	1911-1989	70000	250	4

Causes of Mangrove Degradation

Degradations of mangroves are caused by nature-induced changes. Tropical storms and tsunami are common in the Bay of Bengal and the Caribbean respectively. The damaged forests take a very long time to recover. To cite an example, a cyclone has destroyed about 8.5 million trees in Bangladesh, which is equivalent to 66.3 million m^3 of sawed timber in the year 1988.

Diseases also cause devastating damages to mangroves. For example, top dying disease has damaged about 45 million *Heritiera fomes* (Sundari) trees. This is about 20% of the entire forests in Bangladesh (Hussain and Acharya, 1994). The top dying disease is believed to be caused by an array of factors -- increased soil salinity due to reduced water flow, reduction in periodic inundation, excessive flooding, sedimentation, nutrient imbalances, pathogenic gall cankers, and cyclone – induced stress.

Biological pests and parasites also have serious impacts on mangroves. Significant damage is caused by grazing of buffaloes, sheep, goats and camels in dry coastal areas of Asia and the Middle East. Young plants are damaged by barnacles and leaf eating crabs of the sesarmid family. Some caterpillars are parasites of the fruits of *Rhizophora*, and these inhibit seed germination.

Mangrove species itself sometimes poses a problem, when it is introduced as an exotic species. For example, the nipa palm, (*Nypa fruticans*) was introduced from Singapore to Nigeria in 1906 to control coastal erosion. However, the palm spread extensive areas and replaced the native mangrove species like *Rhizophora* in Nigeria. Hence, the Federal Ministry of Environment of Nigeria has developed the 'Nypa Palm Control programme' to control the invasive species.

Causes of Mangrove Destruction

Globally mangroves are destroyed by man-made activities, which pose significant threats and they are detailed briefly as follows:

Urbanization: Coastal mangroves have been cleared for human inhabitation in many areas like Singapore, Jakarta, Bangkok, Rangoon, Kolkata (Calcutta), Mumbai (Bombay), Lagos, Maracaibo, Recife, Free town, Douala *etc*.

In India, Mumbai is one of the best examples for the mangrove destruction due to urbanization. All the seven islands of Mumbai were reclaimed and linked to a continuous landmass after destroying mangroves in the process.

Agriculture: The history of restriction of Sundarbans is nothing but the history of conversion of mangrove forests for agricultural purposes. This reclamation process was initiated in 1770 and it continued till recent past. In the largest delta region of the world, existing between India and Bangladesh, 1,50,000 ha of mangroves were destroyed during the past 100 years, and these were mainly reclaimed for agriculture.

The mangrove areas are deforested and reclaimed with rainwater to drain the salt content of the soil and these areas are protected from seawater intrusion by constructing embankments. Once the salt is leached to a sufficient level, the land is cultivated either with paddy or coconut.

Aquaculture practices: A large scale destruction of mangroves was made for aquaculture in several countries. To cite an example, in the Philippines, between 1968 and 1983, 2,37,000 ha of mangroves were lost for pond construction. This is almost half of the total national mangrove area (Fernandez, 1978). One major issue associated with the farms located in mangrove habitats is acidification of pond waters that kills aquatic organisms. In Ecuador, the decline in mangrove areas was largely due to the construction of 21,587 ha of shrimp ponds, compared to only 1,157 ha for urban expansion in 1969-84. In Thailand, around 50% of the total denuded mangrove area of 1,71,472 ha was converted into aquaculture ponds during the period 1961-87.

Fig.12. Possible factors responsible for degradation of mangroves and depletion of fishery resources at Pichavaram situated in southeast coast of India. This specific area has already lost 75% its green cover within the last century and about 90% of the forest area is degrading (From Kathiresan, 2000)

Cutting for timber, fuel and charcoal: Mangroves are cleared for timber, charcoal and firewood. Because of higher calorific value, the mangrove twigs are used as firewood. The mangrove wood is rich in phenols, and hence is highly resistant to deterioration, and it is widely used as timber for construction purpose. The mangrove wood is highly suitable for chipboard industry and quality paper. As a result, several companies have been established for paper mills and chipboard factories in Indonesia. Within two years, the timber companies obtained timber by clearing 1,37,000 ha of mangroves (Erftemeijer *et al.*, 1989).

Prevention of freshwater flow and tidal flow: Mangroves are best developed in areas that receive freshwater run-off and tidal water flushing. Embankment construction or siltation at the river mouths restricts the inflow of tidal water in mangrove swamps. Dam and barricade constructions in upstream areas for diverting water for irrigation purposes have resulted in poor flow of freshwater into mangrove swamps. The poor flows of tidal and freshwater result in high salinity of mangrove swamps and thus reduce the growth of mangroves. To cite an example, in Colombia, large parts of mangrove forests along the lagoon of Cienaga Grande de Santa Marra, have died within 3-decades (Mastaller, 1989). Another good example is at Pichavaram, south India, where the mangroves are largely dying due to hypersalinity and other associated factors like increasing of temperature, poor precipitation, poor flushing of mangrove soil by tidal waters *etc*. These have been illustrated diagrammatically in Fig. 12.

Oil pollution: Oil or gas exploration, petroleum production, and accidents by large oil tankers cause significant damage to mangrove ecosystems. To cite an example, Nigeria's richest oil wells are situated close to inshore where rich mangroves once existed. Similarly oil tanker accidents in the Gulf of Mexico and in the Caribbean areas resulted in oil spillage that severely damages the coastal systems. As a result, the entire mangrove ecosystem got affected, causing defoliation of trees, mortality of all sessile and benthic organisms and contamination of many water fowls. Once the mangrove forest is affected by oil pollution, it will take a long time of at least 10 years for recovery of the forest.

Pollution issues: Mangrove habitats serve as a dumping ground for solid wastes and for discharging the effluents from various sources. The best examples of this are from Brazil and Singapore. In India as well, the mangroves that existed in major coastal cities like Kolkata and Mumbai are adversely affected by pollution.

War problems: The best example for this kind of mangrove destruction occurred in the Vietnam War. During the war period (1962-71), about 71 million liters of defoliant chemicals were sprayed over the coast, that resulted in the destruction of 1,04,000 ha of mangrove forest (Ross, 1974).

Mining operations: This was a serious problem in countries like Thailand. Until the late 1980's, 4,27,000 hectares along the Thailand coasts in the vicinity of mangrove belts were mined for tin.

Damages Caused & Need for Conservation

The value of mangroves has gone unrecognized for many years and the forests are disappearing in many parts of the world. These impacts are likely to continue, and worsen, as human populations expand further into the mangroves. In regions where mangrove removal has produced significant environmental problems, efforts are underway to launch mangrove agroforestry and agriculture projects. Mangrove systems require intensive care to save threatened areas. So far, conservation and management efforts lag behind the destruction; there is still much to learn about proper management and sustainable harvesting of mangrove forests (Kathiresan and Bingham, 2001).

Even where efforts have been made to slow the destruction, remaining forests have a number of problems. In some areas, the health and productivity of the forests have declined significantly. The causes of these tragic losses differ from habitat to habitat but are generally tied directly or indirectly to human activities. Individual study is required to determine the most effective remedial measures. Where degraded areas are being regenerated, continued monitoring and thorough assessment must be done to help us understand the recovery process (van Speybroeck, 1992). This knowledge will help us develop strategies to effectively rehabilitate degraded mangrove habitats the world over.

References

Alvarez-Leon, R. (2001). Las Tortugas marinas de Colombia: estado actual de su conocimiento. Rev. Acad. *Columbi. Cienc*., **25**(95): 269-286.

Duke, N.C., Meynecke, O.J. , Dittmann, S., Ellison, A.M., Anger, K., Berger, U. Cannic, S., Eiele,K., Ewel, K.C., Field, C.D., Kodedam, N., Lee, S.Y., Marchand, C, Nordhanus, L., and Dahdough-Guebas, (2007). A world without mangroves? Letters. www. Sciencemag.org. p41.

Erftemeijer, P. Allen, G. and Zuwendra, (l989). Preliminary resource inventory of Bintuni Bay and recommendations for conservation and management. In: Dir. Gen. Forest Protection and Nature Conservation and Asian Wetland Bureau, Bogor, Indonesia, 1-151.

FAO. (2001). Global Forest Resources Assessment 2000: Main report. FAO Forestry Paper 140. Rome. www.fao.org/forestry/fo/fra/main/index.jsp

FAO, UNEP, (1981a). Los Recursos Forestales de la America Tropical Proyecto de Evaluación de los Recursos Forestales Tropicales (en el marco de SINUVIMA) FAO, UNEP, Rome. 349 pp.

FAO, UNEP, (1981b). Tropical Forest Resources Assessment Project, Forest Resources of TropicalAfrica. Part II: Country Briefs FAO, UNEP, Rome. 586 pp.

FAO, UNEP, (1981c). Tropical Forest Resourcess Assesment Project, Forest Resources of Tropical Asia. FAO, UNEP, Rome. 475 pp.

Fernandez, P.M. (1978). Regulations and their impact on mangrove areas for aquaculture – the Philippine experience. *Workshop Proceeding on the conversion of mangrove areas to aquaculture*, Iloilo, pp. 78-84.

Hussain, Z. and Acharya, G. (Eds.) (1994). Mangroves of the Sundarbans, Volume **2** : Bangladesh". IUCN, Gland, Switzerland, 257 pp.

Kathiresan, K. (2000). A review of Studies on Pichavaram mangrove, southeast India. *Hydrobiologia*, **430** : 185-205.

Kathiresan, K. and Bingham B. L. (2001). Biology of mangrove and mangrove ecosystems. *Advances in Marine Biology*, **40** : 81-251.

Mastaller, M. (1989). Rehabilitation der Lagune Ciengaga Grande de Santa Marta, Kolumbien. Projekt prufungsberichti. A. GIZ, Eschborn, pp. 1-152.

Mastaller, M. (1996). Destruction of mangrove wetlands-causes and consequences. *Natural Resources and Development*, **43**(44) : 37-57.

Ross, P. (1974). The mangrove of South Vietnam; the impact of military use of herbicides. In: Walsh, G.E., Snedaker, S.C. and Teas, H.J. (Eds.), *Proceeding of International Symposium on Biology and Management of Mangroves*, 8-11 Oct. 1974, Hawaii, Gainsville, Unit. of Florida, pp. 126-136.

Spalding, M. (1997). The global distribution and status of mangrove ecosystems. *International Newsletter of Coastal Management-Intercoast Network*, Special edition, **1** : 20-21.

Van Speybroeck, D. (1972). Regeneration strategies of mangroves along the Kenyan coast. In : Jaccarini, V. and Martens, E. (eds.) The ecology of mangrove and related ecosystems, Kluwar Academic Publishers, Netherlands, pp. 243-251.

Uthoff, Dieter (l996). From Traditional use to total destruction-Forms and extent of economic utilization in the southeast Asian mangroves. *Natural Resources and Development*, **43/44** : 59-94.

Annex BR11

A. Z. Md. Zahedul Islam, "Study of the Morphology of the South Talpatti Landmass, Mandarbaria Island and Bhangaduni Island in the Northern Bay of Bengal using Remote Sensing and GIS Techniques", Bangladesh Space Research and Remote Sensing Organization (SPARRSO), (April 2008)

Study of the Morphology of the South Talpatti Landmass, Mandarbaria Island and Bhangaduni Island in the Northern Bay of Bengal using Remote Sensing and GIS Techniques

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April-2008

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Study of the Morphology of the South Talpatti Landmass, Mandarbaria Island and Bhangaduni Island in the Northern Bay of Bengal using Remote Sensing and GIS Techniques

1. Introduction: South Talpatti landmass is a coastal feature situated in the Bay of Bengal at the South-West corner of the international border between Bangladesh and India. It is a disputed landmass concerning its ownership by Bangladesh and India. The exact morphological status of the South Talpatti is not known because of the dispute that constraints to carry out conventional survey. There is concern in Bangladesh about the exact morphological status of the South Talpatti. Primary analysis of satellite images depicts that morphological status of the Mandarbaria Island and Bhangaduni Island needs to be studied to reveal the morphological evolution of the South Talpatti landmass. Hence, Bangladesh Space Research and Remote Sensing Organization (SPARRSO) undertook a study to determine the morphological status of the islands/landmass. This report presents the results of the study been carried out by SPARRSO in this context.

Remote Sensing (RS) techniques have been used in this study to generate base information on the morphological status of South Talpatti landmass. Remote Sensing data has world-wide acceptance and, thus, results obtained from this study have the same level of acceptance. In order to retain the acceptability of the findings of this study, standard RS techniques have been used.

2. Objectives of the study

i. To study the morphological change of the South Talpatti landmass, Mandarbaria Island and Bhangaduni Island in time domain.

ii. To reveal the status of the South Talpatti landmass as coastal features.

3. Study Area

The study area includes the South Talpatti landmass and its surroundings. Figure 1 shows the study area on MSS (Multi-Spectral Scanner) image of Landsat satellite. The year of the image is 1973 and the position of the South Talpatti landmass (the center of gravity of the polygon delineating the surface of the South Talpatti over water) in this year is 89 08 40.41 E and 21 35 58.31 N. The South Talpatti landmass is situated on the east of the international border between

Bangladesh and India running through the middle of the main channel of the border river. The other two Bangladeshi rivers- Raimangal and Jamuna also flow through the Raimangal estuary east of the South Talpatti. Mandarbaria Island is situated in Bangladesh at about 8 km north-east of the South Talpatti landmass and Bhangaduni Island is situated in India at about 24.5 km west of the South Talpatti landmass.

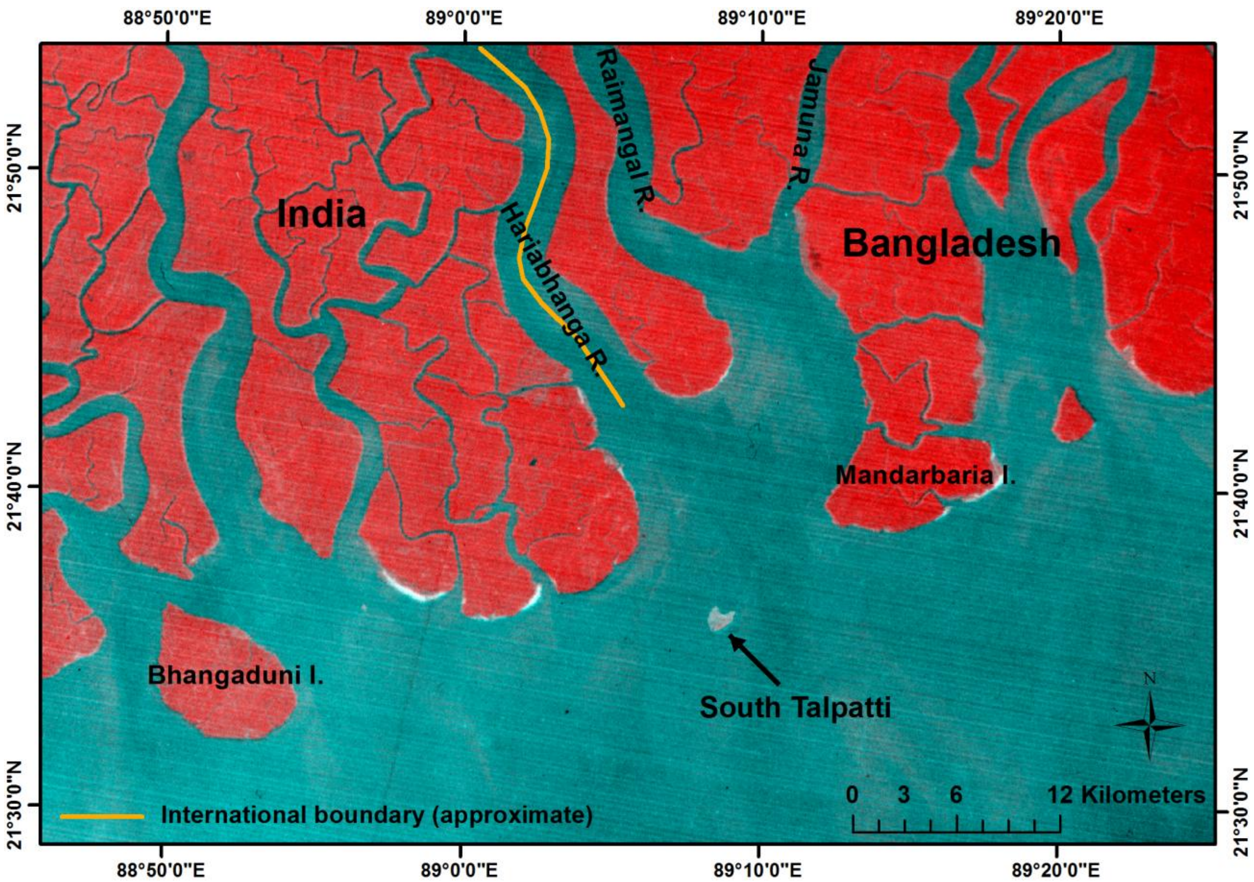

Figure 1. Landsat MSS image of 1973 showing the position of the South Talpatti landmass, Mandarbaria Island and Bhangaduni Island.

3. Data Used

The base information needed for the study are the extent and geographic positions of the South Talpatti landmass in the years under study. Satellite based time series data have been used to generate base information. In order to study the morphological changes for wider time frame, satellite images have been used starting from its inception of operational use in early seventies. Table 1 gives the information on the satellite images used for the study. A total of 17 satellite images have been used for the study.

Table 1. Satellite images used for the study

Sl. No.	Date of Image	Satellite/Sensor	Bands	Resolution, m
1	21-02-1973	Landsat MSS	4, 5, 6, 7	80
2	05-12-1975	Landsat MSS	4, 5, 6, 7	80
3	10-01-1976	Landsat MSS	4, 5, 6, 7	80
4	21-01-1979	Landsat MSS	4, 5, 6, 7	80
5	21-02-1980	Landsat MSS	4, 5, 6, 7	80
6	17-11-1980	Landsat MSS	4, 5, 6, 7	80
7	27-12-1981	Landsat MSS	4, 5, 6, 7	80
8	13-03-1985	Landsat MSS	4, 5, 6, 7	80
9	03-01-1989	Landsat MSS	4, 5, 6, 7	80
10	14-01-1990	Landsat TM	3, 4, 5	30
11	14-11-1990	Landsat TM	3, 4, 5	30
12	18-02-1997	Landsat TM	3, 4, 5	30
13	17-11-2000	Landsat TM	3, 4, 5	30
14	04-11-2004	Landsat TM	3, 4, 5	30
15	07-01-2005	Landsat TM	3, 4, 5	30
16	11-12-2005	SPOT	Pan	05
17	11-02-2006	Landsat TM	3, 4, 5	30

Tidal heights at the South Talpatti landmass at the time of acquisition of the images have been estimated using the Co-Tidal Chart taking “Hiron Point” measuring station as reference.

4. Methodology

Remote sensing and GIS techniques have been used for generation of digital data layers required for the study. The following are the main methodological steps used in the study:

i) Geo-referencing of the images based on a reference TM image (1997). MSS images have been re-sampled to the pixel dimension of TM images (30 m).

ii) Enhancement of the images to clearly identify the existence and extent of the South Talpatti landmass.

iii) Generation of spatial database of the South Talpatti and its surroundings through on-screen digitization of the images and vector layer management.

iv) Tabulation of the areas of South Talpatti in different years along with the tidal heights at South Talpatti at the time of acquisition of images.

v) Generation of vector layer composite of all the years. This composite layer was used to prepare gross existing area of the South Talpatti during the study period and to detect changes of the coastal areas near the South Talpatti.

5. Product Generated

i. Composite of images to present time-series morphological evolution of the South Talpatti landmass (Figures 2-4).

ii. Image map presenting the movement of the top surface (visible over water) of South Talpatti landmass in different years (Figure 5).

iii. Image map to present the track of movement of the top surface (visible over water) of South Talpatti landmass during the study period (Figure 6).

iv. Tabulation of the area of South Talpatti landmass seen over water along with the Tidal heights to analyse the status of it as coastal feature (Table 2).

v. Image map showing the erosion in the coastal area near the South Talpatti (Figure 7).

vi. Image map showing the erosion in the Mandarbaria and Bhangaduni islands (Figures 8 and 9).

6. Analysis

South Talpatti landmass is seen to be visible up to 1990 at best on satellite images (Figures 2-4). The shapes of the top surface of South Talpatti (over water) are seen different in different years. From table 2 it is seen that, for similar conditions of tidal heights in different years, like 1975 and 1981, 1980 (February) and 1985, and 1980 (November) and 1990 (January), there is no consistency of area-tidal height relationship of South Talpatti. This indicates the morphological instability of South Talpatti landmass as coastal feature.

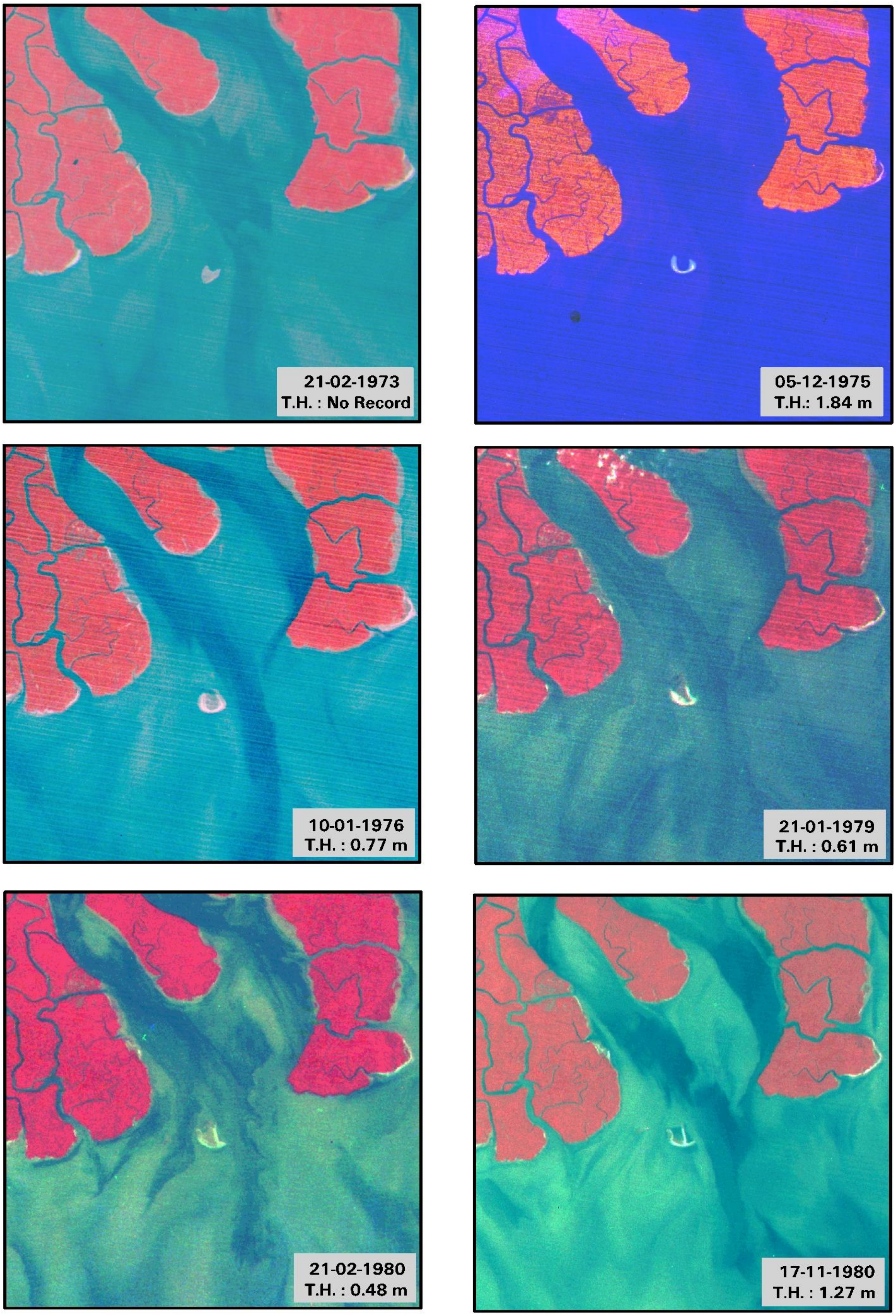

Figure 2. Extent of South Talpatti on Landsat satellite images in '73, '75, '76, '79 and '80 along with the tidal heights at South Talpatti at the time of acquisition of images.

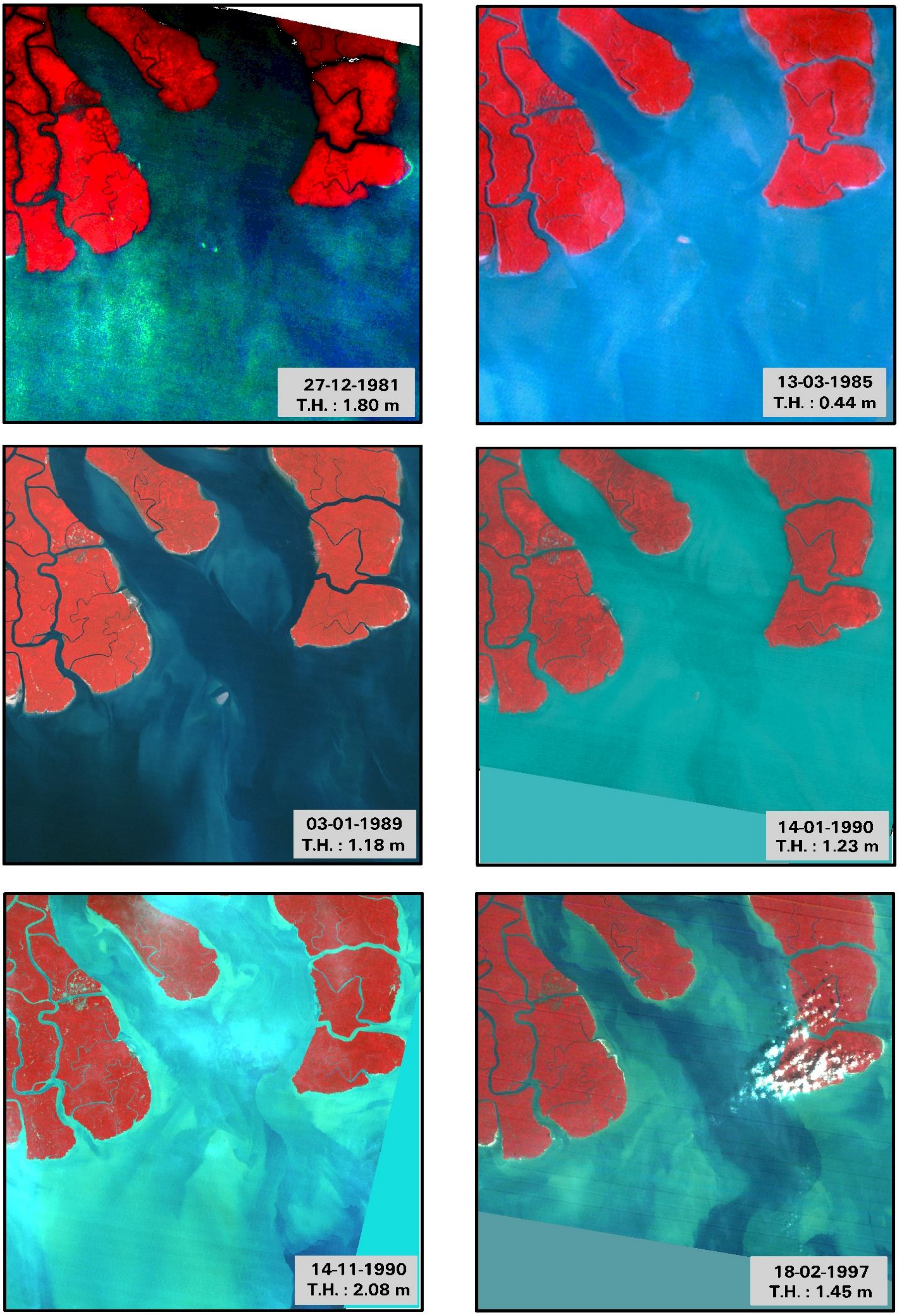

Figure 3. Extent of South Talpatti on Landsat satellite images in '81, '85, '89, '90 and '97 along with the tidal heights at South Talpatti at the time of acquisition of images.

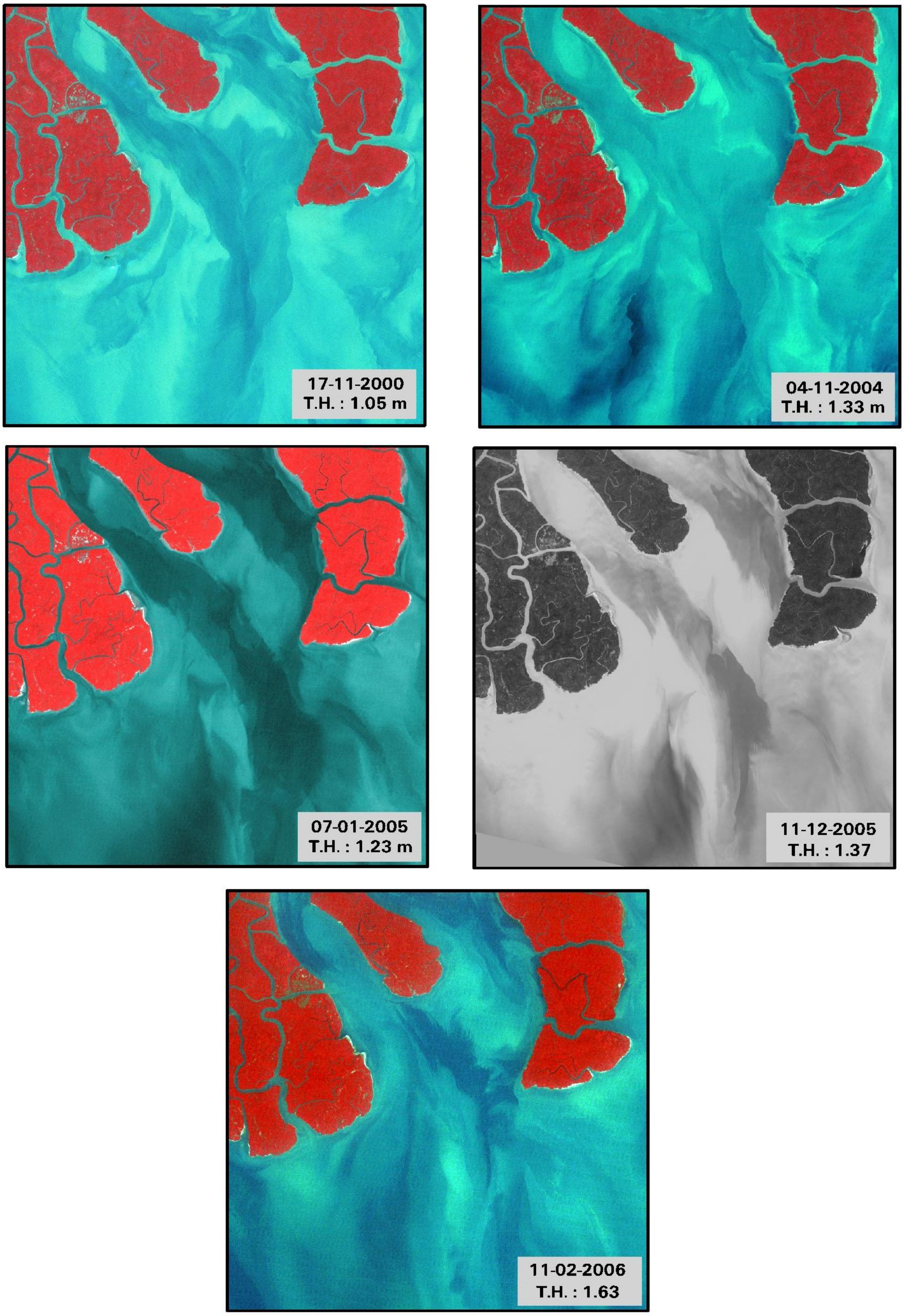

Figure 4. Extent of South Talpatti on Landsat satellite images in 2000, '04, '05 and '06 along with the tidal heights at South Talpatti at the time of acquisition of images.

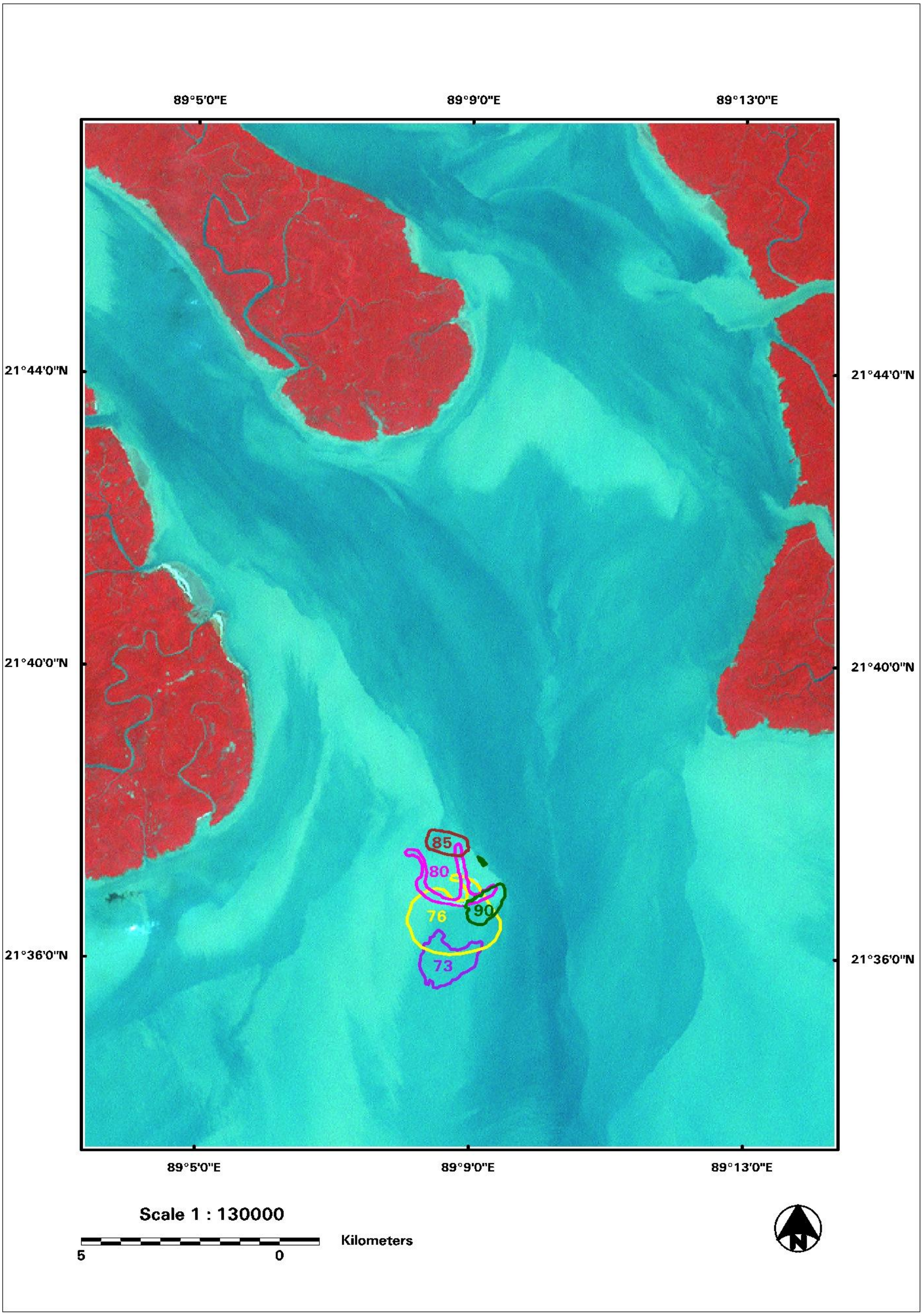

Figure 5. Movement of the top surface (visible over water) of South Talpatti landmass in different years. Only six years are shown for simplicity of presentation.

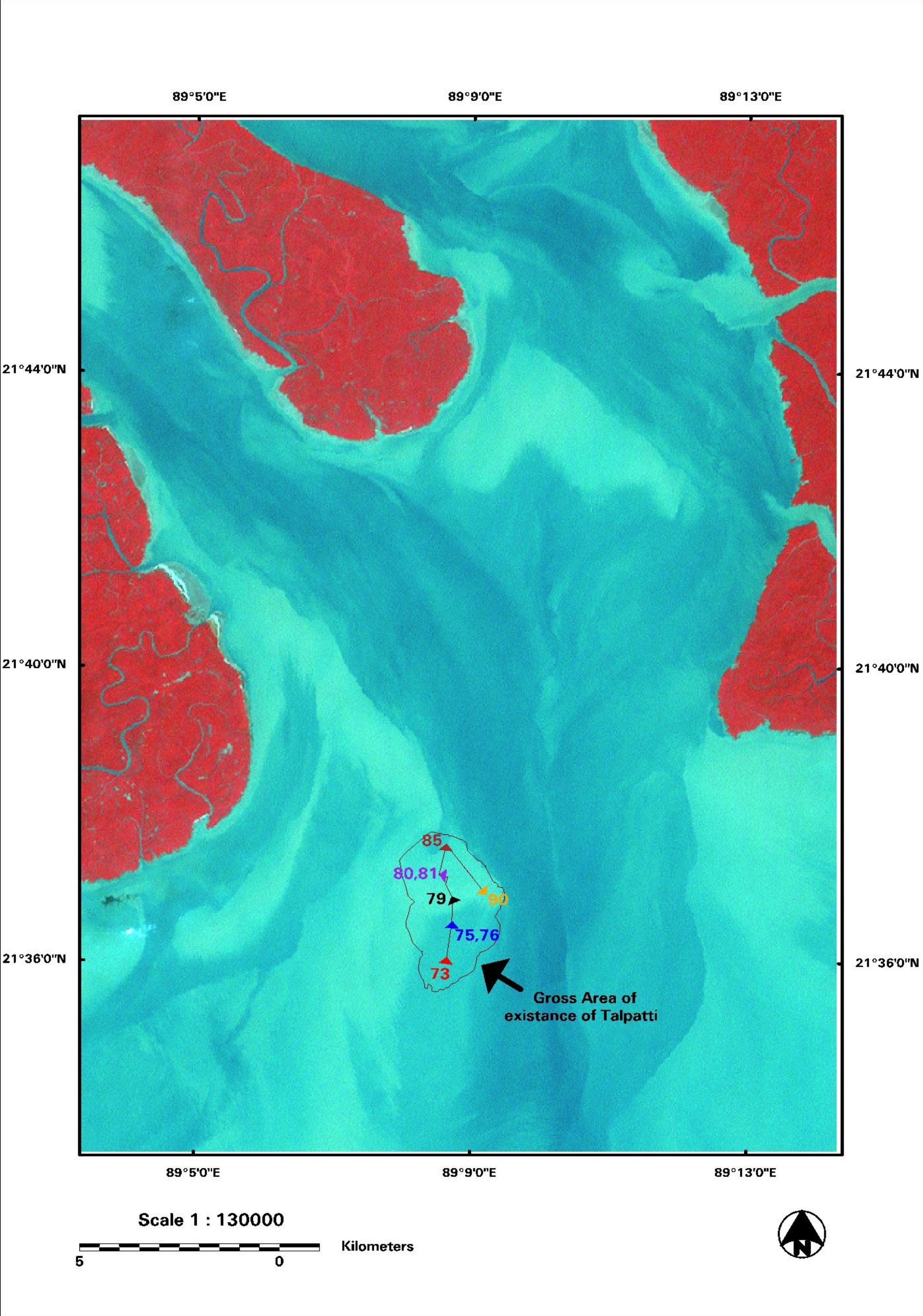

Figure 6. Track of movement of the top surface (visible over water) of South Talpatti landmass during the study period. For simplicity of presentation, tracks for all the years are not shown.

Table 2. Areas of South Talpatti estimated from images along with tidal heights

SL. No.	Date of Image	Image Acquisition time, BST	Area of South Talpatti, Sq. Km	Tidal Height at South Talpatti, m *	Nearest HW or LW at South Talpatti,		
					TIME, BST	Height, m	Tidal Conditio
1	21-02-1973	0930	1.295	-	-	-	-
2	05-12-1975	0930	1.068	1.84	1138	2.29	HW
3	10-01-1976	0930	3.127	0.77	1008	0.70	LW
4	21-01-1979	0930	0.792	0.61	0838	0.62	LW
5	21-02-1980	0930	1.235	0.48	0842	0.44	LW
6	17-11-1980	0930	0.774	1.27	0435	2.20	HW
7	27-12-1981	0930	0.171	1.80	1038	2.02	HW
8	13-03-1985	0930	0.512	0.44	0840	0.35	LW
9	03-01-1989	0930	0.636	1.18	1238	0.79	LW
10	14-01-1990	0930	0.054	1.23	1208	2.02	HW
11	14-11-1990	0930	0.013	2.08	0808	2.29	HW
12	18-02-1997	0930	00	1.45	0838	1.49	HW
13	17-11-2000	0930	00	1.05	0812	0.87	LW
14	04-11-2004	0930	00	1.33	0823	1.25	LW
15	07-01-2005	0930	00	1.23	0652	1.63	HW
16	11-12-2005	0930	00	1.37	0548	2.24	HW
17	11-02-2006	0930	00	1.63	0952	1.69	HW

Note:

* Tidal heights have been estimated at image acquisition time from the Co-Tidal Chart of Bangladesh Navy using Hiron Point as reference station.

Table 2 shows that in 2000, 2004, 2005 and 2006 the tidal heights at South Talpatti were lower than that in 1975, 1981 and 1990 (November), but South Talpatti was not visible in 2000, 2004, 2005 and 2006 though it was visible in 1975, 1981 and 1990. In 2000, the tidal height at South Talpatty at the time of acquisition of images (9.30 BST) was 1.05 m (low tide condition), but South Talpatti was not visible on Landsat TM image with 30m spatial resolution. SPOT panchromatic image of 11 November, 2005 (tidal height at South Talpatty was 1.37 m) with 05 m resolution was used to identify the existence of micro structures of the South Talpatti landmass. No such structure was found. This analysis indicates that South Talpatti has been on a course of top surface erosion.

Figure 5 shows that the top surface of the South Talpatti has been on a course of movement. Figure 6 shows the track of the movement. Starting from 1973, it moved towards north direction up to 1985, and then moved back towards south-east direction up to 1990. After 1990, South Talpatti is not visible till now on the satellite images used for the study.

Multi-temporal comparison of satellite images reveals that the coastal area near the South Talpatti has been on a course of erosion since (or before) 1975. Figure 7 shows the extent of erosion. Figure 8 and 9 show details of the erosion in the Mandarbaria (in Bangladesh) and

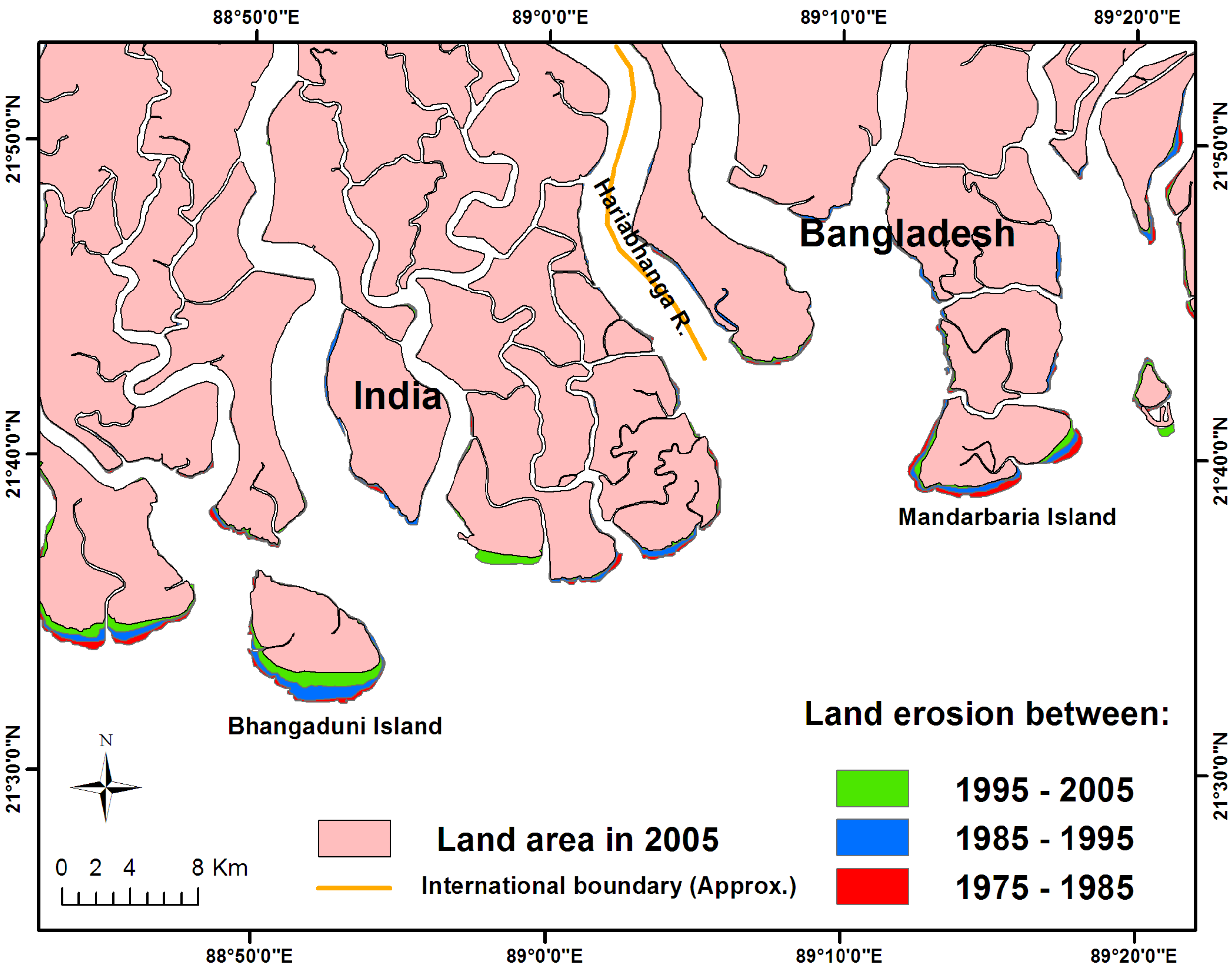

Figure 7. Extent of erosion in the coastal area near the South Talpatti landmass.

Bhangaduni (in India) islands respectively. Table 3 presents the quantitative information on the erosion in the Mandarbaria and Bhangaduni islands. It is seen from figures 7, 8 and 9 and table 3 that the coastal area near the South Talpatti has been eroding significantly during the last five decades. With respect to the land area in 1975, the Mandarbaria and Bhangaduni islands lost about 22 % and 29 % of their land areas respectively in 2005. Highest erosion occurred in the Mandarbaria island between 1975-2005 is about 1.25 Km. The same for the Bhangaduni island is about 1.75 Km. Both these island are thickly wooded which indicates that there has been existing strong erosional force in the area. This erosional force is the cause of the morphological instability of the South Talpatti which was basically a tiny fragile landmass comparing to the Mandarbaria and Bhangaduni islands.

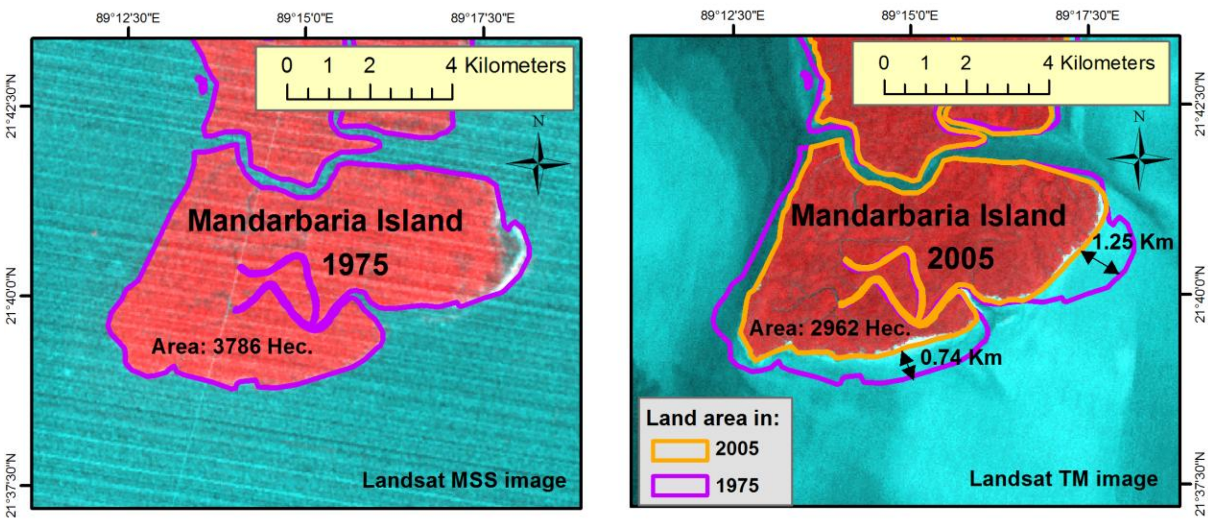

Figure 8. Satellite image map showing details of the erosion in the Mandarbaria island

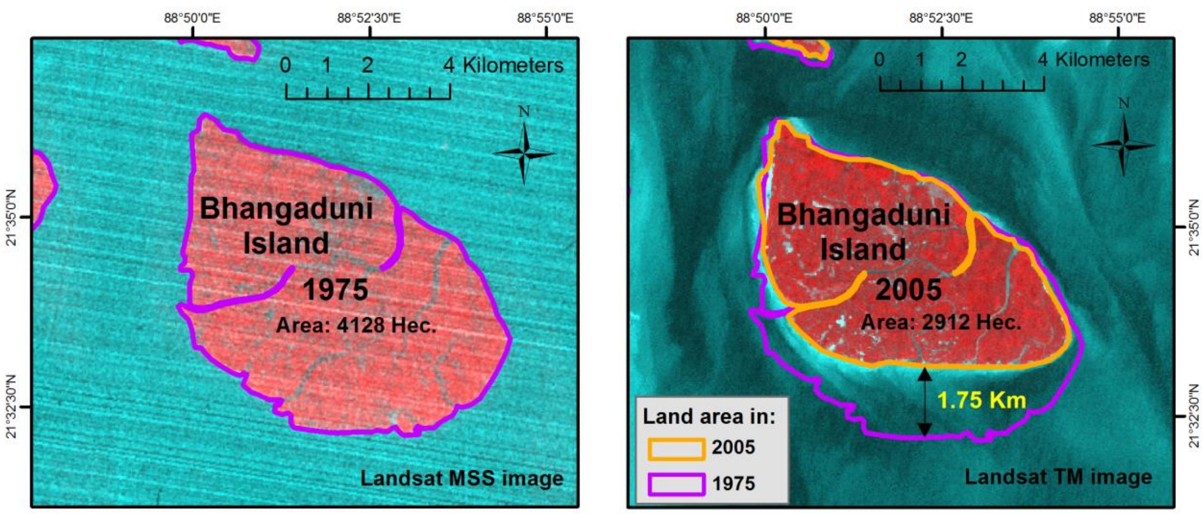

Figure 9. Satellite image map showing details of the erosion in the Bhangaduni island

Table 3. Statistics on the erosion in the Mandarbaria and Bhangaduni islands.

Island	Area in 1975, Hectare	Area in 2005, Hectare	Loss of area due to erosion		Highest erosion, Km
			Area, Hectare	% of the area in 1975	
Mandarbaria	3786	2962	824	21.76	1.25
Bhangaduni	4128	2912	1216	29.46	1.75

7. Conclusion

From the above analysis, it is evident that presently South Talpatti landmass is not an island and at best is a morphologically instable **Low Tide Elevation.**

Annex BR12

C. Loucks et al., "Sea level rise and tigers: predicted impacts to Bangladesh's Sundarbans mangroves", *Climate Change,* Vol. 98, No. 1 (2010)

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LETTER

Sea level rise and tigers: predicted impacts to Bangladesh's Sundarbans mangroves

A letter

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Abstract The Sundarbans mangrove ecosystem, shared by India and Bangladesh, is recognized as a global priority for biodiversity conservation. Sea level rise, due to climate change, threatens the long term persistence of the Sundarbans forests and its biodiversity. Among the forests' biota is the only tiger (*Panthera tigris*) population in the world adapted for life in mangrove forests. Prior predictions on the impacts of sea level rise on the Sundarbans have been hampered by coarse elevation data in this low-lying region, where every centimeter counts. Using high resolution elevation data, we estimate that with a 28 cm rise above 2000 sea levels, remaining

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tiger habitat in Bangladesh's Sundarbans would decline by 96% and the number of breeding individuals would be reduced to less than 20. Assuming current sea level rise predictions and local conditions do not change, a 28 cm sea level rise is likely to occur in the next 50–90 years. If actions to both limit green house gas emissions and increase resilience of the Sundarbans are not initiated soon, the tigers of the Sundarbans may join the Arctic's polar bears (*Ursus maritimus*) as early victims of climate change-induced habitat loss.

1 Introduction

Tigers occupy only 7% of their historic Asian range, and only about 4,000 are estimated to be living in the wild (Dinerstein et al. 2007). In Bangladesh, they are confined to the Sundarbans, a globally important mangroves ecosystem that extends into India and represents the last stronghold of tigers adapted to living in mangrove forests (Dinerstein et al. 2007; Gopal and Chauhan 2006; IUCN 2008; Sanderson et al. 2006). The mean elevation for most of the Sundarbans is less than one meter above sea level (Canonizado and Hossain 1998). Consequently, sea level rise (SLR) poses the single greatest climate change threat to the viability the Sundarbans forests (Field 1995).

Globally, sea level has increased by 1.8 ± 0.5 mm year^{-1} from 1961 to 2003, but 3.1 ± 0.7 mm year^{-1} from 1993 to 2003 (Bindoff et al. 2007). SLR is also related to a number of regional processes that may contribute to sea level changes different from the global average. These include geological processes (e.g., geological subsidence), drainage and withdrawal of water, oil and gas (Ko and Day 2004; Morton et al. 2002) and sedimentation (Broadus 1993). Using tidal gauge records, researchers at the SAARC Meteorology Research Centre (SMRC) in Dhaka, Bangladesh found an increasing east–west trend of 4 mm–7.8 mm year^{-1} rise in sea levelfor the Sundarbans from 1977 to 1998 (Alam 2003; SMRC 2003), which is greater than the average global SLR estimate during the same period.

Global and regional projections of the future rate of SLR also vary. Bindoff et al. (2007) predict that sea level will rise by 4 mm year^{-1}, with estimates of global SLR ranging between 0.22 and 0.42 ± 0.15 m by the mid 2090s. However, more recent global projections suggest that the rate of SLR is greater than previously thought and that sea levels are likely to rise in excess of one meter by 2100 (Hansen 2007; Pfeffer et al. 2008; Rahmstorf 2007). Regionally, estimates range from 0.3 to 0.5 m by 2050 (Government of Bangladesh 1993, 2005) and 0.3–1.0 m by 2100 (Agrawala et al. 2003; Government of Bangladesh 2005).

Most predictions on the impacts of sea level rise on the Sundarbans have used relatively coarse (>1 m vertical accuracy) elevation data (Dasgupta et al. 2007; Sarwar 2005; World Bank 2000). Using scale-appropriate elevation data, our study assesses the potential impact of SLR on Bangladesh's Sundarbans tiger population. We find that the Sundarbans, and its biodiversity, may be vulnerable to much lower increases in sea level than previously thought.

2 Materials and methods

We use a new sub-meter digital elevation model (DEM), with eight estimates of SLR to predict effects on tiger habitat and population size. To create our continuous

DEM we imported 80,584 GPS elevation points—measured in mm above sea level—into a GIS. The point data was initially collected by FINNMAP, a Finnish consulting firm, in 1991 for the Government of Bangladesh. We used a radial basis interpolation function which forces the elevation surface to go through each input elevation point. We used 4 mm year^{-1} as a conservative estimate of annual SLR upon which to predict potential impacts to tiger habitat and assumed 10 km^2 as the minimum habitat patch size and 5 km as the maximum dispersal distance. For each of the eight SLR time steps we identified year 2000 land area that would fall below the rising elevation of the sea. To assess the potential range of tiger population for each time step, we combined three classes of relative tiger abundance (Barlow et al. 2008) with two sets of three potential female tiger home range sizes, based on local telemetry of females ($n = 2$) and a literature review of home range sizes in other habitats. We derived two estimates of total breeding female population, which we merged with two estimates of male:female sex ratios to derive four estimates of total adult tiger populations at each SLR time step (see Supplementary Information for additional details on methods).

3 Results

Both tiger habitat (Table 1, Fig. 1) and tiger populations (Fig. 2) in the Bangladeshi Sundarbans will likely reach a critical threshold at SLR between 24 and 28 cm above the year 2000 baseline; beyond 28 cm Sundarbans tiger populations are unlikely to remain viable. Prior research on tiger population viability has shown that the ability of a population to persist as the number of breeding individuals goes from 50 to 25 declines in a non-linear manner, given stochastic, demographic, genetic, and environmental events (Chapron et al. 2008; Kenny et al. 1995). At a 28 cm rise in sea level, total estimated remaining habitat is 3.8% of the baseline, fragmented into five patches, and all models estimate total adult tiger populations at less than 20 (range = 5–19; Fig. 2b). Furthermore, the current protected area system—encompassing approximately 900 km^2 (22%) of the year 2000 land area

Table 1 Remaining tiger habitat associated with increasing sea levels

Sea level rise (cm) (baseline is year 2000)	High tiger abundance habitat (km^2)	Medium tiger abundance habitat (km^2)	Low tiger abundance habitat (km^2)	Total tiger habitat (km^2)
0	574	1,445	2,155	4,175
4	574	1,442	2,153	4,169
8	551	1,352	2,117	4,021
12	527	1,229	1,941	3,697
16	458	1,011	1,477	2,946
20	309	622	840	1,771
24	142	236	296	674
28	37	74	48	159

Total tiger habitat is separated into high, medium and low relative tiger abundance categories (Barlow et al. 2008)

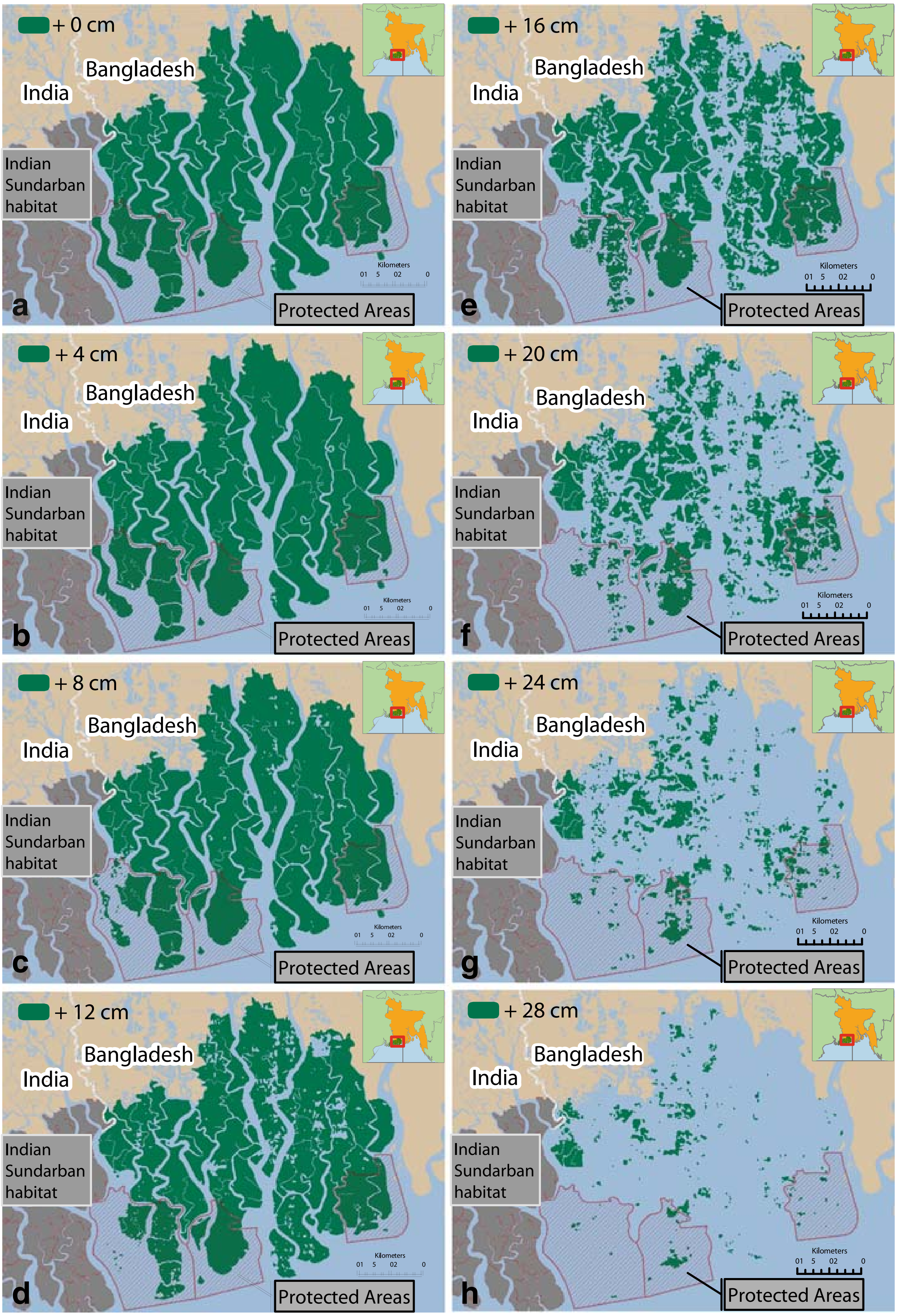

Fig. 1 Predicted tiger habitat loss in the Bangladeshi Sundarbans under increasing sea levels. Sea level is shown for eight elevations (year 2000 is baseline). The land area that lies above the predicted sea level is shown in *green*. SLR impacts are only shown for the Sundarbans, and not the surrounding land area

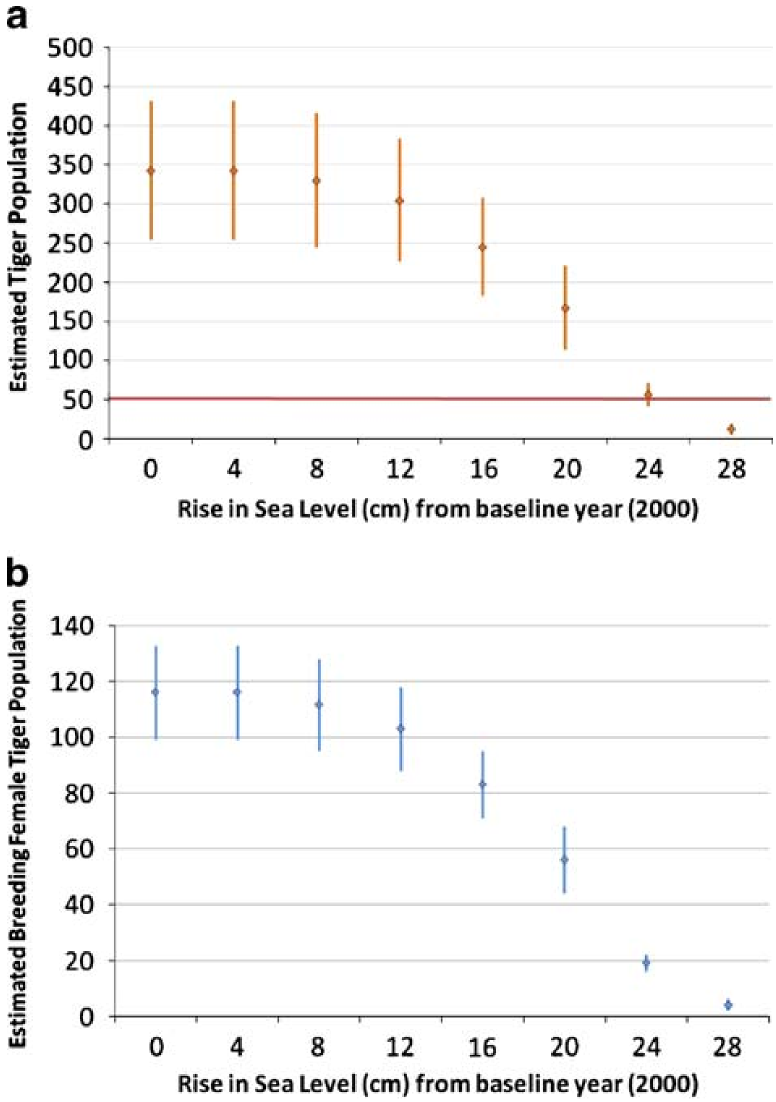

Fig. 2 Adult tiger population estimates with associated increasing sea levels. **a** Female breeding tiger population, showing mean, minimum and maximum estimates; **b** Total adult resident tiger population showing mean, minimum and maximum estimates. *Red line* indicates level at which the ability of a population to persist declines in a non-linear manner (Kenny et al. 1995)

and classified as a UNESCO World Heritage Site—is rendered largely ineffective in protecting tiger habitat at sea levels greater than 28 cm (Fig. 1).

4 Discussion

How much time do these tigers have? Using a conservative rate of 4 cm per decade increase, which is consistent with the 4th IPCC report on sea level rise (Bindoff et al. 2007) and local tidal gauge records (SMRC 2003), we predict the Sundarbans will realize a 28 cm increase in sea level around 2070. Using high and low SLR estimates from IPCC model projections bounds this prediction to between 2060 and 2100 (Bindoff et al. 2007). The protected area system, which is located on the seaward side of the Sundarbans, loses habitat at generally the same rate as the rest of the Sundarbans (Fig. 1). While there is wide variation in predictions of sea level rise, we structured our analysis to focus on the height in which a rise in sea level would greatly reduce tiger persistence beyond 50 years, not the year in which it is likely to happen.

The benefit of this approach is that our findings can be revised if sea level rises faster or slower than predicted.

Like any prediction of the future, ours must be interpreted with caution. We did not assess the Indian portion of the Sundarbans because of data limitations. It may be possible that together the Indian and Bangladesh portions of the Sundarbans could continue to act as a single meta-population, increasing the number of total breeding individuals and extending the viability of the populations beyond the predictions presented here. Furthermore, we did not incorporate potential effects of geological processes, drainage, withdrawal of water, and sedimentation; factors which may reduce or increase the level of permanent inundation. There is also some evidence to suggest that the Bangladesh coast, including the Sundarbans, is currently growing in land mass through sediment accretion (Inman 2009). We were unable to ascertain whether the mangroves would be able to adapt to the pace of changing bio-physical conditions, including rising seas. Lastly, our study assumes that once the sea level rises above the land in the Sundarbans that this will no longer be potential habitat. There may likely be a time lag from inundation to non-use of the area by tigers or their prey.

The Sundarbans and its biodiversity is critical to the survival of millions of Bangladeshis (and Indians) who share the coast and benefit from the ecosystem services (e.g. protection from cyclones, food and building supplies, fisheries, and carbon cycling) (Alley et al. 2007; Biswas et al. 2008; Iftekhar and Islam 2004) the Sundarbans provide (Agrawala et al. 2003; Islam and Haque 2004). As such, strategies to conserve the Sundarbans must begin as soon as possible (Government of Bangladesh 2008). Potential adaptation activities to conserve tigers need to focus on conserving both their mangrove refuge and the prey on which they depend. Globally, action should include limits on carbon emissions to slow climatic change. Regionally, potential adaptation activities should focus on better coordination among neighboring countries to identify mechanisms that would increase sediment delivery and freshwater flows to the coastal region to support agriculture and replenishment of land (Agrawala et al. 2003; Government of Bangladesh 2008). Locally, management activities that conserve habitat or limit threats include building dykes, developing and planting mangroves that can adapt to the rising seas and changing salinity, and limiting poaching or retaliatory killing of tigers and their prey.

Mangrove ecosystems have a natural resiliency that enables them to succeed in the dynamic interface between land and sea (McLeod and Salm 2006). However, due to a number of natural and anthropogenic factors, the Sundarbans may not be able to keep up with the current rate of sea level rise, which is predicted to increase (Rahmstorf 2007). While tigers are a highly adaptable species, thriving in the snows of Russia to the tropical forests of Indonesia, the Sundarbans ecosystem has become an isolated refuge, boxed in by humans and the sea. Although there is considerable uncertainty regarding the degree of future habitat loss due to SLR, it is still imperative to act now to mitigate the potential habitat loss. If we fail to act globally, regionally, and locally to conserve the Sundarbans, our collective inaction may result in the tiger joining the polar bear (*Ursus maritimus*) as early victims of climate-change induced habitat loss.

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References

Agrawala S, Ota T, Ahmed AU, Smith J, Aalst MV (2003) Development and climate change in Bangladesh: focus on coastal flooding and the Sundarbans. Organization for Economic Co-operation and Development (OECD), Paris

Alam M (2003) Bangladesh country case study. National Adaptation Programme of Action (NAPA) Workshop, Bhutan, pp 9–11

Alley RB, Berntsen T, Bindoff NL, Chen Z, Chidthaisong A, Friedlingstein P, Gregory J, Hegerl G, Heimann M, Hewitson B, Hoskins BJ, Joos F, Jouzel J, Kattsov V, Lohmann U, Manning M, Matsuno T, Molina M, Nicholls N, Overpeck J, Qin D, Raga G, Ramaswamy V, Ren J, Rusticucci M, Solomon S, Somerville R, Stocker TF, Stott PA, Stouffer RJ, Whetton P, Wood RA, Arblaster DWJ, Brasseur G, Christensen JH, Denman KL, Fahey DW, Forster P, Jansen E, Jones PD, Knutti R, Le Treut H, Lemke P, Meehl G, Mote P, Randall D, Stone DA, Trenberth KE, Willebrand J, Zwiers F (2007) Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change: summary for policymakers. IPCC Secretariat, Geneva

Barlow ACD, Ahmed MIU, Rahman MM, Howlader A, Smith AC Smith JLD (2008) Linking monitoring and intervention for improved management of tigers in the Sundarbans of Bangladesh. Biol Conserv 141:2032–2040

Bindoff NL, Willebrand J, Artale V, Cazenave A, Gregory J, Gulev S, Hanawa K, Le Quéré C, Levitus S, Nojiri Y, Shum CK, Talley LD, Unnikrishnan A (2007) Observations: oceanic climate change and sea level. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Biswas SR, Mallick AU, Choudhury JK, Nishat A (2008) A unified framework for the restoration of Southeast Asian mangroves-bridging ecology, society and economics. Wetlands Ecol Manag 17:365–383

Broadus JM (1993) Possible impacts of, and adjustment to, sea level rise: the cases of Bangladesh and Egypt. In: Warrick RA, Barrow EM, Wighley ML (eds) Climate and sea level change: observation, projection and implication. Cambridge University Press, Cambridge, pp 263–275

Canonizado JA, Hossain MA (1998) Integrated forest management plan for the Sundarbans reserved forest. Mandala Agricultural Development Corporation and Ministry of Environment and Forest, Dhaka, Bangladesh

Chapron G, Miquelle DG, Lambert A, Goodrich JM, Legrandre S, Clobert J (2008) The impact on tigers of poaching versus prey depletion. J Appl Ecol 45:1667–1674

Dasgupta S, Laplante B, Meisner C, Wheeler D, Yan D (2007) The impact of sea level rise on developing countries: a comparative analysis. World Bank Policy Research Working Paper No. 4136. http://ssrn.com/abstract=962790. Accessed 27 July 2009

Dinerstein E, Loucks C, Wikramanayake E, Ginsberg J, Sanderson E, Seidensticker J, Forrest J, Bryja G, Heydlauff A, Klenzendorf S, Leimgruber P, Mills J, O'Brien TG, Shrestha M, Simons R, Songer M (2007) The fate of wild tigers. Bioscience 57:508–514

Field CD (1995) Impacts of expected climate change on mangroves. Hydrobiology 295:75–81

Gopal B, Chauhan M (2006) Biodiversity and its conservation in the Sundarban mangrove. Ecosyst Aquat Sci 68:338–354

Government of Bangladesh (1993) Assessment of the vulnerability of coastal areas to sea level rise and other effects of global climate change. Department of the Environment, Dhaka

Government of Bangladesh (2005) National adaptation program of action. Ministry of Environment and Forest, Dhaka, Bangladesh

Government of Bangladesh (2008) Bangladesh climate change strategy and action plan 2008. Ministry of Environment and Forests, Dhaka

Hansen JE (2007) Scientific reticence and sea level rise. Environ Res Lett 2:024002

Iftekhar MS, Islam MR (2004) Managing mangroves in Bangladesh: a strategy analysis. J Coast Conserv 10:139–146

Inman M (2009) Where warming hits hard. Nature 3:18–21

Islam MS, Haque M (2004) The mangrove-based coastal and near shore fisheries of Bangladesh: ecology, exploitation and management. Rev Fish Biol Fish 14:153–180

IUCN (2008) Panthera tigris. http://www.iucnredlist.org/details/15955. Accessed 27 July 2009

Kenny JS, Smith JLD, Starfield AM, McDougal C (1995) The long-term effects of tiger poaching on population viability. Conserv Biol 9:1127–1133

Ko JY, Day JW (2004) A review of ecological impacts of oil and gas development on coastal ecosystems in the Mississippi Delta. Ocean Coast Manag 4711–12:597–624

McLeod E, Salm RV (2006) Managing mangroves for resilience to climate change. IUCN, Gland
Morton RA, Buster N, Krohn MD (2002) Subsurface controls on historical subsidence rates and associated wetland loss in southcentral Louisiana. Gulf Coast Assoc Geol Soc 52:767–778
Pfeffer WT, Harper JT, O'Neel S (2008) Kinematic constraints on glacier contributions to 21st-century sea-level rise. Science 321:1340–1343
Rahmstorf S (2007) A semi-empirical approach to projecting future sea-level rise. Science 315: 368–370
Sanderson E, Forrest J, Loucks C, Ginsberg J, Dinerstein E, Seidensticker J, Leimgruber P, Songer M, Heydlauff A, O'Brien T, Bryja G, Klenzendorf S, Wikramanayake E (2006). Setting priorities for the conservation and recovery of wild tigers: 2005–2015. WCS, WWF, Smithsonian, NFWF-STF, New York, Washington
Sarwar MGM (2005) Impacts of sea level rise on the coastal zone of Bangladesh. Master's thesis, Lund University, Sweden
SMRC (2003) The vulnerability assessment of the SAARC Coastal Region due to sea level rise: Bangladesh case study. SAARC Meteorological Research Center, Dhaka
World Bank (2000) Bangladesh: climate change and sustainable development. Rural Development Unit, South Asia Region, Dhaka

Annex BR13

G. Gopinath, "Critical Coastal Issues of Sagar Island, east coast of India", *Environmental Monitoring and Assessment,* Vol. 160 (2010)

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Critical coastal issues of Sagar Island, east coast of India

Girish Gopinath

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Abstract Sagar Island, situated in the east coast of India and one of the biggest deltas in Sundarban group, faces coastal erosion and degradation of coastal vegetation and various natural hazards. Erosion is mainly due to clay mining, wave activities, and the impact of river and tidal currents of Muri Ganga and Hugly Rivers. Further, the coastal zone of Sagar Island faces increasingly severe problems of rapidly growing human population, deteriorating environmental quality, and loss of critical habitats. Sagar Island has been victimized several times by tropical cyclones and influenced daily by tidal fluctuations. The island needs immediate attention on the coastal zone in order to protect the shoreline and ecosystem. The capability of satellite remote sensing to provide synoptic, repetitive, and multispectral data has proved to be very useful in the inventory and monitoring of critical coastal issues. Sagar Island and its environs are subjected to both natural and anthropogenic activities that continuously modify the region.

Keywords Critical coastal issues · Sagar Island · India

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Introduction

Coastal zone refers to a broad geographic area in which terrestrial and marine factors are mixed to produce unique landforms and ecological systems. It is a zone where marine influence can be seen in landward areas and terrestrial influence on the sea. Estuaries, creeks, river discharges, and human activities directly influence the coastal ecosystems. Continuous physical interaction between the land, the sea, and the atmosphere makes the coastal zone an area of dynamic processes. Various landforms, shoreline configuration, ecology, and environmental conditions of this zone are constantly changing as a result of natural and anthropogenic activities. Coastal zones usually have much biological diversity and are often quite rich in living resources. Coastal habitats, especially wetlands, mangroves, salt marshes/pans, and sea grasses, are rapidly being devastated under pressure of urbanization, industrialization, and recreation. These influences create unique association of plants and animals, which are normally not found in upland or purely marine environment. Some coastal areas and coastal waters are also vast reservoirs of nonliving mineral resources, including oil and gas. Thus, coastal areas and coastal waters are biologically and ecologically important and also have great economic potential.

India has a coastline of 7,516 km and nearly 250 million people live within a distance of 50 km from the coast (Thanikachalam and Ramachandran 2002). The coastal zone is characterized by a variety of coastal ecosystems like mangroves, lagoons, coral reefs, sea grass, salt marsh, estuary, creek, etc. Coastal ecosystems are important for millions of people around the world as they provide subsistence. In the state of Tamil Nadu (east coast of India), between the year 1988 and 1998, 25.56 km^2 of coral reefs and 2.16 km^2 of seaweeds were lost in Gulf of Mannar (Thanikachalam and Ramachandran 2002, 2003). Between the year 1986 and 1993, a 0.36-km^2 area of mangrove in Pichavaram was lost and nearly 2,500 km^2 of the mangrove were lost in entire India between 1986 and 1994 (Krishnamoorthy 1995). Apart from the anthropogenic activities, natural causes also play an important role in coastal environment changes. In the Gulf of Mannar coast, between the year 1969 and 1998, 4.34 and 23.49 km^2 of mainland coast and 4.16 and 3.31 km^2 of island coast were eroded and accreted due to the combined action of anthropogenic and natural agents (Thanikachalam and Ramachandran 2003). Availability of repetitive, synoptic, and multispectral data from various satellite platforms have helped to generate information on varied aspects of the coastal and marine environment (Nayak 2002). Studies on rapid erosion of coast of Sagar Island and its environs were carried out by various authors (Dinesh Kumar et al. 2007; Gopinath and Seralathan 2005; Bandopadhyay

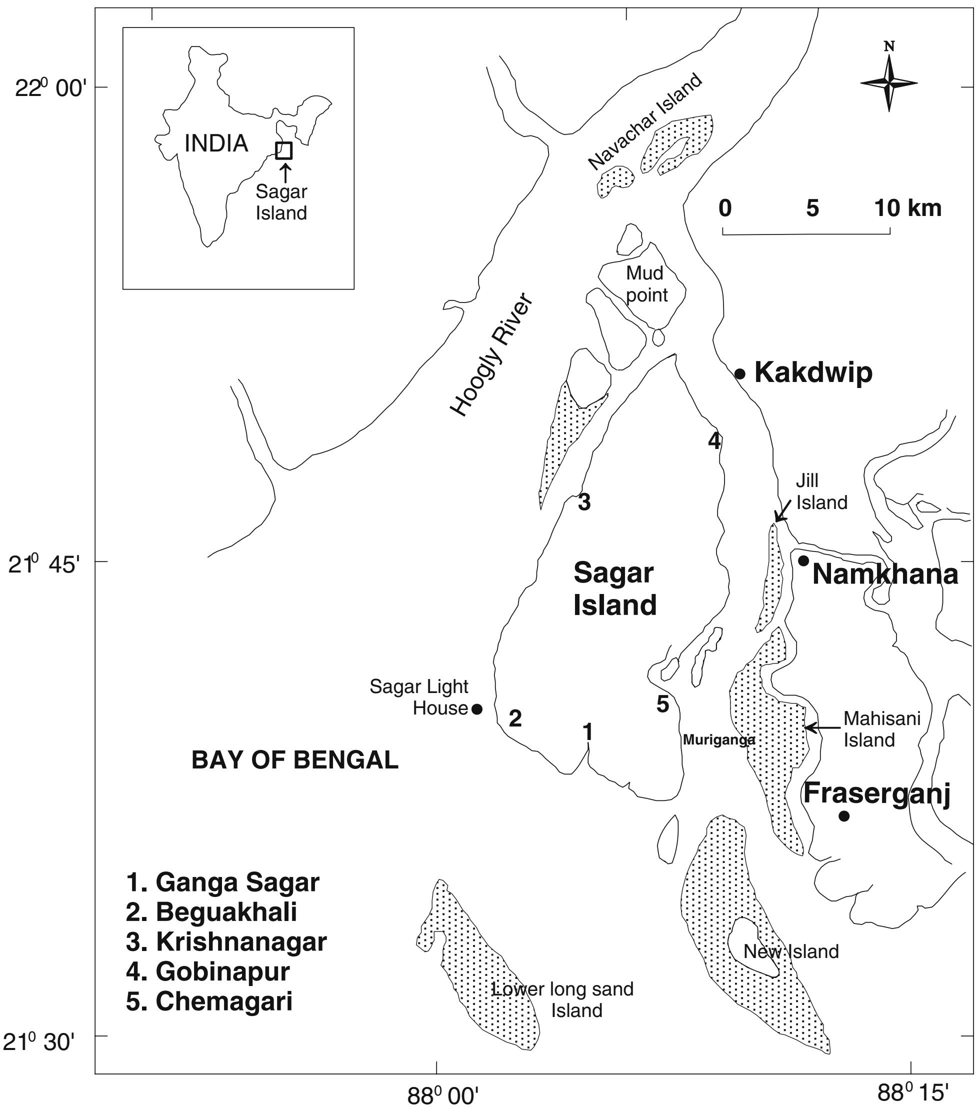

Fig. 1 Location map of Sagar Island

2000; Das 2000). There is an inevitable need to monitor and manage the coastal zones regularly, properly, and optimally. In the present study, an investigation has been carried out on critical coastal issues of Sagar Island, India.

Study area

Sagar Island, the largest island of the Sundarbans deltaic complex, was selected for the present study. The island is situated in the estuarine environment of Hugli River. It is bounded by Hugli River in the north and west, Muri Ganga River in the east, and Bay of Bengal in the south. Hugli and Muri Ganga Rivers control the sedimentation of this island. The landmass of this island extends from 21° 37′ 21″ to 21° 52′ 28″ N and 88° 2′ 17″ to 88° 10′ 25″ (Fig. 1). The length of the island is 30 km in the north–south direction and has a maximum width of 12 km. The island is accessible by the "ferry" service across the Muri Ganga River. The island is affected several times by the tropical cyclones and influenced daily by tidal fluctuations. Global as well as regional changes in climate may induce substantial change in its physical, chemical, and social environment.

Materials and methods

As part of data collection, field survey was conducted along the coastal zone of Sagar Island. Landuse/landcover data, namely mangrove forests, casuarina plantations, agricultural fields, and sandy beaches, have been demarcated on the basis of field truth. The type, intensity, and condition of coastal vegetation were noted on the basis of field observations and the information gathered from the local people. At some of the places where coastal erosion is severe, the condition of coastal vegetation, especially the mangroves, is critical. But artificial cultivation of mangrove at a small scale is also noticed in a few places.

Multidated (1996, 1998, and 1999) satellite data of IRS-1C LISS III (both digital and geo-coded FCC) of the study area were collected from NRSA, Hyderabad. Geocoded data was used in the field to obtain ground control points and digital data was processed in the laboratory using digital techniques. Linear Imaging Self Scanning (LISS) III Camera, one of the three sensors on IRS-1C, provides multispectral data in four bands: two in visible (0.52–0.59 and 0.62–0.68 μm), one in infrared (0.77–0.86 μm), and one in short wave infrared (1.55–1.70 μm) regions of the electromagnetic spectrum. The selected data represent the periods immediately after monsoon (October 1999) and post-monsoon (December 1996 and 1998).

Analysis and interpretation of satellite data was done by digital image processing. The abovementioned satellite images were rectified with reference to Survey of India topomap nos. 79 C/1 and 79 C/2 and field ground control points. An area of interest, i.e., Sagar Island, was selected as a subset from rectified images. An image analysis carried out for 1996 and 1999 satellite data and georectified topomap of 1967 revealed the erosion rate of the island. Various parameters retrieved from satellite data are shown in Table 1.

Table 1 List of parameters retrieved from satellite data

Field data	Parameters retrieved
Erosion rate	Erosion rate during 1967 to 1996 1996 to 1999
Landuse and landcover	Supervised classes: sandy beaches, agricultural fields, land vegetation, casuarina, mangrove
Sediment distribution	Sediment distribution on coastal waters

Critical coastal issues—discussions

The major critical environmental issues of the island are coastal erosion, degradation of mangrove forests, demographic aspects, and natural hazards.

Coastal erosion

Analysis of satellite data reveal that coastal erosion is increasing at a faster rate since 1996 especially along the east coast of the Island when compared to that during the period between 1967 and 1996. The study reveals that the total landcover in Sagar Island shows a decreasing trend from 223.4 to 202.6 km^2 during 1996 to 1999 (Gopinath and Seralathan 2005). The analysis of multitemporal satellite data shows that the whole island is eroding at a faster rate (Gopinath and Seralathan 2005). Another best example for coastal erosion on western part is the presence of remains of an old light house and a new one shown in Fig. 1. The Kapil Muni original temple (southern part of the island) was devoured by the sea during British rule. A new one had to be built several kilometers inland, but now the sea is closing in on that as well. Coastal erosion is controlled by various parameters like nature of beach sediment, beach morphology, tidal currents, wave activities, etc. It is observed from the field that, in most of the eroding sites, the nature of the sediment is mostly silt and clay. Usually sandy beaches get eroded faster than muddy beaches, but in the study area some of the muddy beaches along the Muri Ganga (eastern side) are severely eroding. It can be attributed to the deposition of sediment in the estuary in the form of shoals and tidal flats which in turn cause the intensity of water flow to be more towards the island. In addition to this, wave and tidal current activities also contribute to erosion of this side up to a certain extent. In the southern part of the island, prominent sandy beaches are identified with more than half kilometer in width (Fig. 2). Basically, this island is a tide-dominated deltaic island. The tidal range varies from 5 to 6 m and the island is 6.5 m above sea level (Mukherjee 1983). The coastal processes such as erosion, deposition, sediment transport as well as wave and current activities continuously modify the shoreline and in turn bring changes in coastal ecosystems of the island, which frequently hits the island.

The major causes of coastal erosion in Sagar Island are listed below:

1. Severe bank erosion is observed on either sides of the northern tip of the island and in the southeastern part of the island. This is due to high flood velocity and the meandering nature of river course.
2. Erosion is also due to extensive clay mining from the banks of Muri Ganga for brick work.
3. Severe erosion near Beguakhali (southwestern) has been observed for a long time. The old light house is now about 100 m offshore of the island. Similarly, the south eastern part of the island has been experiencing erosion. The wave erosion is the main reason.
4. Sagar Island has been affected several times by tropical cyclones.
5. The sea level rise in this part has been estimated as 2.6 mm per year (Baksi et al. 2001).

Degradation of mangrove

Another major issue of the island is degradation of mangrove forests which have an adverse

Fig. 2 Prominent sandy beaches with ripple marks on the southwestern part of the Sagar Island

impact on marine bio-resource productivity, which is directly related with the socioeconomic status of the coastal community. Mangroves are the main resources of the nutrients of coastal waters. But they are being destroyed by natural phenomenon and anthropogenic activities. Mangroves protect the island from severe erosion, but the rate of erosion has been increased in different parts of the island. This is mainly due to deforestation of mangrove forests.

There are a total of 17 genera and 69 species of mangrove plants identified in Sundarban. The total area of mangroves in India is estimated to be 6,750 km^2, which constitute 8% of the total Indian coastline. There are 48 plant species belonging to the mangrove vegetation in India alone. Out of 6,750 km^2, Sundarban has the largest area of 4,200 km^2.

The coastal habitat of Sagar Island, especially mangroves and wetlands, are being degraded. Mangroves in India have suffered from various biotic problems such as reclamation, deforestation, and pollution. The abiotic problems like extreme climates resulting in cyclones and floods also pose a danger to mangroves. Mangroves have been declared as ecologically sensitive areas under the Environment Protection Act, 1986. All exploitation and developmental activities in these areas have been banned by the Government of India. Disposal of wastes from the adjoining industries and also carrying of wastes by pipelines through the mangrove areas have also been prohibited. A statewide committee has been formed for effective management of the mangrove ecosystem.

The total area of mangrove forest on 1996 (Table 2) was 0.9 km^2. The mangrove area is increased in the year 1998 due to some artificial plantation. The total area of mangrove in that year was 2.1 km^2. In the year 1999, mangrove forest decreased to 1.3 km^2 due to human interference and other natural activities. So an immediate step should be taken for the conservation of this mangrove ecosystem.

Table 2 Changes in landuse and landcover in Sagar Island during 1996–1999

Classes	Area, km^2		
	1996	1998	1999
Casuarina	6.5	7.4	7.2
Mangrove	0.9	2.1	1.3
Sandy beach	2.3	1.2	1.2
Land vegetation	79.4	64.68	75.9
Agriculture fields	134.3	130.4	118.6
Total	223.4	205.78	202.6

Population growth

Another major problem of the island is overpopulation. As the population is increasing, the pressure on the island is increasing in all fronts like space to live, resources, pollution, and environmental degradation. The population of the island in the year 1864 was 1,488, i.e., 5.2 persons per square kilometer. On 1991 census, the population is 149,222 which is 100.2 times more than the 1864 census. On 2001, it is estimated to be 185,301 (Baksi et al. 2001). Since the availability of natural resources is limited by the rate of processes of the earth system and their renewal, it is clear that the quality of the life cannot be sustained at a safe level of dynamic equilibrium unless resource expenditure is restricted. More than 60% of the world's population lives in a belt within about 60 km of coastal zone, with around two-thirds of the world's cities with a population of over 1.6 million people.

The coastal environment issues are highly complex due to multifarious use of the coastal zone like settlement, waste disposal, aquaculture, fishing, and recreation. As land becomes more and more crowded and terrestrial resources get used up, greater attention is now being paid to the development of the sea as a natural source of bioresources supply. For the professional scientist, naturalist, and the public at large, the sea is an infinite source of pleasure, study, and inspiration.

Cyclone, flooding, and sediment distribution pattern

Sagar Island is victimized several times by tropical cyclones and influenced daily by the tidal fluctuation that continuously modifies the region. Major hazards such as cyclones, flooding, and discharge of huge sediments modify the morphology of the island.

Tropical cyclone constitutes one of the most destructive natural disasters that affect Sagar Island.

Cyclone affects the island with strong wind, heavy rainfall, and flooding, so beach erosion takes place more and the shoreline changes critically. This suggests that mangrove afforestation should be taken up in cyclone-prone areas to protect the life and property in coastal regions. Generally, remote sensing data are used for tracking, monitoring, and forecasting of cyclones, assessment of damage, and preventive measures. INSAT data are regularly utilized to monitor the track of cyclones and forecasting their crossing point on land. IRS 1C/1D data are used to assess the damage caused by cyclones. IRS WiFS data are utilized to delineate area under thrust. LISS data is found to be more suitable to assess damage caused to agricultural and horticultural areas. PAN data provides structural damage caused to large buildings.

The important aspect of damage assessment is to provide input within 2–3 days of the event. It is necessary to use radar data in such cases. The most disastrous cyclone affected Sagar Island on 4th October, 1864.

The influence of Hugli and Muri Ganga Rivers on the coastal stretches of the island is the major cause of degradation/change of morphology and ecosystem. It is very clear from the satellite data that these two rivers discharge large amounts of sediment towards the Bay of Bengal (Fig. 3). Further, it is observed that the eastern part of the island is characterized by a high percentage of erosion due to nature of river banks and flooding effect from Muri Ganga River.

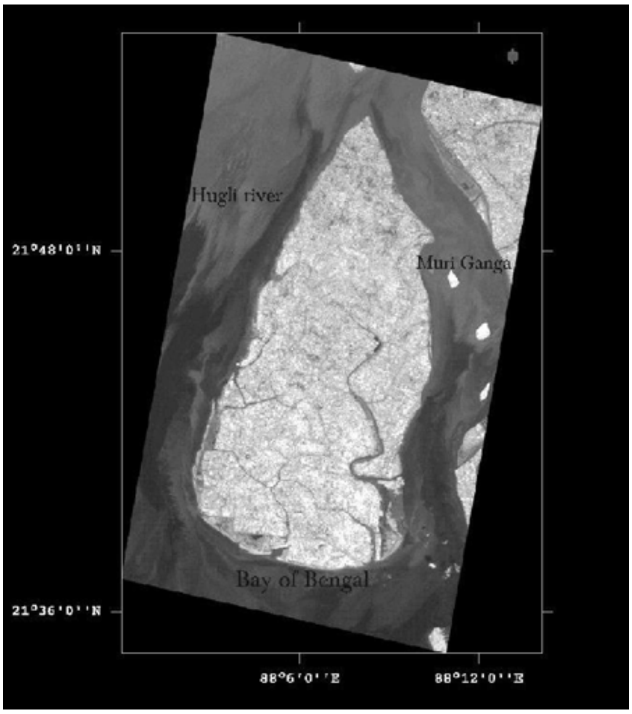

Fig. 3 Sediment distribution pattern of Hugli and Muri Ganga river (IRS 1C LISS III, band 3)

Conclusion

The coastal regulation zone (CRZ) of Sagar Island itself is a critical area due to the erosion process, sea level rise, degradation of mangrove forest, and concentration of people, with the lack of adequate waste disposal and other various factors. As the population of the island increases rapidly, people are migrating towards the CRZ. Ultimately, they depend upon the coastal resource and cut down mangrove trees for building their homes, making of boats, fuel purpose, etc. As the coastal zone is ecologically sensitive, all human activity which adversely impacts the coastal environment should be restricted.

References

Baksi, A., Hazra, S., Sen, G., & Mukherjee, A. D. (2001). Estimation of relative sea level rise from Tide Gauge data of Sagar island of Bay of Bengal. *Journal of Coastal Research*.

Bandopadhyay, S. (2000). Sagardwip: Some environmental problems and men. In B. Maity (Ed.), *Bish Sataker Sagardwip (20th Century Sagar Island) Quarterly April–June.*

Das, G. (2000). History of Sagardwip: 1815–1915. In B. Maity (Ed.), *Bish Sataker Sagardwip (20th Century Sagar Island) Quarterly April–June.*

Dinesh Kumar, P. K., Gopinath, G., Laluraj, C. M., Seralathan, P., & Mitra, D. (2007). Change detection studies of Sagar island, West Bengal (India) using IRS IC LISS III DATA. *Journal of Coastal Research, 23*(6), 1498–1502. doi:10.2112/05-0599.1.

Gopinath, G., & Seralathan, P. (2005). Rapid coastal erosion of the Sagar Island, West Bengal. *Environmental Geology, 48*(8), 1058–1067.

Krishnamoorthy, R. (1995). *Remote sensing of mangrove forest in Tamil Nadu coast, India* (202 p.). Ph.D. thesis, Anna University.

Mukherjee, K. N. (1983). History of settlement in the Sundarbans. *Indian Journal of Landscape Systems and Ecological Studies, 6*, 1–19.

Nayak, S. R. (2002). *Application of remote sensing to coastal zone management in India.* Paper presented in ISPRS Technical Commission VII Symposium on Remote Sensing and Environment Monitoring and ISRS Annual Convention held at Hyderabad, India.

Thanikachalam, M., & Ramachandran, S. (2002). Conservation of coral reefs in Gulf of Mannar: A remote sensing and GIS approach. *Indian Society of Geomatics (ISG) Newsletter, Special Issue on Coastal & Marine Environment, 8*(2 & 3), 65–71.

Thanikachalam, M., & Ramachandran, S. (2003). Shoreline changes along the coast of Gulf of Mannar and its influence on coral reefs: A remote sensing and GIS approach. *Journal of the Indian Society of Remote Sensing, 31*(3), 157–174.

Annex BR14

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Response of the Sundarbans coastline to sea level rise and decreased sediment flow: A remote sensing assessment

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A B S T R A C T

The Sundarbans is the world's largest remaining single block of mangrove forest, covering approximately 1 million ha (~10,000 km^2) of the Ganges–Brahmaputra delta along the coastal areas of India and Bangladesh. Sea level rise and alteration of water flows of the Himalayan headwaters are among the major disturbances threatening these coastal areas. But very few studies exist on the dynamics or current status of the Sundarbans coastline. We used Landsat images spanning from 1973 to 2010, and an algorithm that we developed, to consistently estimate the spatiotemporal dynamics of erosion and accretion for four different time intervals and the whole study period. Our results show that the direction and extent of erosion and accretion rates varied throughout the different periods. Erosion was the highest in the 1973–1979 interval, with 23.2 km^2 year^{-1} of land loss. However, that rate substantially declined in the following periods, reaching a rate of 7–10 km^2 year^{-1}. Accretion showed a rate of 10 km^2 year^{-1} between 1973 and 1989, but substantially declined to ~4 km^2 year^{-1} between 1989 and 2010. Accretion rate has declined in the recent years but erosion rate has remained relatively high. As a result the delta front has undergone a net erosion of ~170 km^2 of coastal land in the 37 years of our study period. These numbers are significantly higher than the previously reported rates and magnitudes of erosion in this area. The methods and maps developed in this study may be helpful in management planning of this vulnerable coastline.

1. Introduction

The coastal area of the Bengal delta was formed within the large Bengal basin during the last 11,000 years, and it extends offshore in the Bay of Bengal as a clinoform (Kuehl et al., 2005; Mikhailov & Dotsenko, 2007). The delta was built by the hydrologic discharge of the Ganges–Brahmaputra (GB) river system. The GB discharge is second only to that of the Amazon River in magnitude, and is driven largely by the southwest monsoon rains, with maximum discharge happening from May–June to November (Coleman, 1969). High volumes of discharge of these two rivers traditionally carried extremely large sediment loads (~10^9 t year^{-1}) from different parts of the Himalayas and the upper parts of the Bengal delta (Goodbred & Kuehl, 2000). Coastal areas of this delta are home to the world's largest continuous patch of mangrove forest, the Sundarbans (Iftekhar & Saenger, 2008), covering approximately 1 million ha, ~60% of which is in Bangladesh and the rest in India (Fig. 1). Radiocarbon and clay mineral evidence suggests that the lower delta plains of the Sundarbans were originally formed by sediments deposited by the Ganges River (Allison & Kepple 2001; Heroy et al., 2003).

Mangrove forests provide critical ecosystem services, fulfill important socio-economic and environmental functions, and support coastal livelihoods. Among other services, these forests provide: 1) a large variety of wood and non-wood forest products; 2) coastal protection against the effects of wind, waves and extreme weather events such as cyclones and tsunamis; 3) habitats for a rich biological diversity — including a number of endangered mammals, reptiles, amphibians and birds; 4) protection and provision of nutrients and energy that sustain coral reefs, sea grass ecosystems and 5) habitat, spawning grounds and nutrients for a variety of fish and shellfish, including three-quarters of all commercially fished species in the tropics (FAO, 2007). Their unique root systems create a great deal of physical roughness, thus capturing and storing vast quantities of sediment from upland and oceanic origin. But the extent and diversity of these forests are declining globally at a rapid rate and much of the remaining forests are in degraded condition (Duke et al., 2007). And yet, despite the value and vulnerability of the mangroves of Bengal delta, very little data exist on the spatiotemporal dynamics of these mangrove lands and the impacts of anthropogenic and natural disturbances on this ecosystem. In fact recent reviews could find no published reports of ecosystem service loss of mangroves due to land-use or climate change (Bouillon et al., 2008; Laffoley & Grimsditch, 2009).

Land dynamics of any delta coastline is mainly controlled by three major factors, namely 1) compaction and tectonic subsidence,

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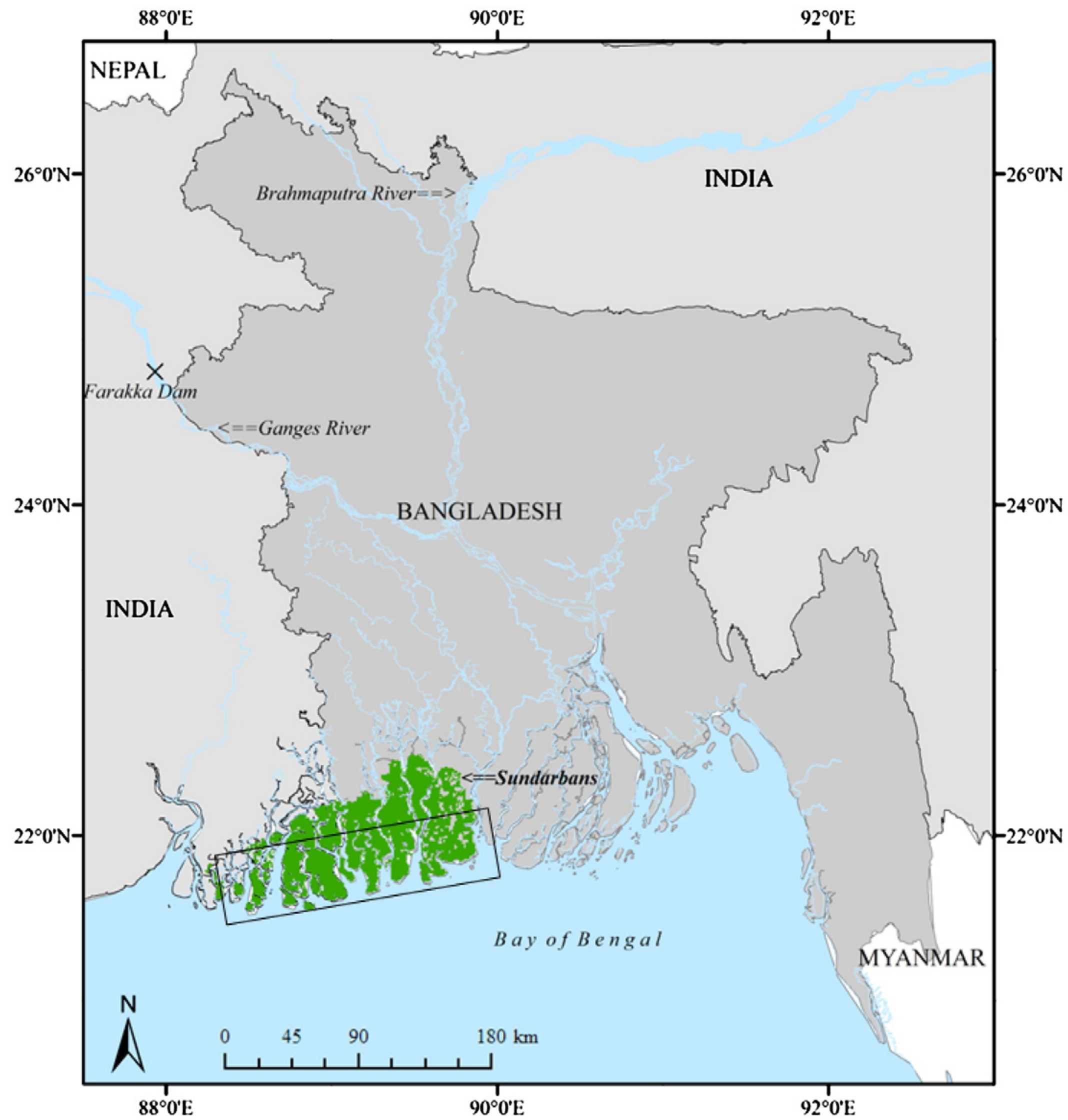

Fig. 1. Location of our study site, the Sundarbans coastline of the Bengal delta, the Ganges–Brahmaputra Rivers, and the Farakka dam are shown here. The green area is the remaining patch of the mangroves, which does not have any dikes along the coastline. The inset shows the area used in this study.

2) relative sea level rise (SLR) and wave action, and 3) sediment supply from the rivers (Syvitski & Saito, 2007). Studies have shown that the coastal areas of the Bengal delta are undergoing a mean annual land subsidence of 15–50 mm (Mikhailov & Dotsenko, 2007; Stanley & Hait, 2000). A recent study of global deltas (Syvitski et al., 2009) showed that the entire Bengal delta is sinking at a “perilous” rate due to sediment compaction from the removal of oil, gas and water from the inland delta's underlying sediments, the trapping of sediment in upstream reservoirs, floodplain engineering, and rising sea level. Also, the Northern Indian Ocean, which includes the Bay of Bengal, is experiencing a relatively high rate of SLR compared to other oceans globally (Han et al., 2010; Unnikrishnan & Shankar, 2007). Based on global sea level data and modeling, Eriscson et al. (2006) have estimated that the SLR of the Bay of Bengal is the world's highest, at >10 mm year^{-1}. Other studies have confirmed this trend, but with rates ranging from 4.0 mm year^{-1} in the western zone to 7.8 mm year^{-1} in the eastern zone (Alam & Ahmed, 2010; SMRC, 2003). In addition to the SLR, strong winds from the southwest and the associated waves flow onto the Bay from June to September (the southwest monsoon season), whereas weaker northeast winds and waves prevail during December–February (Unger et al., 2003).

The GB river system, and ultimately the Bengal delta, has undergone some drastic changes in the last century (Mikhailov & Dotsenko, 2007). Construction of dikes and polders along the upland river banks has changed the sedimentation process of the rivers. Large scale dike building in most rivers in the Bengal basin has been initiated in the 1960s. The most recent and one of the most significant anthropogenic disturbances of the Ganges occurred in 1975 when India completed a dam on the river in Farakka, West Bengal, approximately 16.5 km west of the western border of Bangladesh (Fig. 1). This dam diverted approximately 1133 m^3/s of water through the Hooghly River inside India, which caused a significant reduction of the flow of water and sediment to the Sundarbans coast of the Bengal delta (Mirza, 1998).

Using digitized survey maps from 1792, 1840, 1904 and 1908, and a Landsat image from 1984, Allison (1998) found that the shoreline and the shallow offshore areas at the western edge of the Bengal delta front are in a net erosional state at a rate of about 1.9 km^2 year^{-1}, with a coastline retreat of as much as 3–4 km in some areas of the western edge since 1792 (approximately 21 m year^{-1}). Allison (1998) attributed this retreat to the fact that the eroded area is composed of inactive deltaic digitate shoal complexes that receive minimal modern GB sediment. Contrarily, another study (Allison & Kepple, 2001) suggested that the delta may still be undergoing accretion at a rate of 7 km^2 $year^{-1}$ along the river mouth regions. Using Landsat images from 1973, 1977, 1989 and 2000 to monitor the mangrove dynamics of the Sundarbans, Giri et al. (2007) found that the forested area has not changed significantly throughout the 25 years of their study. However, they also found that erosion has claimed almost 38 km^2 of land along the major river channels and the extreme southern edge of the Sundarbans during their study period. These papers (Allison, 1998; Allison & Kepple, 2001; Giri et al., 2007) are among the relatively small number of studies of this densely populated and vulnerable delta that have reported the overall land accretion and erosion along the Sundarbans coastline. But none of the studies to date have reported any details of spatiotemporal patterns of land dynamics along the entire coastline of the Bengal delta.

Under global climate change and the related SLR, exploring spatiotemporal dynamics of the changing coastline and the drivers of those changes is essential to understand how the delta front is responding to the natural and anthropogenic changes, and to assess the vulnerability of coastal areas. In this study we used a time series of Landsat images from 1973 to 2010 to systematically explore the spatiotemporal trends of land dynamics along the Sundarbans coastline. By 'land dynamics' we refer to either erosion or accretion of land. Also, results from published studies on Bay of Bengal surface currents, SLR, sediment flow and land subsidence were used to deduct probable cause–effect relationships of the trends in coastal land dynamics.

2. Study site

Our study site was the Sundarbans coastline of the Bengal delta in Bangladesh and India (Fig. 1). The linear length of the Sundarbans coastline is ~180 km from the western to the eastern edge. Due to local subsidence, and to save the land from being inundated, embankments have been erected along most of the coastal areas of the Bengal delta, except in the Sundarbans coastline. Anthropogenic activities, such as fishing, logging and other types of resource harvesting, occur inside the mangrove forest, and the rivers and their subsidiaries flowing through the mangroves are highly affected by the human intervention/engineering works upstream (dams, flow diversion). But embankments have not been erected along the coastlines of the Sundarbans in Bangladesh and India. Hence, unlike the adjacent non-mangrove coastlines of the Bengal delta, the land dynamics of the Sundarbans coastline is not artificially restricted or controlled, constituting a natural setting for studying the impacts of SLR and anthropogenic upstream disturbances on the delta front. Therefore, this study was focused on the Sundarbans coastline and the immediate river mouths that are affected by surface current actions of the Bay of Bengal (as per Allison, 1998). Smaller river banks in the inland areas of the Sundarbans were not included in this study (Fig. 1, inset).

3. Data and methods

3.1. Landsat images

Cloud cover is a consistent problem in all tropical regions, including the Bengal delta. Because the aim of this study was to delineate the changing coastlines, images needed to be totally cloudless, at least over the coastlines of interest. That restricted the number of images that could be used in this study. Images from 1973, 1979, 1989, 2000 and 2010 suited the cloud-free criteria. These images were downloaded from the United States Geological Survey (USGS) EarthExplorer web site where archived satellite image data are available (http://edcsns17.cr.usgs.gov/EarthExplorer/). Images from 1973 were the earliest available from Landsat for that region.

Table 1
Information about the Landsat images used in this study.

Year	Satellite	Date	Cloud cover	Pixel size (m)	Path/row
1973	Landsat MSS 1	02/21/1973 and 02/02/1973	0%	60	148/45 147/45
1979	Landsat MSS 3	04/02/1979 and 02/26/1979	<10%	60	147/45 148/45
1989	Landsat TM 4	01/19/1989 and 01/1/2/1989	0%	30	138/45 137/45
2000	Landsat 7 ETM+	11/17/2000 and 02/28/2000	0%	30	138/45 137/45
2010	Landsat TM 5	01/21/2010 and 01/30/2010	0%	30	138/45 137/45

The 1973 and 1979 images were from the Landsat Multi Spectral Scanner (MSS). The rest of the images were from Landsat Thematic Mapper (TM, 4 and 5) and Enhanced TM (ETM+). Two adjacent Landsat images (path 148 and 147, row 45 for Landsat MSS; path 138 and 137, row 45 for TM and ETM+) are needed to cover the entire Sundarbans coastline of Bangladesh and India. Details of the images used in this study are given in Table 1. All images except one were from the winter season when most of the cloud-free days occur in that region. The exception was one image from May 1979, which is the end of summer season in that region.

For detecting land dynamics images have to be georeferenced. The two 2010 images were georeferenced first. USGS supplies recent Landsat images with basic georeferencing and a 2008 GIS vector map of the Sundarbans (source: Bangladesh Forest Department) was used to further georeference the 2010 image. The final georeferenced image product had $<\pm 0.5$ pixel root mean squared error (RMSE). Since the two adjacent images covering the Bangladeshi and Indian parts of the Sundarbans fall in two different Universal Transverse Mercator (UTM) zones (46 N and 45 N respectively), the images were reprojected to Lambert Azimuthal Equal-area projection. This projection preserves the area of individual polygons while simultaneously maintaining a true sense of direction from the center (White et al., 1992). Due to the equal-area property, this projection is useful for statistical analysis of land change. Nearest-neighbor resampling was used to maintain the spectral integrity of the image. This georeferenced 2010 image was used as the reference for rectifying all other images. For consistence, all images were resampled to a spatial resolution of 30 m. Resampling the 60 m MSS pixels to 30 m neither improved nor degraded the spatial resolution of the MSS images, whereas resampling the 30 m TM pixels to match the 60 m MSS pixels would have degraded spatial resolution of the TM images. We performed uncertainty analyses for both 30 m and 60 m pixels (Section 3.3).

Since the goal of the image interpretation steps was to distinguish between land and water in each image, combination of the green, red, and near-infrared bands of the images were used to create false-color images (Nayak & Bahuguna, 2001). All vegetated areas in these false-color images showed different hues of red; bare soils were colored in shades of brown; and mudflats or sandy beaches were colored in shades of white. Water bodies were either in shades of blue or black, since water absorbs infrared radiation. Some muddy water showed a brownish hue, but from the morphological structure of the river mouths and the bay, it could be clearly identified as water and not soil. Normalized difference vegetation index (NDVI) images were also created using the red (R) and near-infrared (IR) bands to verify the land–water boundary, since the NDVI values of water are negative and those of dry terrestrial surface are positive. NDVI values show this characteristic (negative for water and positive for terrestrial surfaces) irrespective of whether radiance or reflectance values of R and NIR are used in its calculation.

We used these NDVI and false color images to classify land and water. But the classification alone was not sufficient in delineating the land area of each delta finger. Each individual delta finger is also internally crisscrossed by small waterways that drain into the large rivers. These internal waterways are commonly narrower than a 30 m pixel and were not the focus of this study. So, in addition to the image classification we also used ArcMap software (ESRI Inc, Redlands, CA, USA) to connect the land pixels in the junction of these waterways and large rivers. Basically, two coastal land pixels, opposite to each other, in the junction of these waterways and rivers were connected in a straight line, in order to form a continuous coastline for each delta finger. The intertidal mudflats were excluded from this study. Binary images of land and no-land (or water) were the resulting products.

3.2. Detecting coastline dynamics

Graphical routines were developed with the Matlab software (version 7.10.0, MathWorks Inc., Natick, MA, USA) to estimate coastline dynamics from the digitized binary images. Rates and azimuthal directions of erosion and accretion were determined for the intervals 1973–1979, 1979–1989, 1989–2000, 2000–2010, and the whole study period 1973–2010. For any given interval, the 'baseline' image was the image of the later year when determining erosion, and that of the earlier year when determining accretion. Perpendicular distances (described next) between the coastline pixels of the paired images were then estimated. For this process, it was critical to determine the position and the orientation of each coastline pixels in the baseline image. The Matlab function "*bwboundaries*" (Image Processing Toolbox, version 7.0) was used to delineate the perimeters of coastal pixels in each image. This function traces the exterior boundaries of each individual 'object' in a binary image (i.e., the land areas adjacent to water and completely separated from other land areas), resulting in a collection of continuous pixel coordinates. These 'objects' in our study were essentially the individual 'fingers' of the delta and the detached islands of the study area in the Bay of Bengal. An advantage of using this function was that the pixel coordinates for

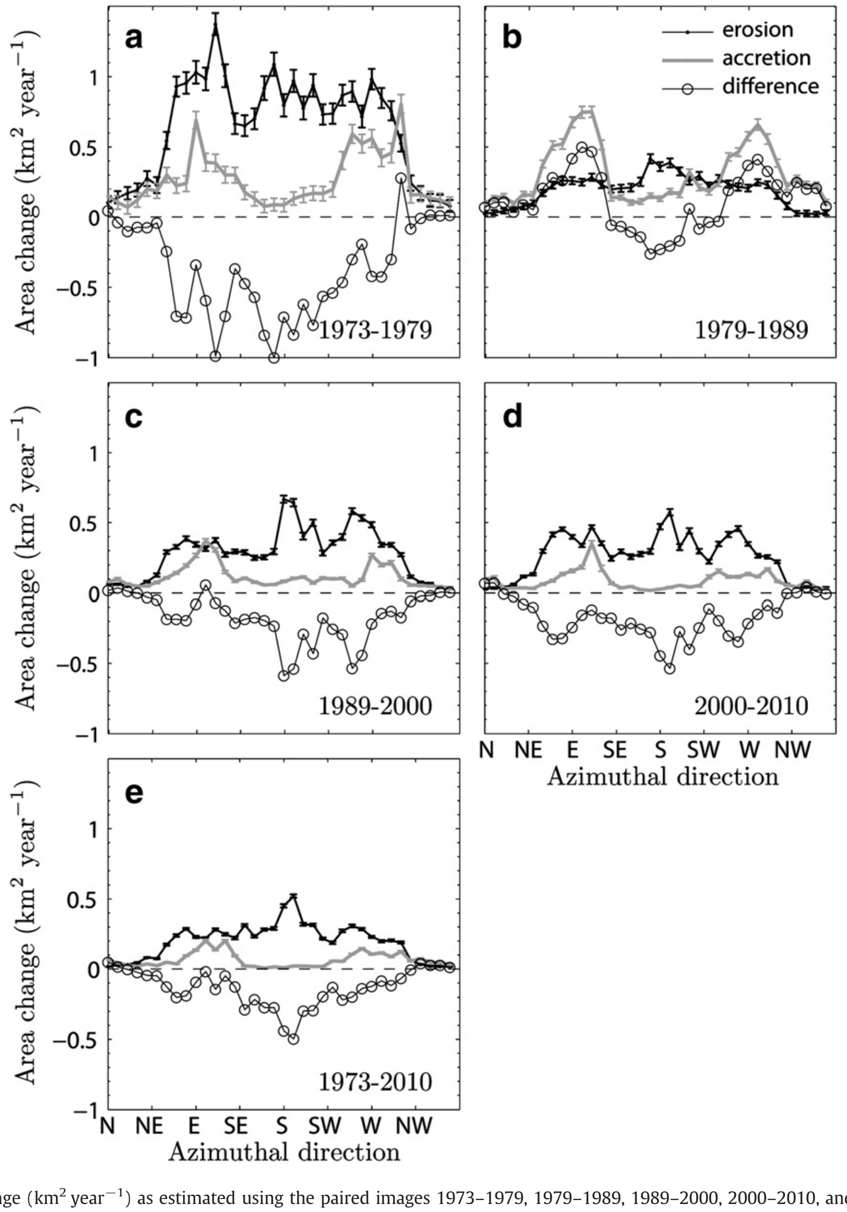

Fig. 2. Rates in coastline area change (km^2 year^{-1}) as estimated using the paired images 1973–1979, 1979–1989, 1989–2000, 2000–2010, and 1973–2010. Erosion (thick black lines), accretion (gray lines) and resulting net difference (thin black lines) are aggregated in bins of 10° of azimuthal direction. The azimuthal direction assumes opposite meanings when describing the erosion and accretion processes. For example, erosion in the south azimuthal direction means that the land loss proceeded from south towards north; but accretion in the south azimuthal direction means that the land gain proceeded from north towards south.

each object were determined and organized in a clock-wise direction, where the 'beginning point' was always the leftmost pixel of the topmost line of each object. This beginning point was considered to have its perpendicular direction pointed towards north. The perpendicular direction of each following pixel in the clock-wise direction was calculated by drawing a line segment that was centered on that pixel and delimited by two terminal points located three pixels apart on each side of that pixel. This procedure occasionally produced unrealistic line segments where the coastline took a sudden change of direction. To correct this 'sudden change' problem the line segments of all pixels were further smoothed using a moving average filter with a window-size equivalent to the 5% of the total number of coastline pixels in each object. The perpendicular direction of land loss or gain, in relation to any specific coastline pixel of the 'baseline' image, was the azimuthal direction of erosion or accretion respectively.

In order to calculate the extent and direction of erosion or accretion, a recursive algorithm was implemented that extended each coastal pixel in the baseline image by a single pixel along its perpendicular azimuthal direction across the other image. This process was repeated until a non-land pixel was encountered. The lengths of these trajectories, multiplied with the area occupied by each pixel (i.e. 900 m^2) provided an estimate of the areas of erosion or accretion in each direction. The direction and area of erosion and accretion were estimated for each coastal pixel of the baseline images for all intervals. The algorithms developed and implemented in the Matlab software for estimating land dynamics were in some aspects similar to the Digital Shoreline Analysis System (DSAS) of the United States Geological Survey (USGS) that has been in use since the mid-1990s (Himmelstoss, 2009). But our method provided the azimuthal distribution of the land dynamics that was needed for this study, which the DSAS software does not provide.

3.3. Uncertainty analysis

The method described in the previous section provided the area and associated azimuthal directions of net erosion and accretion for each interval of the study, which were divided by the numbers of years in each interval to obtain the annual rates. Erosion and accretion rates were then grouped into bins of azimuthal directions of 10° intervals, where 355°–5° corresponded to North, 85°–95° to East, etc. Statistical analyses were performed separately for each bin and interval. Uncertainty in the rates of accretion and erosion was estimated by numerical propagation of the error associated with the calculation process. Two main independent sources of uncertainty were identified: 1) the uncertainty caused by the georeferencing process, which we assume affecting only the position of the first and last point of each erosion/accretion trajectory (and therefore also the direction), and, 2) the uncertainty associated with the digitizing process of mixed pixels along the coastline, which we assumed affecting only the area of the first and last pixels of the erosion/accretion trajectory. A mixed pixel along the coastline occurred when the targeted surface area represented in a pixel was composed of both soil and water. For the georeferencing process, the error was assumed to be normally distributed with the mean equal to 0 and standard deviation equal to the RMSE resulting from the georeferencing procedure (± 0.5 pixel, i.e. 15 m or 30 m depending on the year). For the digitizing process, the error was assumed to be uniformly distributed, with a range between 0 m and 900 m^2 (or 3600 m^2 in the case of 1973 and 1979).

Propagation of the error was estimated for each pair of images of any interval using Monte Carlo simulations with 1000 repetitions. For each repetition, the position of each coastal pixel and the distance of the trajectory were 'perturbed' by a value randomly generated from the above described distributions. The rates and azimuthal direction of land erosion or accretion were estimated as described in the previous section. The propagated uncertainty was assumed normally distributed, and the associated standard deviation and 95% confidence interval were estimated from the 1000 'samples' of each synthetic dataset.

4. Results and discussion

The annual rates of erosion and accretion, and their differences, in all azimuthal directions at different time intervals are shown in Fig. 2 and Table 2. Erosion and accretion rates varied throughout the different periods. Erosion was the highest in the 1973–1979 interval with 23.2 km^2 $year^{-1}$ of land loss. However, erosion substantially declined in the following periods, reaching rates between 7 and 10 km^2 $year^{-1}$. When summed using the four individual intervals, the total land loss due to erosion was 415 km^2. Accretion rate in the 1973–1979 period was similar to that in the 1979–1989 period (~10 km^2 $year^{-1}$), but the rate substantially declined in the 1989–2000 and 2000–2010 periods (~4 km^2 $year^{-1}$). Again, when summed using the four individual intervals, the total land gained by accretion was 245 km^2. Three out of four periods resulted in a net land loss due to erosion (between 60 and 80 km^2), with only 1979–1989 showing a net gain in land (about 40 km^2).

The land dynamics was also estimated using the 1973–2010 image pair as a measure of the net total erosion and accretion occurred in the Sundarbans coastline in the 37 years of this study. There was quite a large difference between these '37-years' values and the ones estimated using the four intervals. Total erosion and accretion during the four intervals were almost two and three-fold, respectively, in comparison to the accretion and erosion resulted from the 1973–2010 image pair. This indicates that both the accretion and erosion processes were highly dynamic during the 37 years of this study, and several areas of the Sundarbans delta underwent both erosion and accretion, although during different times, as shown in Fig. 2. The total land change was about −170 km^2, indicating that the overall loss of land was the dominant process for the period of study. In general, both accretion and erosion rates were very low or negligible in the north-west to north-east directions. Accretion occurred mainly along the west and east directions (Fig. 2). Erosion showed a more uniform distribution in its directionality, but higher rates could be observed across the south to west directions, in particular in the periods after 1979.

Spatial distributions of accretion and erosion for all intervals are shown in Fig. 3. During the 1973–1979 interval most of the accretion

Table 2
Accretion and erosion rates in the Sundarbans coastline estimated for each sub-period and for the entire period of our study. Standard error is shown for the total accretion and erosion rates.

Period	Accretion (km^2 $year^{-1}$)	Total accretion (km^2)	Erosion (km^2 $year^{-1}$)	Total erosion (km^2)	Difference (km^2)
1973–1979	9.5	56.8 ± 1.0	23.2	139.4 ± 1.3	−82.6
1979–1989	11	110.8 ± 0.8	6.9	68.7 ± 0.8	42.1
1989–2000	4.2	45.7 ± 0.3	10.2	112.9 ± 0.5	−67.2
2000–2010	3.1	31.2 ± 0.3	9.4	93.5 ± 0.4	−62.3
Total	6.6	244.5 ± 1.3	11.2	414.5 ± 1.6	−170.0
1973–2010	2.4	89.0 ± 0.5	7.2	264.6 ± 0.9	−175.6

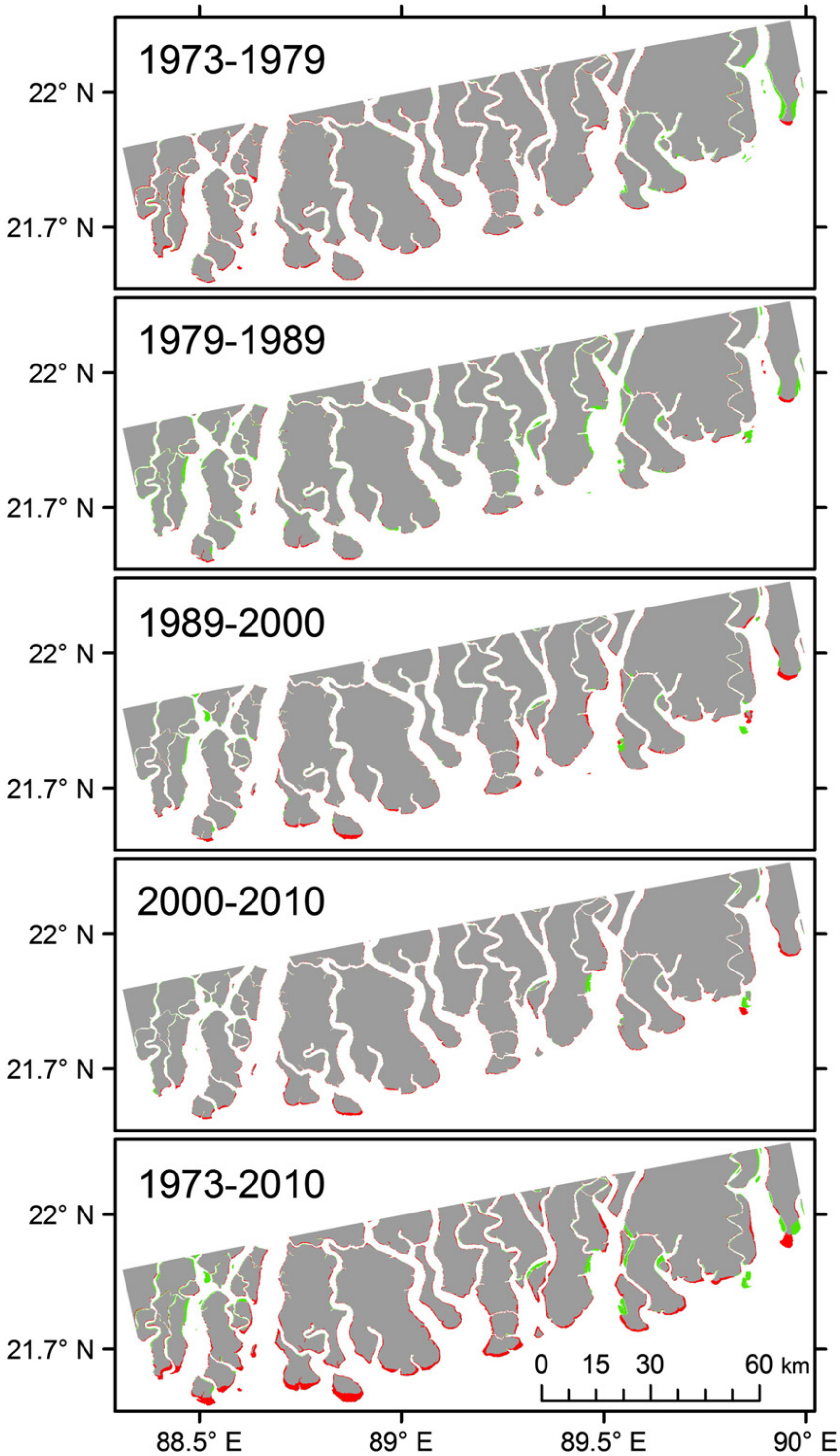

Fig. 3. Changes in coastline area as estimated using the Landsat images of 1973, 1979, 1989, 2000, and 2010. Red and green areas describe erosion and accretion, respectively.

occurred in the eastern section of the Sundarbans, but erosion was prevalent in all areas (Fig. 3a). During the 1979–1989 interval accretion occurred in almost all areas, but not in the southern edges. In the southern edges the prevalent process was erosion, except for some areas in the eastern section of the study area (Fig. 3b). During the 1989–2000 and 2000–2010 intervals, most of the land gain occurred in the eastern and western sections of the Sundarbans, whereas the middle section primarily underwent erosion (Fig. 3c–d).

The rates of linear coastal erosion (m $year^{-1}$) in all azimuthal directions for the study period (1973–2010) are shown in Fig. 4. These distances are grouped into bins, as described in Section 3.3. We found that the distribution of distances in each bin were positively skewed (inset, Fig. 4) and could be best described using a log-normal distribution. The median distance, and 25, 75, and 95 percentile distances of these log-normal distributions for each bin and time period are shown in Fig. 4. The median value of erosion was ~6 m $year^{-1}$ for the south, 3 m $year^{-1}$ for east and west azimuthal directions, and negligible for north.

The retreat of Sundarbans coastline was expected under SLR, since there are no dikes or other anthropogenic structures to protect these

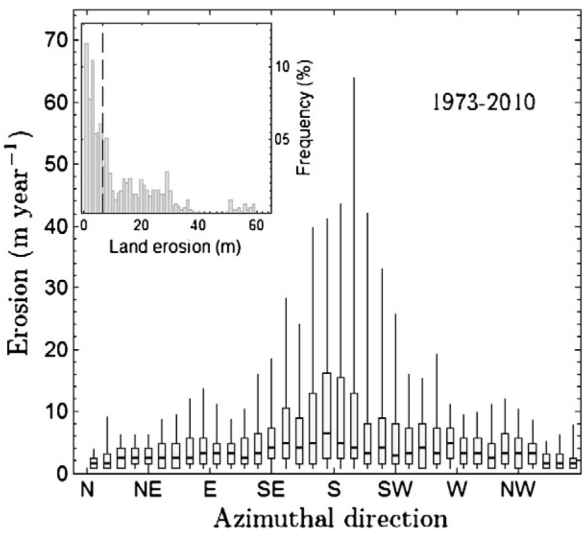

Fig. 4. Erosion rates (m year^{-1}) of the Sundarbans coastline estimated using 1973 and 2010 Landsat images. The erosion rates are disaggregated in bins of 10° of azimuthal direction. Bottom and top edges of boxes are the 25 and 75 percentile, respectively. Thick solid lines inside the boxes are the medians. Vertical lines outside the boxes are the 5 and 95 percentile. The inset shows the distribution of erosion rates along the south direction (i.e. between 180° and 190°). For each bin, the distribution of the erosion rates was found highly skewed and best described as a log-normal distribution. The dashed line is the median of the distribution.

coastlines. The advent of the Farakka dam in 1975 caused a significant anthropogenic disturbance in the flow of discharge and sediment of the Ganges to the Sundarbans coast (Mirza, 1998). Measurements at the Hardinge Bridge on the Ganges inside Bangladesh indicated that the discharge of the Ganges decreased more than 30% between 1974 and 1979 (Tanzeema & Faisal, 2001). This decrease of discharge must also have decreased the sediment supply, since the sediment content of the Ganges is proportional to its discharge (Islam et al., 1999). The relatively high rate of erosion along the Sundarbans coastline during the 1973–1979 interval (Fig. 3a) may have been due to this abrupt disturbance on sediment flow. It is pertinent to mention here that the 26 December 2004 Sumatra Tsunami had a minimal impact on our study area, with <1 m of tsunami height reaching the Sundarbans coastline (see Fig. 1 of Titov et al., 2005).

A noticeable feature of the land dynamics of the Sundarbans coastline is that the rate of accretion has been declining in all successive periods (Fig. 2a–d). This trend of declining accretion may be due to the fact that the delta as a whole is sediment-deprived due to dams and other anthropogenic disturbances upland (Syvitski et al., 2009). Contrary to the decreasing rate of accretion, the rate of erosion remained relatively stable after the 1973–1979 interval (Fig. 2a–d). Except for the northern directions (N, NE NW), which are mainly landward directions, erosion was occurring in all other directions, potentially indicating the steady impacts of SLR in the Bay of Bengal. Probable causes of the azimuthal difference in the rate of erosion may also be a combination of surface wave and tidal actions. Surface waves of the Bay of Bengal are predominantly from the southwest direction, whereas the tidal action is from the south (Poterma et al., 1999). The East India Coastal Current (EICC) flows northward along the Bay of Bengal during the rainy seasons of March–September, and in the opposite direction during the dry seasons, October to January (Shankar et al., 1996). So, the combined force of waves and tide is stronger on the south azimuthal direction than on other directions.

In total, the Sundarbans coastline lost ~170 km^2 of land during the 37 years of the study period (or approximately 4.6 km^2 year^{-1}). This estimate is much higher than what was reported by previous studies (38 km^2 in Giri et al., 2007; 1.9 km^2 year^{-1} in Allison, 1998). The median value of total linear land loss was more than 220 m in the southern (seaward) direction during the 37 years of this study. But the linear loss was not evenly distributed throughout the whole coastline, either in the south or any other azimuthal direction. As can be seen from the inset in Fig. 4, the distribution of the land loss (distance) was positively skewed, probably due to the local effects such as sediment composition and compaction (Allison, 1998) and wave action (Shankar et al., 1996). The skew in the distribution of linear distances was more pronounced in the south (seaward) direction and less in all other directions (Fig. 4). The 75 percentile distance of land loss in the south was ~20 m year^{-1}, approximately equal to what Allison (1998) reported for only the western edge of the delta. Allison (1998) used a composite of digitized survey maps of the British Navy from 1792 to 1908 and compared that with a Landsat image of 1984 to derive the linear distance of land loss in 76-year interval. Our study shows that not just the western edge but rather the entire Sundarbans coastline has been retreating at a similar rate in 37 years, indicating an enhanced rate of erosion in recent years.

The results of this study can potentially be used in conservation management of the Sundarbans. The Indian portion of the Sundarbans core area, now a National Park, is designated a wilderness zone under the West Bengal Amendment of the Indian Forest Act (1988). Maintenance of environmental stability, preservation of the remaining natural forests, increase in forest cover through afforestation and social forestry programs, and enhanced productivity of forests to meet essential national needs are among the mangrove-management related main features of this Forest Act (Iftekhar, 2008). Bangladesh portion of the Sundarbans forest, officially called the Sundarbans Reserved Forest (SRF), has a history of scientific management and is managed for commercial timber production by the Forest Department (FD) of the Ministry of Environment and Forests (MoEF). Coastal afforestation, creation of wildlife sanctuaries and controlled timber extraction are among the major steps that are currently being taken in the SRF (Iftekhar & Islam, 2004). The land-gain areas along the Sundarbans coastlines can be targeted for enhanced afforestation with appropriate salt-tolerant mangrove species. The land-loss areas can be targeted for selective dike building (with proper consideration of down-current erosion) to prevent further loss of land.

5. Conclusions

Our study highlights the complexities involved in the spatiotemporal dynamics of the retreating Sundarbans coastline of the Bengal delta. Cloud-free Landsat images were used for coastline delineation, and algorithms were developed to derive distances and areas of land dynamics in a consistent fashion for the whole coastline for every interval. Even though coastal retreat is a 'natural' global process in the general context of SLR, this study explored the effects of SLR and decreased discharge and sediment flow of the contributing river to the coastline. The Bengal delta was built by the GB discharge, so accretion was the dominant process for thousands of years. Even though some previous reports from sampling studies have indicated that the Bengal delta is still undergoing accretion (Allison & Kepple, 2001) other recent modeling studies have indicated that the delta is sinking due to sediment compaction (Syvitski et al., 2009). Results of this study are the first to demonstrate that the entire non-diked portion of the Bengal delta's Sundarbans coastline is currently in a net erosional state. The spatial and temporal characteristics of the retreat were characterized using a time series of satellite images, thus reducing uncertainties that are inherent with modeling and sampling studies of spatially continuous processes such as coastal dynamics. The spatiotemporal analyses of this study may help future studies to reveal the local/global nature and causes of the spatial variations in erosion and accretion that have been reported here. It is our anticipation that the results of this study would be applicable in the management planning of the Sundarbans—the largest single patch of the remaining mangrove forests in the world.

Annex BR14

Acknowledgments

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References

Alam, M. J. B., & Ahmed, F. (2010). Modeling climate change: Perspective and application in the context of Bangladesh. In Y. Charabi (Ed.), *Indian Ocean Tropical Cyclone and Climate Change* (pp. 19). : Springer Science+Business Media B.V, doi:10.1007/978-90-481-3109-9_3.

Allison, M. A. (1998). Historical changes in the Ganges–Brahmaputra delta front. *Journal of Coastal Research*, *14*(4), 1269–1275.

Allison, M. A., & Kepple, E. B. (2001). Modern sediment supply to the lower delta plain of the Ganges–Brahmaputra River in Bangladesh. *Geo-Marine Letters*, *21*, 66–74.

Bouillon, S., Borges, A. V., Castañeda-Moya, E., Diele, K., Dittman, T., et al. (2008). Mangrove production and carbon sinks: A revision of global budget estimates. *Global Biogeochemical Cycles*, *22*, GB2013, doi:10.1029/2007GB003052.

Coleman, J. M. (1969). Brahmaputra River: Channel processes and sedimentation. *Sedimentary Geology*, *3*(2–3), 131–239.

Duke, N., Meynecke, J., Dittmann, S., Ellison, A. M., Anger, K., et al. (2007). A world without mangroves. *Science*, *317*(5834), 41–42.

Eriscson, J. P., Vörösmarty, C. J., Dingman, S. L., Ward, L. G., & Meybeck, M. (2006). Effective sea-level rise and deltas: Causes of change and human dimension implications. *Global and Planetary Change*, *50*(1–2), 63–82.

Food, Agriculture Organization of the United Nations (FAO) (2007). The world's mangroves 1980–2005. *FAO Forestry Paper 153*. Rome: FAO.

Giri, C., Pengra, B., Zhu, Z., Singh, A., & Tieszen, L. (2007). Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973–2000. *Estuarine, Coastal and Shelf Science*, *73*(1–2), 91–100.

Goodbred, S. L., & Kuehl, S. A. (2000). The significance of large sediment supply, active tectonism, and eustasy of margin sequence development: Late Quaternary stratigraphy and evolution of the Ganges–Brahmaputra delta. *Sedimentary Geology*, *133*, 227–248.

Han, W., Meehl, G. A., Rajagopalan, B., Fasullo, J. T., Hu, A., et al. (2010). Patterns of Indian Ocean sea-level change in a warming climate. *Nature Geoscience*, *3*, 546–550, doi:10.1038/ngeo901.

Heroy, D. C., Kuehl, S. A., & Goodbred, S. L. (2003). Mineralogy of the Ganges and Brahmaputra Rivers: Implications for river switching and Late Quaternary climate change. *Sedimentary Geology*, *155*, 343–359.

Himmelstoss, E. A. (2009). DSAS 4.0 Installation Instructions and User Guide. In R. Thieler, E. A. Himmelstoss, J. L. Zichichi, & A. Ergul (Eds.), *Digital Shoreline Analysis System (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008–1278*.

Iftekhar, M. S. (2008). An overview of mangrove management strategies in three South Asian countries: Bangladesh, India and Sri Lanka. *International Forestry Review*, *10*, 38–51.

Iftekhar, M. S., & Islam, M. R. (2004). Managing mangroves in Bangladesh: A strategy analysis. *Journal of Coastal Conservation*, *10*, 139–146.

Iftekhar, M. S., & Saenger, P. (2008). Vegetation dynamics in the Bangladesh Sundarbans mangroves: A review of forest inventories. *Wetlands Ecology and Management*, *16*, 291–312.

Islam, M. R., Begum, S. F., Yamaguchi, Y., & Ogawa, K. (1999). The Ganges and Brahmaputra rivers in Bangladesh: Basin denudation and sedimentation. *Hydrological Processes*, *13*, 2907–2923.

Kuehl, S. A., Allison, M. A., Goodbred, S. L., & Kudrass, H. (2005). The Ganges–Brahmaputra Delta. In L. Gosian, & J. Bhattacharya (Eds.), *River deltas — Concepts, models, and examples. SEPM Special Publication*, *83*. (pp. 413–434).

Laffoley, D. A., & Grimsditch, G. (2009). *The management of natural coastal carbon sinks.* Gland Switzerland: IUCN 53 pp.

Mikhailov, V. N., & Dotsenko, M. A. (2007). Processes of delta formation in the mouth area of the Ganges and Brahmaputra rivers. *Water Resources*, *34*(4), 385–400.

Mirza, M. M. Q. (1998). Diversion of the Ganges water at Farakka and its effects on salinity in Bangladesh. *Environmental Management*, *22*(5), 711–722.

Nayak, S., & Bahuguna, A. (2001). Application of remote sensing data to monitor mangroves and other coastal vegetation of India. *Indian Journal of Marine Sciences*, *30*(4), 195–213.

Poterma, J. T., Luther, M. E., & O'Brien, J. J. (1999). The seasonal circulation of the upper ocean in the Bay of Bengal. *Journal of Geophysical Research*, *96*(C7), 12,667–12,683.

Shankar, D., McCreary, J. P., Han, W., & Shetye, S. R. (1996). Dynamics of the East India Coastal Current 1. Analytic solutions forced by interior Ekman pumping and local alongshore winds. *Journal of Geophysical Research*, *101*(C6), 13,975–13,991.

SMRC (2003). *The vulnerability assessment of the SAARC coastal region due to sea level rise: Bangladesh Case, SMRC-No. 3.* Dhaka, Bangladesh: SMRC Publication.

Stanley, D. J., & Hait, A. K. (2000). Holocene depositional patterns, neotectonics and Sundarban mangroves in the western Ganges–Brahmaputra delta. *Journal of Coastal Research*, *16*(1), 26–39.

Syvitski, J. P. M., Kettner, A. J., Overeem, I., Hutton, E. W. H., Hannon, M. T., et al. (2009). Sinking deltas due to human activities. *Nature Geoscience*, *2*, doi:10.1038/ngeo629.

Syvitski, J. P. M., & Saito, Y. (2007). Morphodynamics of deltas under the influence of humans. *Global and Planetary Changes*, *57*, 261–282.

Tanzeema, S., & Faisal, I. M. (2001). Sharing the Ganges: A critical analysis of the water sharing treaties. *Water Policy*, *3*, 13–28.

Titov, V., Rabinovich, A. B., Mofjeld, H. O., Thomson, R. E., & Gonzales, F. I. (2005). The global reach of the 26 December 2004 Sumatra tsunami. *Science*, *309*, 2045–2048.

Unger, D., Ittekkot, V., Schäfer, P., Tiemann, J., & Reschke, S. (2003). Seasonality and interannual variability of particle fluxes to the deep Bay of Bengal: Influence of riverine input and oceanographic processes. *Deep-Sea Research II*, *50*, 897–923.

Unnikrishnan, A. S., & Shankar, D. (2007). Are sea-level-rise trends along the coasts of the north Indian Ocean consistent with global estimates? *Global and Planetary Change*, *57*, 301–307.

White, D., Kimerling, J. A., & Overton, S. W. (1992). Cartographic and geometric components of a global sampling design for environmental monitoring. *Cartography and Geographic Information Science*, *19*(1), 5–22.

Annex BR15

Geological Survey of India, “Endangered Sundarbans” (available at <http://www.portal.gsi.gov.in/portal/page?_pageid=127,723790&_dad=portal&_schema=PORTAL&linkId=1216>)

Endangered Sundarbans

Sea level rise & Global warming: A serious concern of modern mankind and its environs specially in coast-bound countries is the rising sea level accentuated by global worming. India is amongst 27 countries that are most vulnerable to sea level rise caused by global warming. One meter rise of sea level is expected to inundate about 1000 sq km area of the Sundarban deltas. Nearly half of the 102 Sundarban islands in India spreading over 9.5 sq km area are uninhabited due to an abnormal rise in the sea level and massive erosion in the last four decades. About a fifth of the southern part of this delta complex, the heart of the Tiger Reserve, is already submerged. At the current rate of erosion a loss of 15% of farmlands and >250 sq km of the National Park in the next two decades is expected. Agricultural yield too has been falling because of rising salinity of the water and soil. The Sagar Island is being submerged by the rising sea. The Bedford and Lohachara islands are vanishing and have already displaced thousand of climatic refugees who reclaimed mangrove forest following ruthless deforestation. Growing list of rare and highly endangered floral and faunal species of Sundarbans is attributable to these effects. A 2007 report by UNESCO, "Case Studies on Climate Change and World Heritage" has stated that an anthropogenic 45-cm rise in sea level (likely by the end of the 21st Century, according to the Intergovernmental Panel on Climate Change), combined with other forms of anthropogenic stress on the Sundarbans, could lead to the destruction of 75% of the Sundarbans mangroves.

Evidence of ecospace shortage for endobenthic bivalves & gastropods riding over the mangrove trees, Bakkhali creeks

Annex BR15

Exposed mangrove roots as sign of beach erosion and retreating mangrove line, Bakkhali

Eroding older dunes along the Bakkhali beach

Exposed older mudflat in the intertidal beach as evidence of coastal erosion at Frazergunj

Biogenic mud volcanoes produced by mud-loving Uca as sign of unstable beach, Bakkhali

Exposed palaeo-woodground in the Bakkhali beach as hard evidence of rising sea

- **Growing human population and cross-border migration**
- **Growing livestock population**
- **Conflicts over ecospace gain** - Growing shortage of wildlife ecospace in Sundarbans is due to spread in anthropological activities. During the last 15 years 111 persons (male 83, female 28) became victims of animal attacks, viz, tiger (82%), crocodile (10.8%) and shark (7.2%) of which 73.9% died. About 94.5% cases the conflict took place in and around the Sundarban Reserve Forest during livelihood activities.
- **Encroachment of land and water**
- **Grazing deep in to wildlife habitats**- As the mangrove forest of Sundarbans Tiger Reserve is bounded all through its periphery by streams and creeks, there is no problem of cattle grazing within the reserve.
- **Poaching of fauna and flora**

Extinct Species: Hog deer *(Axis porcinus)*, water buffalo *(Bubalus bubalis)* , swamp deer *(Cervus duvauceli)* , *Javan rhinoceros (Rhinoceros sondaicus) , single horned rhinoceros (Rhinoceros unicornis) and the mugger crocodile (Crocodylus palustris) have become extinct in the Sundarbans at the beginning of the last century*

Endangered Species: Two amphibians, 14 reptiles, 25 aves and five mammals are presently endangered. The endangered species that lives within the Sundarbans are Royal Bengal Tiger, estuarine crocodile, river terrapin (Batagur baska), olive ridley turtle, Gangetic dolphin, ground turtle, hawks bill turtle and King crab (Horse shoe).Two amphibians, 14 reptiles, 25 aves and five mammals are presently endangered. The endangered species that lives within the Sundarbans are Royal Bengal Tiger, estuarine crocodile, river terrapin (Batagur baska), olive ridley turtle, Gangetic dolphin, ground turtle, hawks bill turtle and King crab (Horse shoe).

Sundarban Eco-development in progress:

1. Excavation of rain water irrigation channel to increase agricultural production.
2. Provision of pisciculture ponds in the buffer area managed by village co-operative for prawns and sweet water fish.
3. Provision of Solar lights in the villages

4. Provision of smokeless chullahs and alternative fuel to save wood consumption.
5. Raising mangrove plantations on the periphery to meet local fuel wood demand.
6. Provision of medical care facilities to the villagers and wildlife.

Cyclone Aila hits Sunderbans: Formed on 23 May 2009; Highest winds 120km/hr; Lowest pressure 968hPa(mbar); fatalities- 330 total, >8202 missing; damage >$40.7 million; areas affected- India & Bangladesh including Sundarbans; this region housing 265 of the endangered Bengal Tiger was inundated with 2.4 m of water and dozens of tiger were feared dead along with deer and crocodiles. Large mangrove trees in hundreds were uprooted.

Origin and course of cyclone Aila across the Sundarbans