

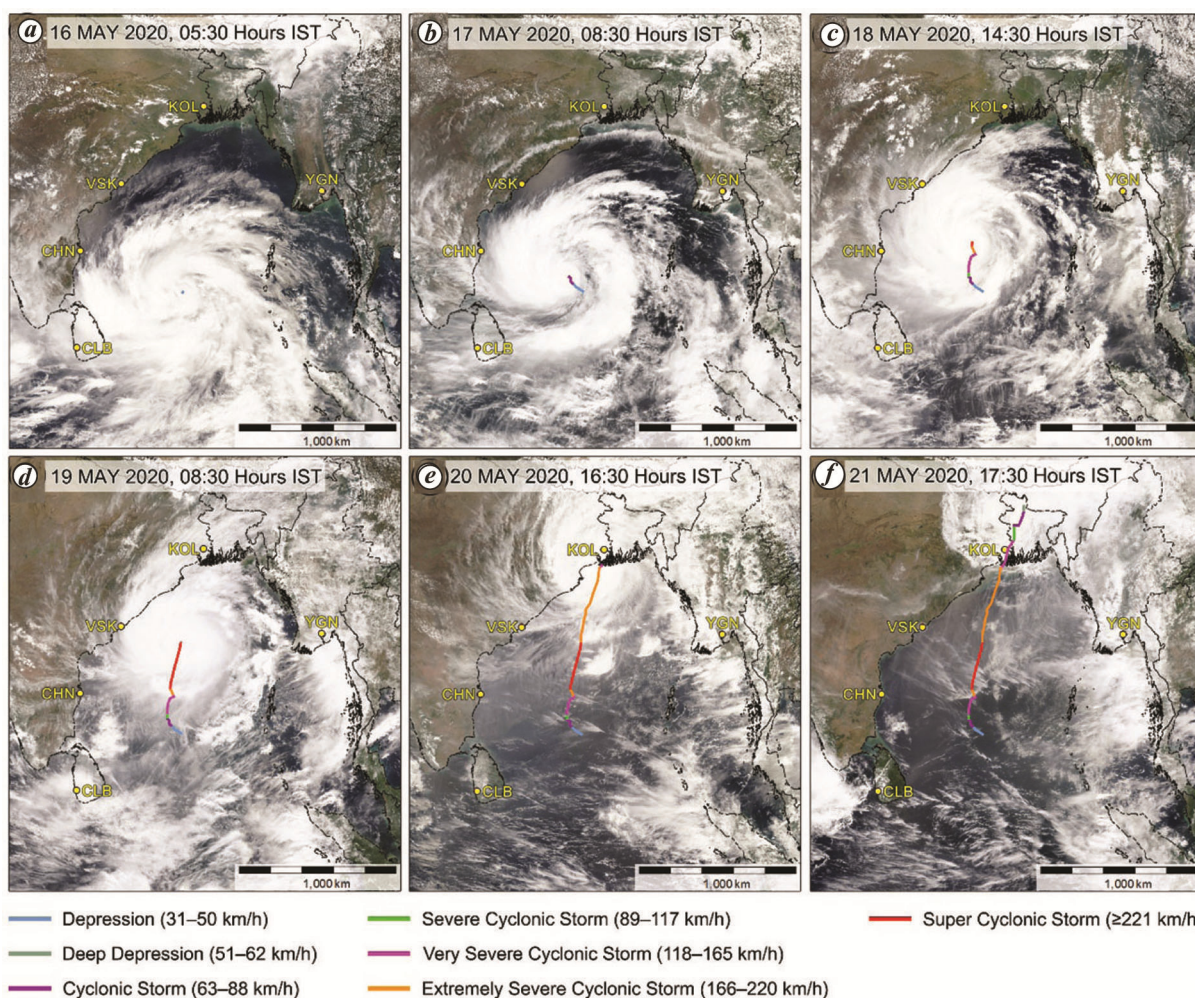
# Cyclone *Amphan* and its impact on the Lower Deltaic West Bengal: a preliminary assessment using remote sensing sources

*Amphan*, the first super cyclone to form in the Bay of Bengal since the 1999 Odisha Super Cyclone, left a devastating impact on the Lower Deltaic West Bengal (LDWB), coastal districts of Odisha and some parts of Bangladesh<sup>1,2</sup>. It made its landfall as a very severe cyclonic storm close to the Saptamukhi Estuary of West Bengal coast (21.65°N, 88.30°E), 100 km south of Kolkata, during 15:30–17:30 IST on 20 May 2020 (ref. 3). Despite the evacuation and other safety measures taken by the administration based on accurate forecast of its movement by the India Meteorological De-

partment (IMD)<sup>3</sup>, the *Amphan* caused massive damages in the aforementioned regions (123 deaths<sup>4–6</sup> and about US\$ 13 billion of property damages in West Bengal only<sup>7</sup>), surpassing most past records from the North Indian Ocean region<sup>1</sup>. In India, the area worst hit was the LDWB, which is delineated on the basis of northern limit of tidal intrusion through estuaries and streams, and includes the districts of Purba Medinipur, South 24 Parganas, North 24 Parganas, Kolkata, Howrah and Hugli. The southern parts of the adjacent Purba Bardhaman and Nadia districts were also

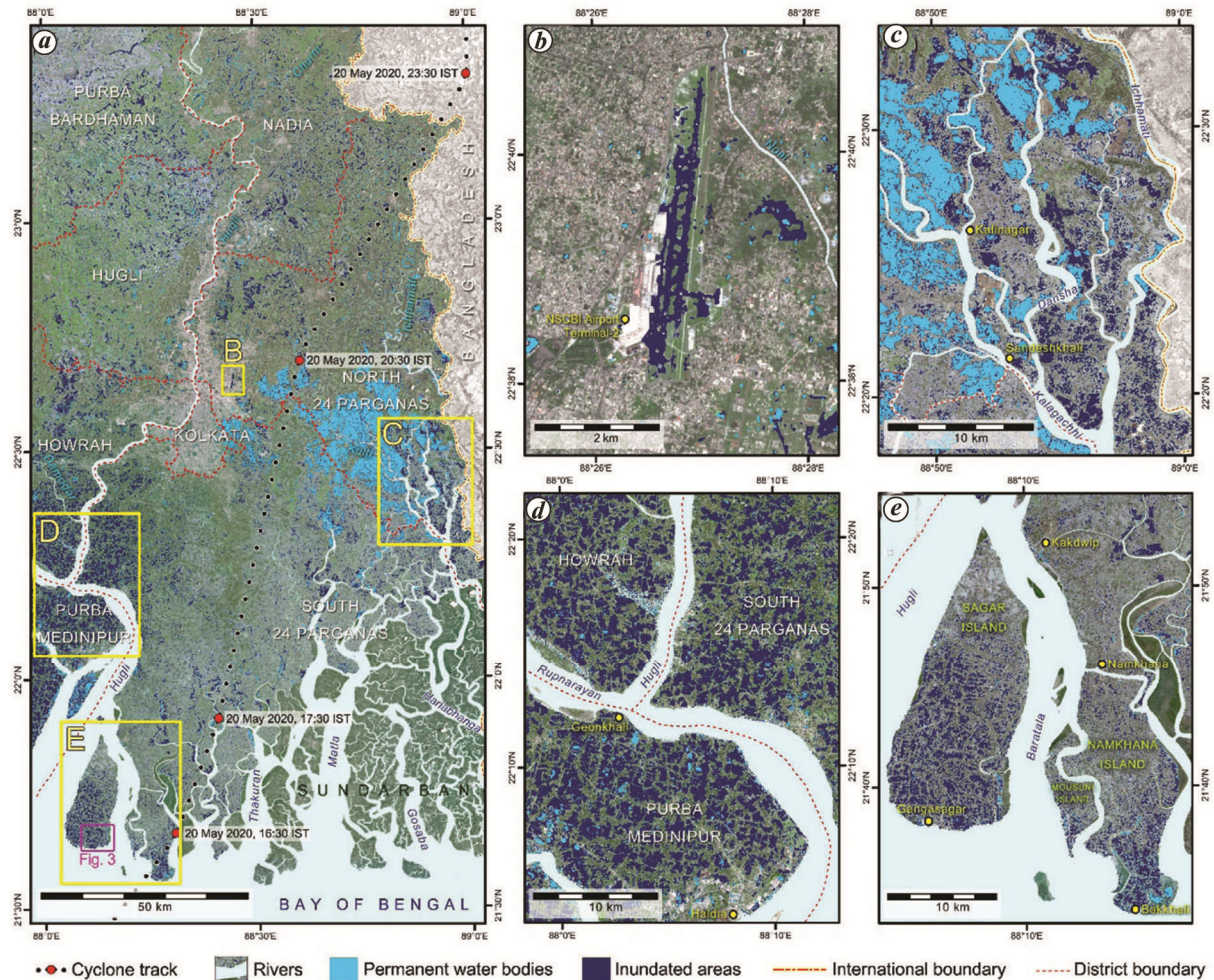
affected. The Government of West Bengal reported severe damages of 2.9 million houses and 1.7 million ha of farmland; some 450,000 electric poles were also grounded<sup>7</sup>. More than 15,000 trees were uprooted in the Kolkata Municipal Corporation area alone<sup>8</sup> and 158,000 ha of mangroves were severely damaged in the Sundarban region<sup>7</sup>.

Cyclogenesis of the *Amphan* ensued with the formation of a convective low-pressure system in the southeastern Bay of Bengal on 13 May 2020 that showed potential for development of a mighty tropical cyclone<sup>3,9</sup>. It rapidly turned into



**Figure 1.** The track of the *Amphan* from initiation to decay (16–21 May 2020). The multicoloured trail represents the movement of the ‘eye’ of the cyclone and category of the storm as it evolved. Date and time in the panels indicate ‘eye’ position at the northern end of the storm track; images represent storm configuration close to that time. CHN, Chennai; CLB, Colombo; KOL, Kolkata; VSK, Visakhapatnam; YGN, Yangon. Storm track source: IMD<sup>3</sup>. Image source: Aqua–Moderate Resolution Imaging Spectroradiometer (MODIS) and Suomi–National Polar-orbiting Partnership (NPP) mosaicked images (a–c, e), Terra–MODIS and Suomi–NPP mosaicked images (d, f).





**Figure 2.** *a*, Inundated areas of the Lower Deltaic West Bengal on 22 May 2020, two days after the landfall of the *Amphan*. Rectangles denote the area enlarged in panels *b–e* and Figure 3, on either side of the storm track. *b*, The inundated area in the Netaji Subhas Chandra Bose International (NSCBI) Airport compound. *c*, Waterlogged areas alongside permanent water bodies of aquaculture farms in Sandeshkhali-I, -II, and Hingalganj blocks of North 24 Parganas district. *d*, Widespread flooding around the confluence of the Rupnarayan and Hugli rivers. *e*, The flood-affected islands of Sagar, Mousuni and Namkhana near the mouth of the Hugli estuary. Data source: Sentinel-1A and -1B Synthetic-Aperture Radar (SAR) C-band images of 19 May 2020 (pre-event) and 22 May 2020 (post-event), overlaid on Sentinel-2A Multi Spectral Instrument (MSI) images of 09 May 2020, Tiles T45QXD, T45QXE, and T45QXF. Storm track and ‘eye’ positions from IMD<sup>3</sup>.

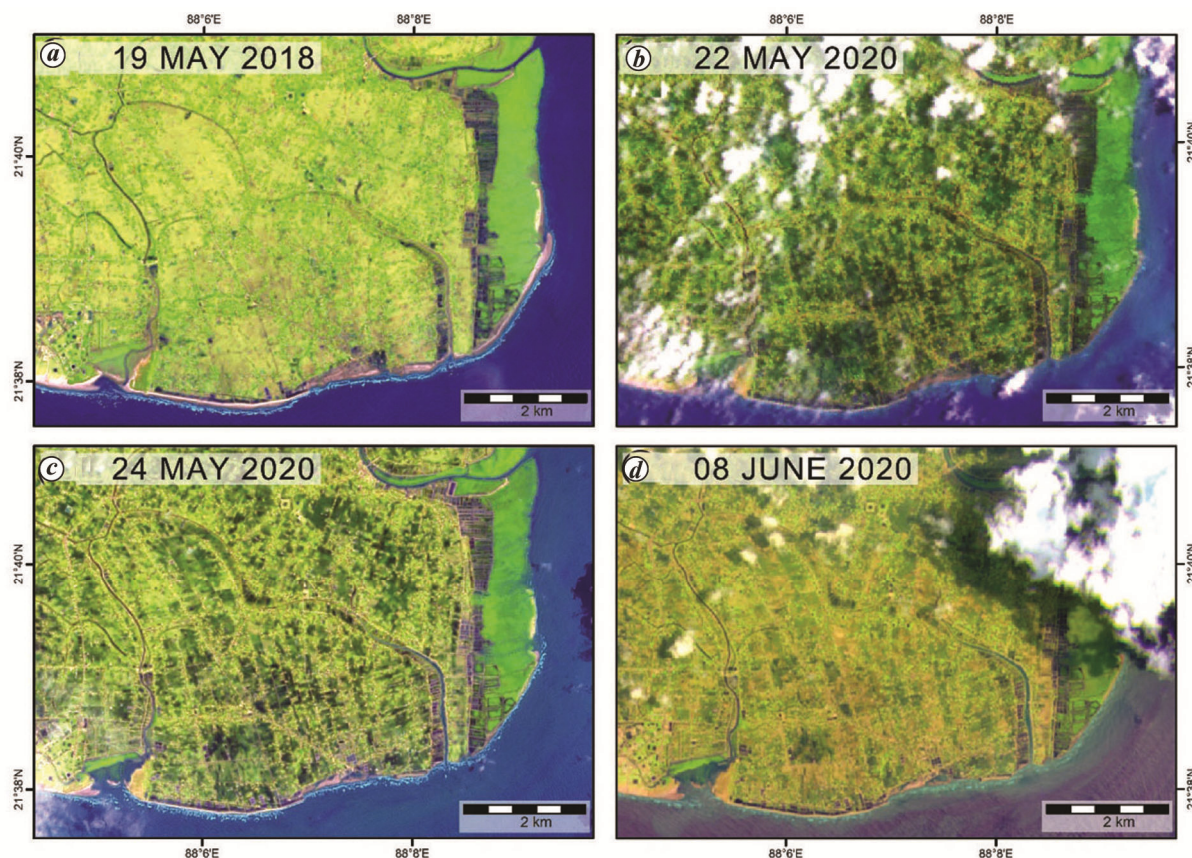
a depression on 16 May 2020 (05:30 IST), and within 12 hours transformed into a deep depression with maximum sustained (3-min average) wind speed of 56 km/h (ref. 3) (Figure 1). The ‘eye’ of the storm initially shifted generally in N32°W direction till 17 May 2020 (17:30 IST), and thereafter started to move towards N24°E, and was positioned around 665 km east of Chennai as an extremely severe cyclonic storm on 18 May 2020 (02:30 IST). Subsequently, the system headed N22°W and strengthened into a super cyclonic storm on 18 May 2020 at 11:30 IST with sustained wind speed of 222 km/h (refs 3, 10). The sustained wind speed reached the maximum of 241 km/h on the same day (23:30 IST)<sup>3</sup>. Afterwards, the *Amphan* continued its

movement in the general direction of N13°E, and was positioned around 26 km south of Sagar Island of West Bengal as an extremely severe cyclonic storm on 20 May 2020 (14:30 IST)<sup>3</sup>. With a forward movement speed of 17.3 km/h towards N39°E, the central part of the storm crossed the Sundarban coastline for about two hours between 15:30 and 17:30 IST on 20 May 2020. It then continued as a very severe cyclonic storm for the next 6 h. Because the *Amphan*’s passage through the seafront occurred during low tide, the storm surge elevations were not exceptional, and saved the region from further damages. The reported storm surge height of 4.6 m was 2.2 m more than the mean highest high tide level of (+) 2.4 m at Sagar

Island<sup>3,11</sup>. The mean-sea-level-adjusted lowest and highest astronomical tide levels at Sagar on 20 May 2020 were (–) 1.33 m at 15:10 IST and (+) 1.85 m at 20:44 IST respectively<sup>12</sup>.

After landfall, the cyclone initially moved towards N16°E, and crossed the densely populated districts of South 24 Parganas, North 24 Parganas, and Kolkata with a maximum sustained wind speed of 157 km/h, gusting to 185 km/h (ref. 3) (Figure 2*a*). The ‘eye’ of the cyclone passed through the eastern outskirts of Kolkata, 10–15 km from the city centre. It then changed its direction to N34°E before entering Bangladesh and causing devastation in its western districts<sup>13</sup>. Finally, after moving generally towards N16°E into the west of Meghalaya, the





**Figure 3.** Time series images showing inundation from *Amphan*-related rainfall, storm surge and post-event recovery in the southeastern Sagar Island. *a*, The pre-event image of May 2018 represents the usual dry, pre-monsoon condition of the area. *b*, In contrast, all low-lying areas are seen to be flooded (dark blue and black) a couple of days after the *Amphan* crossed over. White patches denote clouds. *c*, *d*, Subsequently, the area shows signs of improvement with draining of floodwater. Source: *a* and *c*, Landsat-8 Pan-fused OLI, path-138 row-045; *b*, Resourcesat-2 LISS-3, path-108 row-056; *d*, Sentinel-2A MSI, tile T45QXE.

system weakened into a low-pressure area (23:30 IST on 21 May 2020)<sup>3</sup>, bringing its 10-day life cycle to end on 22 May 2020.

Accompanied by torrential rainfall<sup>14</sup> (236.3 mm in Kolkata on 20 May 2020), the *Amphan* pounded the LDWB with complete disruption of civic facilities and large-scale storm inundation. The affected area (32,951 km<sup>2</sup>) was comprised of eight districts of the LDWB region mentioned earlier. Synthetic-Aperture Radar (SAR) C-band data of 19 May 2020 (pre-event) and 22 May 2020 (post-event) from Sentinel-1A and -1B satellites were processed using Sentinel Application Platform (SNAP) for extraction of the storm-inundation zones from this region (Figure 2). After radiometric calibration and terrain correction, histogram thresholding method was applied to the images for differentiating water pixels from non-water pixels. The threshold parameters were validated with the Sentinel-2A Multi Spectral Instrument (MSI)

image of 9 May 2020 (which is close to the event date) as proxy accuracy assessment. Next, water pixels were converted to polygons to get the inundation area vectors. Finally, district-wise inundated area statistics were generated by spatial analysis using vector overlay of pre- and post-inundation water areas.

The results show that 12.3% of the study area was inundated by storm waters of the *Amphan*. Expanse-wise, the two coastal districts were worst hit, with 1,809 km<sup>2</sup> (38.2% of district area) and 622 km<sup>2</sup> (6.2%) inundated in the Purba Medinipur and South 24 Parganas districts respectively. Inundation amounts for the other districts were: North 24 Parganas (420 km<sup>2</sup>, 10.3%), Hugli (298 km<sup>2</sup>, 9.5%) and Howrah (289 km<sup>2</sup>, 19.7%). Maximum waterlogging can be identified around the Hugli Estuary region, and in the reclaimed areas of the Sundarban in North 24 Parganas and South 24 Parganas districts (Figure 2). The runways and tarmac of the Netaji

Subhas Chandra Bose International Airport of Kolkata were completely flooded and damaged by the cyclone<sup>15</sup> (Figure 2*b*). Some recovery of the flooded areas was seen during the weeks following the event and before the onset of the monsoons, as the breached coastal embankments were repaired and accumulated waters drained (Figure 3). The impacts of salt water incursion into the farmlands, however, are likely to remain for years.

In the South and North 24 Parganas districts, the reclaimed Sundarban area is inherently vulnerable to tropical cyclones since its tidal islands were started to be embanked a couple of centuries ago. Prior to the *Amphan*, major cyclones like the *Aila* (May 2009)<sup>16</sup> and the *Bulbul* (November 2019) battered this region in recent past, significantly affecting its socio-economic fabric. Despite being a more intense storm, the *Amphan* did not cause coastal flood like the *Aila* event, because, unlike the former, landfall of the latter coincided almost exactly with

the highest high tide on a new moon day<sup>17</sup>. Notably, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change stated that in the North Indian Ocean region, frequency of tropical storms will remain unaltered in the coming decades, with increasingly extreme rainfall events occurring near storm centres<sup>18</sup>. Management plans for the LDWB, therefore, should prepare the region for embracing more storms like the *Amphan* in near future.

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Received 1 July 2020; revised accepted 4 September 2020

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## Shortening seed germination time for *Borassus flabellifer* using compost pit seed pretreatment

Palmyra or the Asiatic palm (*Borassus flabellifer*) is a multipurpose palm belonging to the Arecaceae family. It is native to the tropical regions of Africa, Asia and New Guinea. Among the five species of *Borassus*, *B. aethiopum* (found in Africa), *B. flabellifer* (found distributed in the coastal areas of the Indian Ocean) and *B. sondaicus* (restricted to mainland Indonesia) are of livelihood and economic importance<sup>1–3</sup>. All its plant parts find use in rural households, starting from its liquid endospermous fruit, neera (sap extracted from the inflorescence), tubers, culm, petiole to its leaf lamina<sup>4,5</sup>. It is dioecious and flowering occurs from March to April. The sex of palm is identifiable after its first flowering, which occurs 12–20 years after sow-

ing. The female inflorescence has 6–12 bunches, and each bunch bears an average of 15–25 fruits. The fruits are smooth, having a leathery, brown outer covering that turns black at maturity<sup>6</sup>. Within the fruit is a fibrous mesocarp with a yellow or orange pulp<sup>7</sup>.

Palmyra is mainly propagated through seeds that are rectangular in shape, 4.5 in long, 4 in wide, and 1.75 in thick in the middle<sup>7</sup>. Palmyra fruits are difficult to dehusk as the fibres tightly adhere to the seeds. In palmyra, it is the hypocotyl that emerges first, growing deep into the ground (sometimes more than 1 m) before the roots and pseudo leaves appear. Germination in palmyra is of tubular type, where plumule emergence occurs from the proximal end of the growing

cotyledon away from the seed. This structure is known as the cotyledonary tube or apocolon. Herein, we refer to germination as the emergence of the hypocotyl.

In the nursery, palmyra seeds are either sown in seedbeds or in mounds of soil to facilitate easy transplantation. Palmyra seeds are hard to germinate; it takes around 60–90 days for germination. Pseudo leaves start emerging in 9–12 months from the date of sowing<sup>7</sup>.

India has nearly 102 million palmyra palms distributed across Tamil Nadu (TN), Maharashtra, Karnataka, Kerala, Odisha and West Bengal. About half of the palmyra population in the country is concentrated in TN, where it is the state tree<sup>8</sup>. On the other hand, reports have