Somalia Field Survey after the December 2004 Indian Ocean Tsunami

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The 26 December 2004 tsunami severely affected Somalia, with some 300 deaths at a distance of 5,000 km from the epicenter of the magnitude 9.0 earthquake. Somalia's physical characteristics allowed a detailed assessment of the far-field impact of a tsunami in the main propagation direction. The UNESCO mission surveyed five impacted towns south of the Horn of Africa along the Puntland coast in northern Somalia: Eyl, Bandarbeyla, Foar, Xaafuun, and Bargaal. The international team members visited Somalia during 2–10 March 2005. The team measured tsunami runup heights and local flow depths on the basis of the location of watermarks on buildings and eyewitness accounts. Maximum runup heights were typically on the order of 5–9 m. Each measurement was located by means of global positioning systems (GPS) and was photographed. Numerous eyewitness interviews were recorded on video.
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INTRODUCTION

On Sunday, 26 December 2004 at 00:58:53 UTC, a great earthquake with a moment magnitude of 9.0—or possibly greater (Stein and Okal 2005)—occurred 250 km southwest of the northern tip of Sumatra, Indonesia. Large tsunamis were generated and severely damaged coastal communities in countries along the Indian Ocean, including Indonesia, Thailand, Sri Lanka, India, the Maldives, and Somalia (Synolakis et al. 2005). The tsunami death toll is currently estimated at 300,000—exact numbers are likely never to be determined, given that detailed pretsunami population censuses were not available in several affected regions, and human remains were occasionally buried without identification. Beyond the loss of human lives, the tsunami also destroyed livelihoods, traumatized whole populations, and severely damaged habitats. In the near field of the epicenter, Sumatra was hardest hit by the tsunami (Borrero 2005a, 2005b). In the far field, the tsunami severely affected Sri Lanka across the Bay of Bengal at a distance of 1,600 km from the epicenter, or a third of the distance between Sumatra and Somalia along the westward path of the tsunami (Liu et al. 2005). The Maldives, at the halfway point between Sumatra and Somalia, were struck an hour after Sri Lanka at a distance of 2,500 km from the epicenter shown in Figure 1 (Fritz et al. 2006, this issue).

In East Africa, the tsunami impact focused on Somalia some 5,000 km to the west of the earthquake epicenter. Hardest hit was a 650-km stretch of the Somalia coastline

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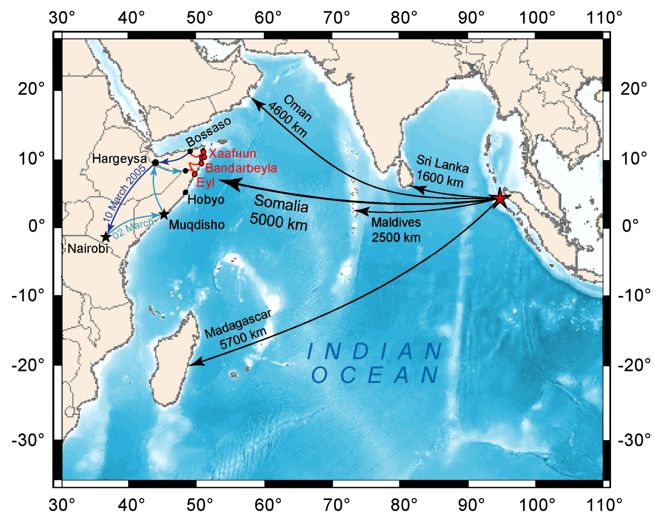

Figure 1. The Indian Ocean, with Somalia along the Horn of Africa. Distances from the epicenter of the 2004 Sumatra-Andaman earthquake (indicated by a star) are shown for companion surveys: Sri Lanka (Liu et al. 2005), Maldives (Fritz et al. 2006, this issue), Madagascar (Okal et al. 2006a, this issue) and Oman (Okal et al. 2006b, this issue).

between Garacad (Mudung region) and Xaafuun (Bari region), which forms part of the Puntland Province near the Horn of Africa. The tsunami resulted in the death of some 300 people and extensive destruction of shelters, houses, water sources, and fishing boats and equipment. Most of the victims were reported along the low-lying Xaafuun Peninsula. The livelihoods of many people residing in towns and small villages along Somalia's Indian Ocean coastline, particularly in the northern regions, were devastated. About 18,000 households were estimated to be directly affected and in need of urgent humanitarian assistance. Since 1991, Somalia has been troubled by war and lawlessness, environmental degradation, health and economic crises, high population pressure and competition over limited resources, and poverty. As a failed state, Somalia has suffered triple natural disasters. It had been affected by flash floods, followed by four years of successive drought that displaced many people from their areas of origin, and finally came the tsunami.

POST-TSUNAMI FIELD SURVEY

The immediate response by various UN agencies and other organizations had focused on meeting the humanitarian lifesaving needs. Various UN agencies were operating in Xaafuun during this tsunami survey. However, limited scientific information was available on the tsunami impact on the Horn of Africa. Therefore, a UNESCO expedition was organized through the Intergovernmental Oceanographic Commission (IOC) in Paris to fill the gap in terms of tsunami inundation and runup. At the end of February 2005, final briefings were held at the United Nations Office at Nairobi (UNON) head-

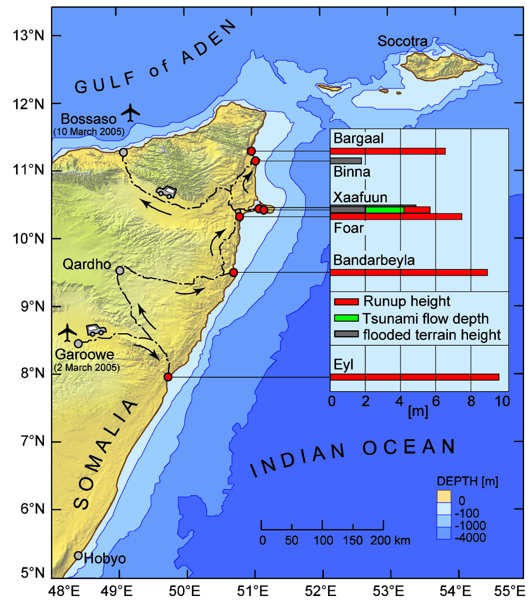

Figure 2. Somalia's Puntland coast with bathymetry contours, the GPS track of the expedition with surveyed locations, and the maximum measured tsunami flow depths and runup heights (SRTM data-based color shaded relief courtesy of NASA-JPL).

quarters in Nairobi, Kenya, which is also the location of the provisional Somali government in exile. On 2 March 2005, the field survey team was dispatched on a United Nations Common Air Service (UNCAS) flight into Garoowe some 1,700 km northeast of Nairobi via Muqdisho (Figure 1). The lawless situation in Muqdisho, with several factions fighting over control and the killing of a BBC reporter upon arrival in Muqdisho a few days prior to the dispatching, prevented the tsunami survey team from venturing beyond the airfield "K50" in Muqdisho. In Garoowe, the expedition was approved by authorities of the Puntland province, and local logistics team members were hired. During 3–9 March, the team covered 1,500 km with off-road vehicles on the rugged terrain of Somalia between Garoowe and Bossaso. On 10 March, the international team members were flown out on an UNCAS flight from Bossaso to Nairobi. The detailed itinerary and an overview of measured runup heights are shown in Figure 2. The measured data were corrected for the tide level upon tsunami arrival on the basis of tide predictions for the port of Hobyo.

The difficult and steep terrain along the Horn of Africa limited the team's shoreline access to just a few locations. The authors surveyed the tsunami impact and wave runup in the coastal towns of Eyl, Bandarbeyla, Foar, Xaafuun, and Bargaal. A variety of standard tsunami field survey techniques (e.g., Synolakis and Okal 2005) were used. Numerous eyewitness interviews were recorded on video to estimate the number of waves, their height and period, and the tsunami arrival time. The team measured the tsunami runup heights and local flow depths on the basis of watermarks and eyewitness accounts. The maximum runup on these steep shores was determined in relation to the sea level at tsunami impact with a laser rangefinder with an integrated digital inclinometer and compass. Each watermark was localized by means of a global positioning system (GPS) and was photographed. Further inundation distances and areas of inundation were documented. In selected areas such as Xaafuun, a detailed grid of various transects and shoreline surveys allowed the team to reconstruct the local topography and tsunami elevation in three-dimensional space. The town of Xaafuun was completely flooded, with depths of up to 2 m, and suffered widespread destruction due to the low elevation at the spit connecting the peninsula to the mainland. Nineteen dead bodies were recovered, and 160 persons were presumed missing in Xaafuun; this amounts to the highest number of casualties in a single African town, even though much greater tsunami runup heights were measured further south along the steep shores. The maximum runup height of almost 9 m was recorded in Bandarbeyla on the basis of debris from houses. An even higher runup point was measured on a cliff near the town of Eyl, based solely on an eyewitness account.

Table 1 gives the full data set gathered during the survey, excluding additional transect points. Twenty-six measurements were retained—principally, runup values obtained from debris, watermarks, and eyewitness reports. The map in Figure 2 summarizes the data set. Maximum runup heights were typically on the order of 5–9 m, with a slight decay toward the north of the surveyed stretch of coastline. The abandoned settlement Binna, situated on a low-lying sand spit sheltering a lagoon, was overwashed, but no flow depth or runup measurements were possible. Thus, they roughly double those reported to the north in Oman (Okal et al. 2006b, this issue) and to the south on Madagascar (Okal et al. 2006a, this issue) as well as Réunion and Rodrigues Islands (Hébert et al. 2005), where limited structural damage and only a few casualties were reported. The surveyed Puntland coast in northern Somalia was by far the area hardest hit to the west of the Indian subcontinent.

FIELD OBSERVATIONS

EYL

The fishing town of Eyl is some 800 km northeast of Mogadishu and 460 km south of the Horn of Africa, within Somalia's Nugaal region. Eyl consists of an inland settlement, Daawad, and the coastal fishing village Baday. Out of a population of 1,200 people, some 95 fatalities and 80 injured persons were reported. In addition, some 48 destroyed houses were reported in a stick hut settlement near the beach in Baday, but no debris was found during the survey 10 weeks after the event. The visited refugee camp in Dawaad accommodated some 400 refugees from the stick hut settlement. The coastal part of Eyl is in the Qooriga Neegro Bay on the north shore of the Eyl River, sandwiched between the sandy beach and 100-m-high cliffs (Figure 3).

The beaches in Eyl, with 3–5% slopes, are among the widest along the Puntland coast, because of the river mouth. In the area north of the river entrance, fishing boats were scattered up to 200 m inland and up to an elevation of 5 m (Figure 4a). The tsu-

Table 1. Data set surveyed by the UNESCO team in March 2005

No.	Site	Latitude (°N)	Longitude (°E)	Vertical survey (m)	Vertical survey Nature of meas.[a]	Inundation (m)	Date and time surveyed Day and month	Date and time surveyed (UTC)	Notes
1	Eyl	7.96542	49.84935	6.36	R	226.7	4 Mar.	6:20	Debris
2a	Eyl	7.96001	49.84540	6.32	R	216.3	4 Mar.	7:00	Sponges
2b	Eyl	7.96071	49.84294	9.52	R	500.7	4 Mar.	7:00	Eyewitness
3	Bandarbeyla	9.49649	50.81292	6.84	R	63.3	5 Mar.	13:29	House debris
4	Bandarbeyla	9.49755	50.81258	6.14	R	44.4	5 Mar.	13:37	House debris
5	Bandarbeyla	9.49592	50.81331	6.64	R	41.3	5 Mar.	13:44	House debris
6	Bandarbeyla	9.49407	50.81420	7.94	R	45.9	5 Mar.	13:54	House debris
7	Bandarbeyla	9.49316	50.81461	8.94	R	48.6	5 Mar.	14:03	House debris
8	Bandarbeyla	9.49186	50.81546	8.64	R	45.2	5 Mar.	14:13	Boat
9	Bandarbeyla	9.49094	50.81599	8.54	R	42.2	5 Mar.	14:16	Cliff scar
10	Foar	10.31333	50.89751	6.37	R	169.5	6 Mar.	13:57	House debris
11	Foar	10.31077	50.89758	7.47	R	62.3	6 Mar.	14:16	House debris
12	Foar	10.30845	50.89774	5.97	R	44.0	6 Mar.	14:28	Flip-flops
13	Foar	10.31144	50.89736	6.37	R	122.3	6 Mar.	14:40	Boat
14	Foar	10.31223	50.89717	6.37	R	145.4	6 Mar.	14:40	House debris
15	Xaafuun	10.42168	51.26221	5.67	R	230.6	7 Mar.	11:45	Debris
16	Xaafuun	10.42105	51.25939	4.24	F	64.3	7 Mar.	12:16	Watermark on wall
17	Xaafuun	10.42135	51.25944	3.72	F	97.3	7 Mar.	12:18	Watermark on wall
18	Xaafuun	10.42161	51.25924	3.55	F	122.6	7 Mar.	14:02	Watermark on wall
19	Xaafuun	10.42185	51.25931	3.43	F	149.8	7 Mar.	14:02	Watermark on wall
20	Xaafuun	10.42228	51.25936	3.92	F	198.0	7 Mar.	14:04	Watermark on wall
21	Xaafuun	10.42260	51.25969	3.97	R	239.8	7 Mar.	12:23	Debris
22	Xaafuun	10.42515	51.25942	4.32	R	509.2	7 Mar.	12:39	Debris
23a	Xaafuun	10.42793	51.25533	5.49	R	662.5	7 Mar.	13:15	Teapot
23b	Xaafuun	10.42834	51.25541	4.49	R	704.0	7 Mar.	13:14	Debris, eyewitness
24	Xaafuun-spit	10.42494	51.19131	4.87	R	305.0	8 Mar.	5:04	Debris
25	Bargaal	11.28567	51.07848	6.49	R	132.3	8 Mar.	14:45	House debris
26	Bargaal	11.28311	51.07861	5.09	R	83.9	8 Mar.	14:36	House debris

[a] Codes to nature of vertical measurements: F = flow depth + terrain elevation, R = runup

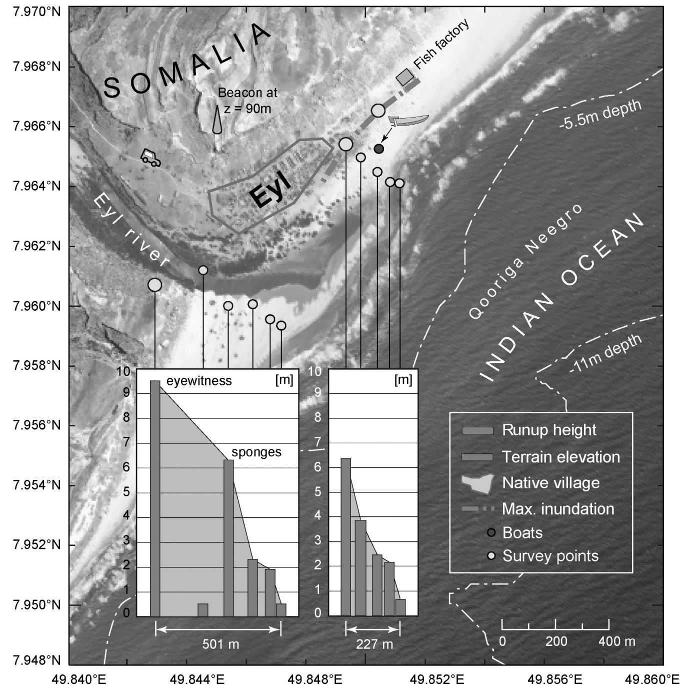

Figure 3. Eyl: Quickbird satellite image with surveyed transect locations, measured tsunami runup heights, and offshore depth contours.

nami destroyed 40 fishing boats and damaged 70 more out of a total of 145 boats in Eyl. The survey team had to rely mostly on the elders of Eyl and their eyewitness accounts to identify the maximum inundation and runup (Figure 4b). The two recorded transects are shown in Figure 3. North of the Eyl River entrance, a 6-m runup was measured, whereas just south of the river, the highest runup of over 9 m was recorded at the foot of the cliff; the latter runup height is based solely on an eyewitness account. No physical evidence was identified at the 9-m runup point, but some sponges were found along the profile at a 6-m elevation. The well-built houses of Eyl along the foot of the cliffs at more than a 10-m elevation were not inundated. The fishing cooperative built in 1975 was not flooded by the tsunami.

BANDARBEYLA

The fishing town of Bandarbeyla is 1,000 km northeast of Mogadishu, 200 km north of Eyl, and 260 km south of the Horn of Africa, within Somalia's Bari region. Out of a population of 7,000 inhabitants, 7 fatalities and 30 injured persons were reported. In addition, 102 houses were destroyed, including 87 stone houses. Bandarbeyla is south of the Wadi Darimoh (Figure 5). The coastline is very steep, and the terrain quickly rises to elevations of up to 400 m as little as 1 km from the shore.

Figure 4. Eyl: (a) fishing boats scattered by the tsunami in the sand dunes north of the town; (b) elders at the maximum runup location; typical stick huts are at the bottom of the 100-m-tall cliff.

Most houses in Bandarbeyla were solidly built of rocks, in sharp contrast to the characteristic stick huts of the nomads. Numerous house walls parallel to the shoreline were pushed in, and house corners collapsed due to local scouring. Rock houses severely damaged by the tsunami along the steep shore in Bandarbeyla are shown in Figure 6. The loss of 120 fishing boats was reported. The remains of fishing boats were found amidst the rubble of collapsed houses at elevations of up to 8 m (Figure 7a). The sur-

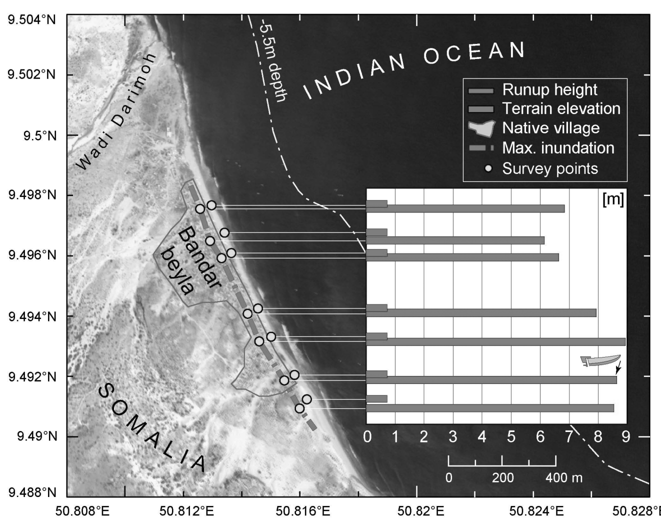

Figure 5. Bandarbeyla: a Quickbird satellite image with surveyed transect locations, measured tsunami runup heights, and offshore depth contours

Figure 6. Bandarbeyla: (a) a destroyed rock house corner and an armed bodyguard leading the way; (b) blowout failure of walls parallel to the shoreline.

veying was conducted with some difficulties, because armed guards were needed to control a hostile mob that gathered at the scene. A laser rangefinder with bearing and inclination modules combined with a GPS allowed a rapid recording of several transects, as shown in Figure 7b, during the surveying of shore erosion at the southern end of Bandarbeyla. The seven recorded runup points are shown in Figure 5. The runup scattered around 6 to 9 m, and the inundation distance varied from 40 to 60 m. The beaches in Bandarbeyla sloped from 10% to 20%.

Figure 7. Bandarbeyla: (a) boats smashed ashore amidst house rubble; (b) surveying of shore erosion with a laser rangefinder.

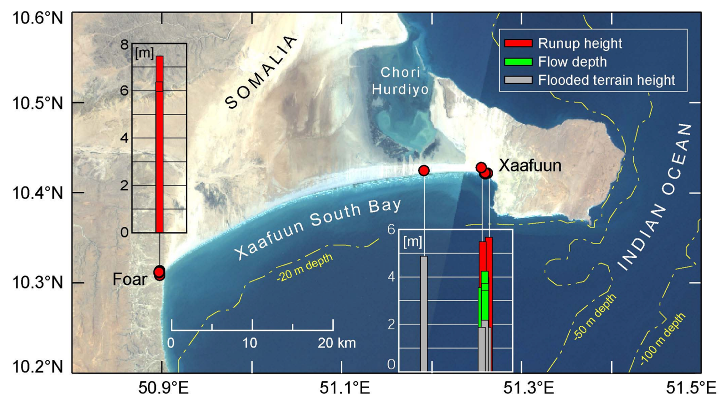

Figure 8. Xaafuun peninsula: a Quickbird satellite image with surveyed locations and maximum tsunami runup heights.

XAAFUUN PENINSULA

The Xaafuun Peninsula within Somalia's Bari region juts out 40 km into the Indian Ocean, forming the easternmost point on the African continent. The promontory is connected to the mainland near Foar only by a low-lying sand spit 20 km long (Figure 8). The sand spit is 1–3 km wide and roughly 5 m high. Large parts of the sand spit were flooded, but no overtopping location of the sand spit was identified. The fishing town of Foar is on the mainland 90 km north of Bandarbeyla and 170 km south of the Horn of Africa. Out of a population of 1,000 inhabitants, 2 fatalities and 6 injured persons were reported. In addition, 50 houses were destroyed, and 30 of 200 fishing boats were lost. Five runup points were measured within a range of 6–7.5 m. The beaches in Foar sloped only 4–12%, which is significantly less inclination than in Bandarbeyla. In Bargaal, which is 110 km north of Foar and 60 km south of the Horn of Africa, the tsunami runup heights decreased, according to measurements of 5–6 m.

The fishing town of Xaafuun is believed to be the location of the ancient trade center of Opone, where ancient Egyptian, Roman, and Arabian pottery has been recovered by archaeologists (Wright and Smith 1988). Xaafuun is 40 km east of Foar and just 2 km east of the sand spit connecting the promontory to the mainland. The coastline of Xaafuun faces toward the southwest (Figure 9). Out of a population of 5,000 inhabitants, 19 dead bodies were recovered, and 160 persons were reported missing. This represents the largest tsunami death toll in a single town to the west of the Indian subcontinent. The entire low-lying western part of Xaafuun was completely flooded by the tsunami. Only the northeastern corner of the settlement next to the salt factory remained unaffected by the tsunami.

A total of 812 houses were destroyed, including 600 stone houses, and an additional 400 houses were reported to be damaged. Figure 10a shows the survey team recording a transect amidst the destroyed mosque and collapsed cement stone houses. Most houses in Xaafuun were built of rocks and cement stones. Numerous house walls parallel to the

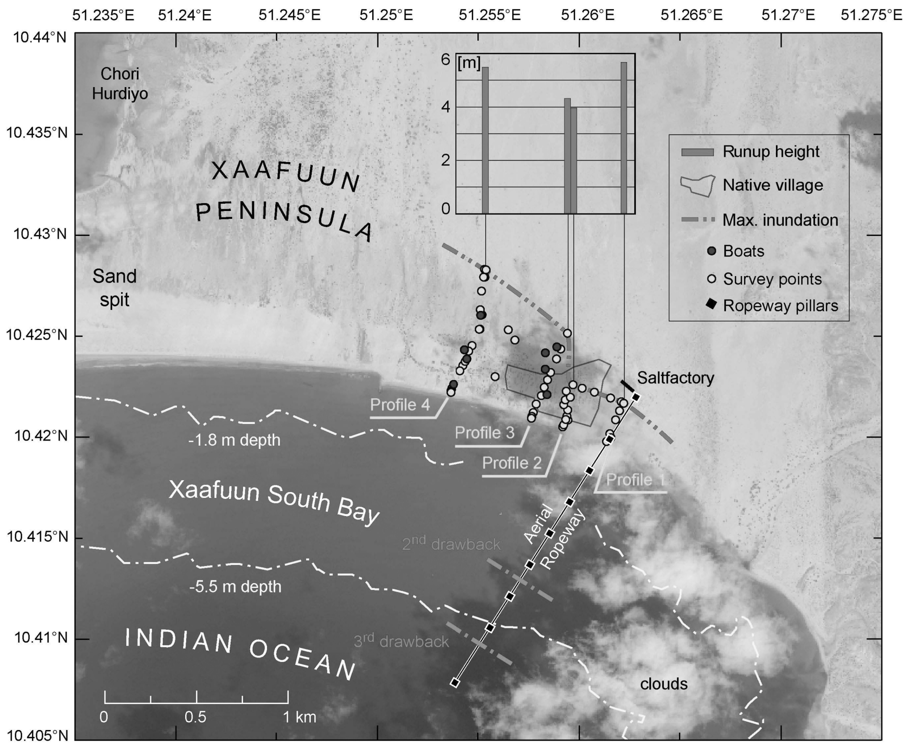

Figure 9. Xaafuun village: a Quickbird satellite image with surveyed transect locations, measured tsunami runup heights, and offshore depth contours.

Figure 10. Xaafuun: (a) a destroyed mosque and cement stone houses; (b) a pier of an Italian salt factory that had been destroyed during World War II.

(a) (b)

Figure 11. Xaafuun: (a) scour damaged a house corner; (b) a flow depth recording based on a watermark on a house wall.

shoreline were pushed in, and house corners collapsed due to local scouring (Figure 11a). The loss of 162 out of 450 fishing boats was reported. The remains of fishing boats were found as far inland as 450 m from the shore. Other debris such as wooden logs, teapots, and bottles were scattered up to 700 m from the shore. In Xaafuun, five flow depth points were measured on the basis of watermarks on house walls (Figure 11b). Along the lateral transects on the outskirts of the village, no flow depth measurements were possible because of the lack of tall vegetation and structures. The low-lying part of the village at an elevation of roughly 2 m was flooded by 2 m of water.

The four recorded transects from the beach to the corresponding runup point are shown in Figure 12. The runup varied from 4 to 6 m. The tsunami penetrated up to 700 m inland on the low-lying western side of Xaafuun, whereas on the eastern side the land was flooded only up to 230 m inland. Sand discolorations characterized the inundation limit besides debris and eyewitness indications. The remains of the Italian salt factory to the east of the village are located at an elevation of 9 m. The distances between the offshore pillars of the aerial ropeway shown in Figure 10b were measured with a laser rangefinder and were later verified on the high-resolution Quickbird satellite image. The first six offshore pillars are 200 m apart, whereas the outermost loading terminal is 300 m from the sixth offshore pillar. Hence, the ropeway extends 1,500 m into the

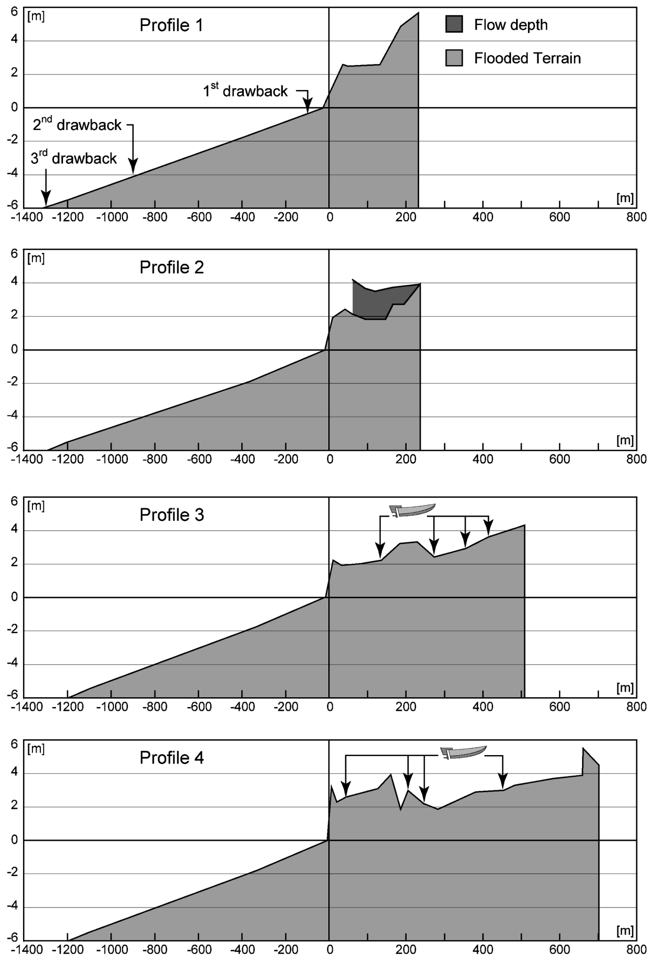

Figure 12. Xaafuun: surveyed transects from the beach to corresponding runup points.

Indian Ocean. The Italian-speaking vice council, Mahad X. Said, standing at the waterfront outside the mosque upon the arrival of the tsunami (Figure 10a), gave a very detailed description of the initial wave sequence. At first, a 100-m drawback was noticed, followed by a first wave flooding the beach. Next, the water withdrew again by 900 m before the second wave partially flooded the town. Finally, the water withdrew again by 1,300 m offshore before the third and most powerful wave washed through the town. These drawbacks correspond to 0.5-m, 4-m, and 6-m depths. The detailed eyewitness account of the numerous drawbacks is founded on the locations of the offshore pillars. The velocity of the third wave closing in on the town was approximately 11 m/sec. This estimate is based on distances determined from the offshore pillars and the time interval

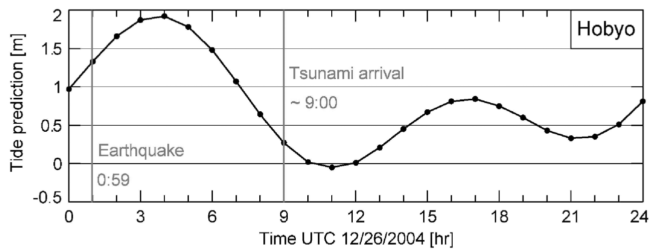

Figure 13. Tide prediction for the port of Hobyo, with the time of the earthquake and tsunami arrival.

given by eyewitnesses, which corresponds to roughly 2 minutes from the maximum drawback to the center of Xaafuun. Four powerful waves were observed, with an estimated wave period of 12 minutes.

Xaafuun was the only town where a small initial drawback was observed. The bathymetry off Xaafuun is extremely shallow, sloping less than 0.5% within the drawback area, as compared with the onshore 5% beach slope along the same transect. Therefore, a small drawback is more likely to be observed than a small wave flooding the beach. In all other towns, an initial rise was reported, which would be expected, given the deformation pattern of the earthquake with uplift on the west and the corresponding field observations in Sri Lanka, India, and the Maldives (Liu et al. 2005, Fritz et al. 2006, this issue). In all towns, at least four waves were observed. Some eyewitnesses indicated numerous waves. The eyewitness estimates of the arrival time concentrated around noon local time (UTC+3) in most towns along the Puntland coast: 8:30 UTC in Bandarbeyla, 9:00 UTC in Foar, 9:45 UTC in Xaafuun, and 9:00 UTC in Bargaal. The total duration of the event was estimated at 3–7 hours, after which the sea returned to normal. Travel times are expected to have been 7.5–8 hours on the basis of the epicentral distance of 5,000 km, also taking into account the variable depth of the Indian Ocean basin (Titov et al. 2005). With a seismic origin time of 00:58:53 UTC, these factors predict first arrivals between 8:30 and 9:00 UTC, which is in good agreement with the eyewitness reports. The tide level prediction for the port of Hobyo 300 km south of Eyl is shown in Figure 13. No tide gauge recordings were available for Somalia.

The tide predictions follow the same pattern, with small phase shifts from Kismayo near the Kenyan border up to the Horn of Africa. Fortunately, the main tsunami waves arrived close to low tide during a receding tide. A tsunami arrival during high tide could have increased the runup heights by up to 2 m, depending on the location.

CONCLUSIONS

The rapid response of the survey team in visiting Somalia after the 26 December event led to the recovery of important data on the characteristics of the tsunami effects and inundation on steep and gentle shores in the tsunami far field. Furthermore, the large penetration distance of the tsunami into towns resulted in important documentation of structural behavior upon tsunami impact. The Puntland coast in northern Somalia was by far the area hardest hit to the west of the Indian subcontinent. The runup heights of up to 9 m are on the same order of magnitude as observed in Sri Lanka, which is a third of the distance from the epicenter (Liu et al. 2005). In contrast, the maximum flow depths in Hambantota along Sri Lanka's southeast coast roughly doubled the few flow depth measurements in Xaafuun (Somalia). The measured inundation distances of up to 700 m are somewhat shorter than in Sri Lanka. This is caused by the typically much steeper shores in Somalia and the lack of shallow coastal plains along the stretch of surveyed coastline. The human loss was limited, primarily because the Puntland coast is one of the least populated coastlines along the shores of the Indian Ocean. Nevertheless, the death toll tripled the fatalities in the Maldives, which are halfway between the epicenter and Somalia. The reduced impact of the tsunami in the Maldives compared to Sri Lanka and Somalia is primarily due to the specific bathymetry of the coral atolls, which are separated by deep ocean channels (Fritz et al. 2006, this issue).

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