The Coast of Kenya Field Survey after the December 2004 Indian Ocean Tsunami

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A field survey of the coast of Kenya was conducted after the 26 December 2004 Indian Ocean tsunami. We visited the coast between Mombasa and the Ngomeni Peninsula north of Malindi from 25 February to 4 March 2005. The tsunami struck the coast during the rising tide, but it caused little damage because warnings had been issued effectively and because large stretches of the coast are protected by reefs. These large stretches of protected coast end at Malindi, and the coasts to the north include sandy beaches and spits like the Ngomeni Peninsula. The maximum recorded runup at this peninsula was 3 m at 43 m from the water level at the time of the tsunami impact.
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INTRODUCTION

Initial simulations of the 26 December 2004 tsunami by Titov (PMEL 2005, Titov 2004) provided information on how the energy was released into the Indian Ocean and toward the coast of Africa, in the Pacific Ocean, and in the Atlantic Ocean. These simulations were widely reproduced in the press, and the results were finally confirmed in the more systematic study of Titov et al. (2005). The initial simulations showed that a fraction of the energy of the tsunami was forced to travel along ridges toward the African coasts. Somalia seemed to be the main focus of the energy, and the coast of Kenya was less impacted. Warnings of the tsunami had reached Kenya from India and/or the Maldives, and action was taken. Hotel resorts and local residents were warned by phone calls (the information migrated from hotel to hotel, as an official warning) and later by radio messages. Individuals who had taken note of the impending danger went to alert the coastal resorts. As a result of these warnings, only one young man died in a boating accident near the shore in Malindi during the tsunami attack.

The field survey in Kenya took place from 25 February to 4 March 2005. During the field survey, runup parameters and other inundation metrics, according to Synolakis and Okal (2005), were determined. We also took samples of sandy deposits left behind by the tsunami that are being analyzed for grain size. The grain-size distributions and their statistical parameters characterize the deposits and provide insights into the mechanism of deposition from the tsunami.

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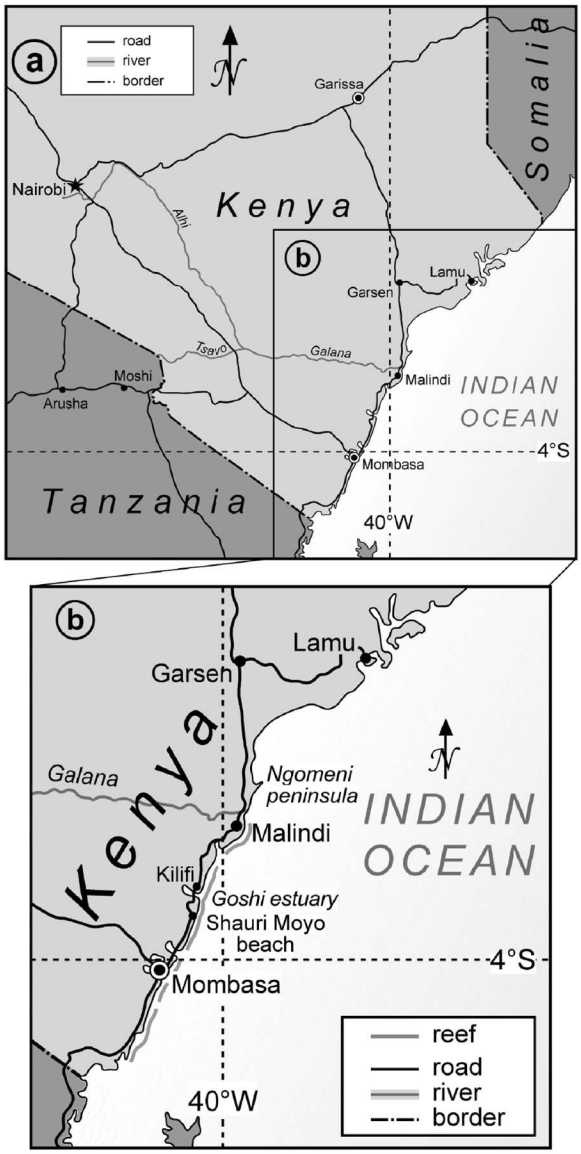

Figure 1. (a) Eastern Kenya and (b) detail of Kenya's southern and central coast. We studied the tsunami impact between Mombasa and the Ngomeni Peninsula. The tsunami inundation could be confirmed at Shauri Mayo beach, Kilifi beach, and the Ngomeni Peninsula.

The starting point of the survey in Kenya was Mombasa. The purpose was to survey beaches between Mombasa and the Ngomeni Peninsula north of Malindi (Figure 1) and to interview eyewitnesses about their observations. For reasons of security, we were advised not to travel overland significantly north of the Ngomeni Peninsula.

Figure 2. Reef top exposed at low tide approximately 10 km north of Mombasa.

EYEWITNESS ACCOUNTS AND FIELD OBSERVATIONS

Figure 1 shows a reef about 100 m offshore of the actual beaches. At low tide, the reef top is exposed (Figure 2), whereas it is submerged at high tide. Interviews with local people and hotel managers confirmed the arrival time of the tsunami at the African coast as being about 1:00 P.M. local time, which is consistent with the tentative simulation by Titov (2004). The variance of this datum is ±0.5 hr, depending on the location. The tsunami struck when the rising tide was halfway toward high tide. Most parts of the coast appear to have been sheltered from the tsunami by the offshore reef.

Overall, people living in reef-protected regions of the coast were surprised by the tsunami in terms of its occurrence. The tsunami did not inundate land, in contrast to the images from amateur videos in Thailand, Sri Lanka, and Aceh (Synolakis et al. 2005). The tsunami impact was remembered by the people as strange or unusual currents between the coast and the reef. These currents can most likely be ascribed to a combination of the presence of the reef breakwater and the rising tide at the time of arrival of the tsunami waves. On the Ngomeni Peninsula, which is not protected by the reef, the tsunami climbed up the coast for several tens of meters. This, however, did not seem to have affected the local villagers, because villages are located about 100 m inland.

However, even if unusual currents had been observed, inundation seldom accompanied those observations (Table 1). For example, near Kilifi (Figure 1b), an Italian estate owner observed unusual currents that can be interpreted as huge eddies or turbulent currents. These eddies or turbulent currents were influenced by a nearby river mouth and could have led to a complex hydrodynamic pattern from the discharge of water from the

Table 1. Observed tsunami impact on portions of the Kenyan coast

Name	Location	Inundation	Observation
Shauri Mayo beach	3°47′10.44″ S 39°50′28.06″ E	<0.5/?	No eyewitness accounts
Goshi Estuary	3°38′16.69″ S 39°50′56.61″ E	No	Unusual currents
Kilifi beach	3°37′33.06″ S 39°52′26.52″ E	0.7/3.0	Unusual currents, eddies in the water
Ngomeni Peninsula	3°00′54.58″ S 40°11′55.54″ E	3.0/43.0	Black sand was not there before tsunami

[a] Inundation is given as runup height/runup distance in meters.
[b] Based on eyewitnesses accounts

Goshi River. At this location, the beach was inundated up to a height of 0.70 m, and the water penetrated horizontally 3 m onto the beach. Houses in this area are not situated directly at the beach; a relatively steep slope protected the houses. Even in the Goshi estuary (Figure 3), no sign of severe tsunami impact could be found. The photo in Figure 3 was taken at about the same tidal stage during which the tsunami struck that area. A wide area of the bay was dry at that time. Furthermore, one can infer that the bay at high tide has a water level 2 m higher than at the current tidal stage shown in this photo. The total difference in the water level between low tide and high tide is about 3 m in this area (Mobilgeographics 2005).

Between the mouths of the Goshi and Galana rivers (Figure 1), no evidence of tsu-

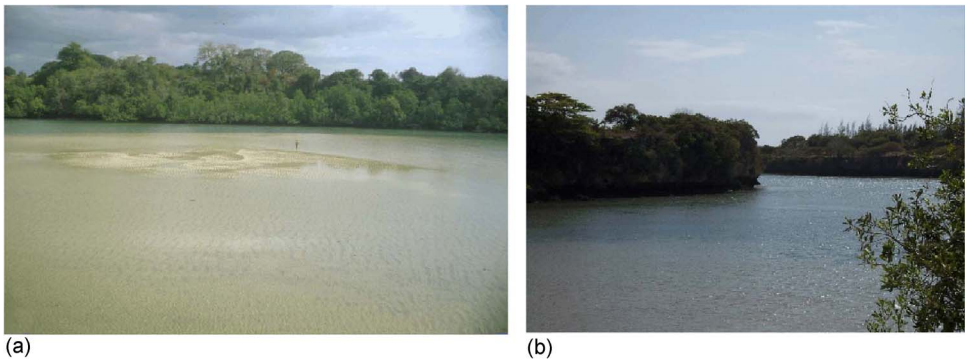

Figure 3. The Goshi estuary south of Kilifi. The river flows from the left to the right. The different colors of the water indicate different water depths; the brownish color of the water implies very shallow water. (a) Aview upstream and (b) a view downstream from the bridge between Shauri Moyo beach and Kilifi (Figure 1b); these photos were taken during the rising tide. At low tide, most of the estuary bottom is exposed.

Figure 4. (a) Tsunami impact evidence at the Ngomeni Peninsula marked by debris. (b) Black sand, rich in heavy minerals, deposited by the tsunami. (c) Tidal situation at about the time of the tsunami inundation. In the area of the Galana River mouth, there is no reef. Oil rigs are visible in the distance.

nami inundation could be observed; eyewitness accounts were difficult to find, since this area is sparsely populated. Even in Malindi, no evidence of tsunami impact could be found at the time of this survey.

On the Ngomeni Peninsula north of Malindi (Figure 1), the tsunami impact was obvious (Figure 4a). Debris consisting of palm trees, plastic bags, and other urban trash marked the runup. The coast north of Malindi is not protected by reefs (Figure 1), and the tsunami runup was uninhibited.

The water evidently climbed up the beach slope, and the runup height reached 3 m, with an inundation distance of 43 m. The flow depth of the water could not be determined because of the lack of clear water marks. According to local people, the black sand (Figure 4b) that covers the surface was not there before the tsunami. A profile of the sand deposits at the tip of the beach slope and the flat area (Figure 4b) showed that

the black sand layers appear to reflect seasonal variations in this part of the sedimentary system. The tsunami deposited a sandy layer with a maximum thickness of 15 cm inboard of the seaward edge of the beach, which tapered out about 15 m inland.

SYNOPSIS

The impact of the 26 December 2004 Indian Ocean tsunami on the coast of Kenya was, fortunately, relatively minor. Warnings of the tsunami had reached Kenya from India and/or the Maldives, and action was taken quickly—consisting of radio and phone messages and individual initiative. Only one fatality was recorded. Because the southern half of Kenya's coast, including the populous city of Mombasa, is protected by reefs, the tsunami impact was minor. North of Malindi and the reef belt, the tsunami runup on sandy spits and beaches reached 3 m at runup distances of over 40 m.

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