Malin–Maharashtra landslides: a disaster triggered by tectonics and anthropogenic phenomenon

The landslide that occurred on 30 July 2014, at Malin village, Ambegaon Taluka (19°9′40″N and 78°41′18″E), 110 km from Pune, West Maharashtra, was a major disaster that crushed a large number of houses and trapped/killed over 160 people in the village. A team of geologists from the Geological Survey of India (GSI) which conducted an on-the-spot study after the event, observed that multiple factors may have caused the disaster. The team observed prominent bench cultivation of paddy in the upslope region of Malin village and the heavy impounding of water demanded by the crops might have promoted infiltration into the soil and loosened it, leading to the major mudflow, burying the Malin village. The team further attributed the disaster to the continuous rain in the preceding 3 days and the large scale flattening of the foothills in the downstream of the village. In addition, the team has predicted future landslides in the area[1]. Some NGOs had witnessed cracks in the region a decade earlier and the villagers have also observed the sudden appearance of three cracks during 2003 (ref. 1). Due to such signals indicating possible landslides, the villagers were evacuated to the adjacent area and housed in specially erected shelters; but they returned to Malin village which led to the large-scale casualities[1]. During their field visit, GSI has further expressed hope that the National Landslide Mapping Program to be launched shortly by GSI would bring out vulnerability maps along with mitigation strategies in the next another 5–6 years. In addition to GSI, a team from Pune University visited the site and made observations that anthropogenic activities have led to the Malin episode[1]. Apart from a few of these visits post disaster, no studies have been carried out in Malin area on the landslide vulnerability. The Padkai scheme launched by Government of Maharashtra for soil and water conservation has not included Malin area as it is not covered by this project. However, this is yet another disaster similar to Uttarakhand, which occurred during June 2013 and killed over 5500 people including the pilgrims and the local people in Kedarnath region. Both disasters have taught us a lesson that, though many scientific studies have been carried out in the last few decades, we are yet to evolve comprehensive, protective and predictive mitigation strategies for such disasters. This communication briefly narrates the geological and anthropogenic complexities prevailing in Malin area. It also emphasizes the input of regional geodynamic processes over the Malin landslides and the need for detailed local and regional studies while developing the holistic mitigation strategies for any region in general and the Malin landslide affected region in particular.

Malin area lies in the Deccan Volcanic province exposing horizontally layered sequence of basaltic lava flows (Deccan Traps) erupted through fissures during the culmination of the Cretaceous period circa 66 million years ago. The massive flow layers form flat topped vast plateaus with steep escarpments. The softer flow layers form obsequent, debris covered and vegetation packed slopes encircling such plateaus and these occur sandwitched between massive flows. These softer thin flows form vegetation rings/bands in between the massive flows as seen in the southern part of the area (Figure 1). Contacts between the flows which have erupted with a time gap, are marked by red boles and flow breccias. The lava flows are highly fractured due to cooling cracks and tectonism[2,3].

While the Malin ridge trends in North–South direction, the fracture swarms seen on either sides of it are aligned orthogonal to it (1, Figure 1); whereas the fracture valley (2, Figure 1), delimiting the Malin ridge to its southeast, is trending in ENE–WSW direction. The observations made in the adjacent areas using the *Google* image show that this ENE–WSW fracture valley extends to a longer distance up to Nandgaon in the southwest, where it exhibits sinistral shifting of Deccan flows, hereafter referred to as flows (1, Figure 2). Its sub-parallel counterpart found to the north west of Malin ridge controls the well-defined escarpment of the flows (2, Figure 2). The other two NE–SW-oriented sub-parallel faults found in the southwestern part of Malin ridge (3&4, Figure 2) also show sinistral shift of flows which is well-manifested in Khandas area (Figure 2). In contrast, the NW–SE oriented faults (5&6, Figure 2) found in Malin area show visible dextral shifting of flows. Such dextral shift of flows and the resultant topographic depression are clearly visible in the form of ‘Z’ shaped flow pattern of the river joining the Ambegoan reservoir (Figure 2) and such drainage anomalies were inferred to represent the dextral strike–slip faulting in parts of south India also[4]. Though these dextral and sinistral shifting of flows appear to be of erosional pattern, such pattern of the flows is attributed to the transverse movements along the faults. All these indicate that there have been strong tectonic activities in Malin area in the Post Deccan Volcanic period. This sub-parallel set of ENE–WSW sinistral faults found to the southeast and northwest and the similar set of NW–SE dextral faults found to the northeast and southwest have bounded the Malin area as a tectonic block. These bounding faults must be causing different types of stress leading to warping and fracturing of the Malin block following the pattern of wrench fault tectonics[5] and detailed studies will elicit more information on this. Further, the ENE–WSW sinistral and the NW–SE dextral faults in the area show that a compressive force can be conceived in NNE–SSW direction[5] (7, Figure 2).

The *Google* image based interpretation of geomorphology and land use/cover of Malin area shows that there are alternate layers of flat topped flow plains (2–4, Figure 3) with the intervening debris laden and vegetation packed obsequent slopes (5, 6). While the flat topped hill of the topmost flow west of Malin village (2, Figure 3) has been deforested for cultivation, the underlying flow plains (3&4, Figure 3) located just above the upslope region of Malin village are being marginally used for cultivation. The intervening debris bearing and vegetation packed obsequent slopes formed by the softer flows (5&6) have been deforested and intensive bench cultivation is going on, in the upslope region (5A), northwest (6A) and south (6B) of Malin village (Figure 3). Further, at the eastern toe of the Malin village, levelling and planation has been done in a vast area for cultivation

Figure 1. Oblique view of *Google* 3D image with representatively shown E–W fracture swarms (1) and ENE–WSW fracture valley (2), Malin Area.

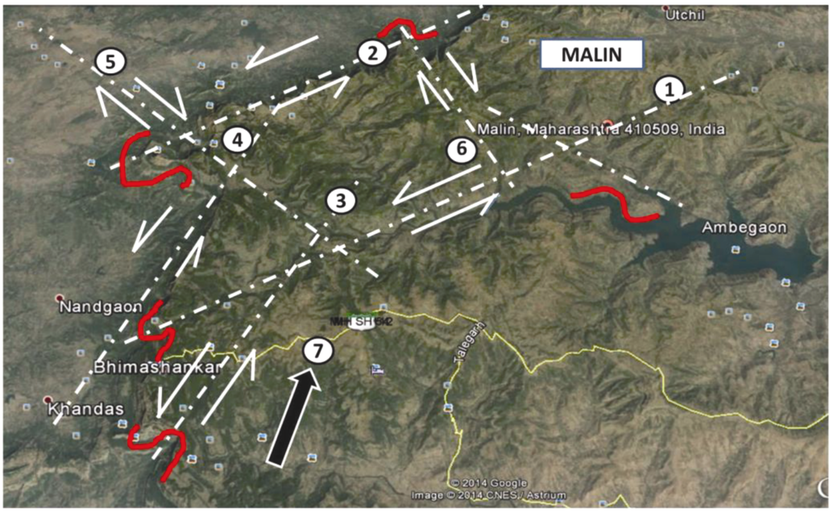

Figure 2. Oblique view of *Google* 3D image showing ENE–WSW (1&2) and NE–SW sinistral faults (3&4), NW–SE dextral faults (5&6), dragging of flows and NNE compressive force, Malin Area.

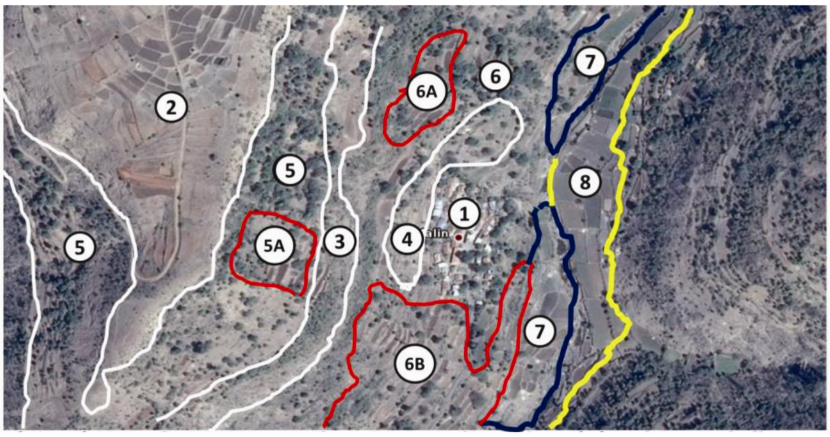

Figure 3. *Google* 3D image showing Malin village (1), cultivated flat flow plain at top of Malin (2), flat flow plains along slopes (3&4), intervened by obsequent vegetated debris slopes (5&6), deforested and bench cultivated obsequent slopes (5A, 6A&6B), levelled foothills along bottom slopes of Malin village (7) and colluvial fills along the drainage (8).

(7, Figure 3). Thus, extensive anthropogenic invasion is taking place in the area in and around Malin village.

Tectonic interpretations of *Google* 3D image showed that the Malin area is bounded on all four sides, in the northwest and southeast by ENE–WSW sinistral faults and in the northeast and southwest by NW–SE dextral faults. Hence, the Malin block must be under the grip of the stresses from the above traverse faults. Further, as these sinistral and dextral faults indicate the possible NNE–SSW compressive force, deformation must be occurring within the Malin block following the wrench fault tectonics[5]. Observations of the local people on the sudden appearance of cracks during 2003 must be related to such deformation only.

Such post-Deccan flows tectonics have been inferred by many, such as E–W cymatogenic arching in Amreli–Narmada area[6], synformal warps and sinistral dragging of beds in Deccan flows due to a set of ENE–WSW sinistral faults in parts of southern Saurashtra[7], regional and local tectonic features along Narmada lineament zone[8], etc.

Among the above, the studies on southern Saurashtra[7] further indicated that such post-Deccan flows tectonics occurs due to the north–northeasterly compressive force, related to drifting of the Indian plate. The post-collision tectonic model developed for the Indian plate[4,9] shows that the north to north–north easterly force which originally drifted the Indian plate is still active and pushing the Indian plate towards northerly directions, but as the Himalayas is obstructing from the north, the Indian plate is whirling with E–W trending alternate arches and deeps, N–S extension fractures, NE–SW sinistral faults and NW–SE dextral faults from Cape Commorin in the south to Himalayas in the north[4,9]. As the tectonics of the Malin area is controlled by similar ENE–WSW to NE–SW sinistral and NW–SE dextral faults, the input of regional tectonics over the Malin area cannot be ruled out.

While such wrench faults related tectonics must be opening up the fractures, the aggressively ongoing anthropogenic activities in the form of deforestion and cultivation in the flow plains, benching and intensive paddy cultivation along the softer obsequent slopes, disturbance of toes in the down slope parts of Malin village and heavy impounding of water in such bench cultivated paddy fields have contributed to the increase of pore pressure resulting in mud flows. Thus, Malin landslides are the cumulative effect of tectonism and anthropogenic activities.

In such tectonically active and anthropogenically invaded Malin area, detailed studies are required on large scale to mitigate landslides, involving (i) Mapping of lineaments using aerial photographs and multidated satellite images bringing out the time series growth and modification of the fractures, (ii) detailed structural mapping, (iii) GPS-based monitoring of the cracks/fractures, (iv) detailed geomorphic mapping, (v) land use/land cover mapping using multidated satellite images, change detection in land use/land cover vis-à-vis rainfall and landslides, (vi) clay mineralogy, (vii) geotechnical investigations, etc. Working out the factor of safety and integration of all would give a viable direction to mitigating landslides in the area.

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Water quality index of estuarine environment

The estuarine environment is characterized by constant churning of freshwater from the river with marine water, which may be challenged by modifications in water quality. Aquatic animals living in such a challenged estuarine environment should be able to match appropriate changes with their physiological requirements. It is observed that estuarine environment is polluted by discharges of domestic sewage and industrial effluents besides other anthropogenic activities including agricultural runoff[1]. These discharges bring considerable amount of pollutants that may cause undesirable changes in the water quality which ultimately cause pollution. Such pollution is a serious threat not only to the aquatic organisms but also to the downstream water users.

Conventionally, pollution status of water resources including estuary can be determined by assessing water quality parameters (WQP) *in situ* and *ex situ*. However, computation of water pollution index (WPI) based on WQP provides relatively precise information on the extent of pollution. The use of WPI is an important tool as it is stretched analysis. Therefore, it has wide applications as the indicator of the quality of sea water[2] and river waters[3–5] as well as drinking water[6]. The water quality of Kollidan estuary[7], Mahi estuary[8,9], Devi estuary[10] and Tapi estuary[11,12] was studied earlier. These studies inferred that these lotic ecosystems are polluted by domestic sewage, industrial effluents and other anthropogenic activities. Further, developmental activities are also reported to affect the riverine, estuarine, coastal and marine environments[13,14].

The WPI is helpful to summarize a large amount of water quality data into simple terms which is one of the most effective ways to communicate information on water quality trends to guide policy makers on effective restoration, conservation and management of water resources. The WPI of Borska Reka river shows increasing organic pollution which results from domestic discharges[15]. Similarly, the coastal environment of Mumbai is affected by local inputs of sewage from drainage, anthropogenic activities and industrial discharges through creeks, rivers and sewage outfall points[16]. Likewise, WQP and pollution index of Danube–Tisa–Danube canal system of Serbia[17] and Woji river, Nigeria[5] were studied and various causes of pollution were underlined.

This study deals with WQP vis-à-vis WPI of Tapi estuary, Gujarat to assess the pollution status which may be helpful to improve the water quality management and policy making to conserve this estuarine ecosystem.

The Tapi estuary is one of the major estuaries of west coast river systems of India and situated at 21°40′N and 72°40′E. Hazira sampling station selected for this study is located on the southern bank of Tapi estuary, which is 8 km away from Surat city (Figure 1).

For the analysis of WQP, the water samples were collected and preserved in pre-rinsed plastic bottles at monthly intervals during January 2011–June 2011. The samples were filtered prior to analysis. Although temperature, pH and dissolved oxygen (DO) were analysed *in situ*, the conductivity, turbidity, nitrate-nitrogen, nitrite-nitrogen, phosphate, biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia, fluoride and chloride were analysed in the Research Laboratory, Department of Aquatic Biology, VNSGU, Surat. For the preservation and analysis of the water samples, the standard methods were followed[18,19].

As WPI represents the sum of the ratio between the observed parameters and regulated standard values, the WPI of Tapi estuary was calculated from the