Disaster, nonlinearity and chaos – An analysis

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An evaluation of disasters in the form of landslides and floods is presented. The study has been carried out in the perspective of nonlinearity, chaos and the complexity of their management. The devastating landslide at Ambootia Tea Estate in the Himalayan Darjeeling District, West Bengal (a vulnerable earthquake zone) which took place in 1966, killing about ten thousand people is discussed in detail and mathematically analysed using the fractal concepts. It is suggested that the Ambootia landslide might be an instance in point when $\|\delta(t)\|$ exceeded *a*, a measure of tolerance that such landslides cannot be predicted longer than a few multiples of $1/\lambda$, where λ is an averaged Liapunov constant.

Keywords: Chaos, disaster, floods, landslide, management, nonlinearity.

DISASTER and emergency situations exemplify the nonlinearity of human events. These are events in which the relationship between relevant variables is churning. Even in our desire to create order and control the situation, events often seem to churn one step ahead of our best efforts. We know that 'Life is… nonlinear. And so is everything else of interest'. Landslides, earthquakes and floods – all are nonlinear events. In this communication, we analyse landslides and floods to bring out the nonlinear chaotic behaviour of a disaster and how the management system has to adopt to mitigate the effects or prevent them, as far as practicable, from happening.

The types of behaviour that the nonlinear systems generate are chaotic. Chaos is one possible result of the nonlinear system dynamics. Chaos is typified by a behaviour that, over time, appears to be at random or in an apparently disorderly manner.

It is this non-average behaviour, the unusual event, the unexpected fluctuation that drives the processes of change. Chaos does, however, occur within definable parameters or mathematical boundaries. When chaos occurs, a nonlinear system does not retrace prior identifiable sequences of behaviour (there is a loss of memory of the initial conditions in chaos) and does not evidence obvious patterns in its behaviour. Chaotic behaviour thus appears extremely disorderly (although chaotic time paths may look random, they are generated by deterministic mathematics). Chaos may be defined as an aperiodic, long-term behaviour in a deterministic system that exhibits sensitive dependence on initial conditions. However, there is an order within chaos, which can be traced by studying the 'attractor' of the system.

Landslides usually take place because of earthquakes, storms and also due to human bungling. In most landslides, the earth itself moves. In the case of earthquakes, the earth behaves in a similar fashion but along the fault. Landslides generally tend to occur in an earthquake (vulnerable) zone. What happens is that the heavy rainfall saturates the ground and the earth begins to give way. The angle of repose is unstabilized and the landslides take place.

Managing disaster epitomizes two aspects of social management: (i) Preventive management (technology is involved), and (ii) Response management (both technology and social aspects are involved).

Morphologically, disaster is again of two types: (a) External – landslides, earthquakes, floods, etc. and (b) Internal – spreading of cholera through bacteria/virus transported by the ocean/sea from other streams or arsenic poisoning of potable groundwater.

When in an emergency, the social structure is threatened, disaster takes place. Also, lack of pre-planning can turn emergency into disasters. One such example is the landslide at Aberfanne, South Wales, UK on 21 October 1966, a man-made disaster which killed a hundred children.

Landslides due to human error are the most unfortunate events threatening the social fabric of a region. At Aberfanne, the landslide was actually initiated by coal-mine waste, dumped by the mine, as a mountain on the side of the local mountain range further up from a flowing stream. The local school was further down the slope crossing the stream. Hundred children were buried under the mine waste, as it slided (the artificial dump) on a morning of heavy fog. The mine waste hit the stream on its way down the slope as it slided (because of an instability in the angle of repose). As soon as it hit the school, the energy was absorbed and the slurry turned into a solid mass again. In fact 144 people, including children were killed, buried under the waste of coal. This reflected the absence of meticulous pre-planning by the National Coal Board, UK.

On 4 January 1982, a storm initiated 18,000 landslides in San Francisco Bay area, which continued for 3 days. In fact, heavy rain saturated the ground and the earth began to give way. In 1966, heavy rainfall initiated the first landslide at Ambootia Tea Estate, Kurseong, Darjeeling District (an earthquake-vulnerable zone), West Bengal and till date recurring landslides during the monsoon season have killed more than ten thousand people.

In 1992, the city of Chicago[1] had a devastating disastrous flood due to a failure in the city's tunnel wall. It was discovered later that a private contractor tried to report the failure (due to a crack), but no city authority responded to it. A crack, that could have been repaired for

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US$ 10,000, finally cost taxpayers, the city and the business an estimated US$ 1.7 billion (op. cit). The nonlinear and explosive effect of a seemingly small crack led to the disaster. This only shows that outcomes of human errors, oversights and even best intentions may later result in real and unexpected surprises.

In the summer of 1993, the Mississippi River had severe floods along its course[2]. For several decades prior to this flooding, the Army Corps of Engineers built a series of levees to protect many riverfront communities (op. cit) and they were considered to be the solution to the local flood problems. The levees, however, also served to change the course of the Mississippi River in many areas. It is now believed that these levees and the decision decades ago to build them, in fact, exacerbated downstream flooding that adversely affected many riverfront communities (op. cit). The apparently simple decisions to help various riverfront populations led to a tangled web of cause-and-effect that over time brought disaster to other communities. The whole disaster is an instance of nonlinear dynamics. It shows that construction of levees is not enough; they have to be checked and monitored from time to time for their structural and locational relationships with the characteristics of the river, which has an inherent nonlinear behaviour.

The lesson is that in an uncertain nonlinear system, a decision taken today may not be valid in future in terms of its quality. A fixed decision (mode locked-in) was taken for an uncertain system. But the behaviour of the river in time–space was not monitored. The situation thus exploded into a real disaster. It is imperative, therefore, to develop the disaster management systems based on instability and variations[3]. A stable management team accepts the problem in a singular perspective and nurtures a rigid view that minimizes possible solution sets. Thus the mode lock-in attitude has to be avoided. The new/replacing members of the unstable teams promote alternative decisions and thus divergent outcomes. Thus, it may be said that the unstable teams represent a more readily adaptive response to changing situations (op. cit). New methods must be evaluated to ensure that a variation in management pattern is practised. Diverse teams should use diverse methods on the same disaster problem by breaking patterns of response in an effort to internalize variation and the potential of learning.

There are other lessons learnt from the above Chicago and Mississippi River disasters[4,5].

(a) One tenet of nonlinear dynamics is that complex systems defy simple formulation and thus may preclude the development of precise mathematical logarithms.
(b) Chaos prevents a stable strategy of problem-solving.
(c) The method of controlling chaos is aimed at altering the orbit of a chaotic system to a more desirable orbit on its attractor. This approach uses continuous tracking and seeks to identify changes in system behaviour that occurs over time. By tracking such changes, alteration of parameters can probably be brought about.

On 5 May 1995, Dallas had a furious flood, which called for a comprehensive review of the Dallas disaster management planning.

Early on 5 May, the weather forecast predicted heavy but seasonally typical spring thunderstorms for the North Central Texas area. These storms often brought tornadoes. The Dallas City Disaster Management Cell immediately devoted disaster resources to prepare for tornado damage and appropriate response. However, torrential rainfall created unexpected levels of flooding. Sixteen citizens lost their lives. Disaster preparedness officials were simply unprepared for this level of flooding, at least in part, due to tornado damage-directed resources.

The misguided planning in Dallas, exemplifies the problem of 'mode lock-in' in a nonlinear dynamic (chaotic) management plan. By locking into system one mode in an early stage, the city created initial conditions, which inhibited flexible response (alternative options) to disaster. This emphasizes the importance of flexible planning and response to disasters. Initial mode lock-in may make alterations in mid-course difficult, particularly if it triggers to alter strategies. In this context, it is interesting to note that the researchers are increasingly becoming critical of the types of models previously used in disaster management planning. Injections of notions of instability, nonlinearity and uncertainty into computer models of social problems and policy options are required. Rugina[6] notes that most modelling efforts are based on mathematics that avoids the uncertainty inherent in real social systems. Traditional modelling thus seeks to generate stable solutions in an unstable world. Therefore, what seems logical is ensuring the availability of a range of adequate responses across a range of potential disaster scenarios.

As mentioned earlier, Ambootia which claims to have a tea estate, suffered a hard-hit landslide during the rains in 1966. The ground gave in because of basically two conditions: (i) Poor maintenance resulting in the thinning-out of thick growth of tea plants and (ii) High use of chemical fertilizers.

Chemical fertilizers are known to loosen the intergranular bond of the soil and the latter becomes loose and friable. In addition, because of the thin growth of the tea plants, the torrential raindrops are not prevented by the leaves from falling directly into the ground and they hit the soil directly. Both the above features triggered the slide and the earth moved, killing thousands of local inhabitants. In the later part of the 20th century when the landslide recurred, the intensity was of a lesser magnitude because by that time the Ambootia Tea Estate had initiated the use of biofertilizers, ignoring chemical ones. The loosening effect of the soil was less and the mass movement, therefore, was of reduced magnitude. This only proved the theory that poor maintenance, the addition of chemical fertilizers and unusual rainfall exacerbated the landslide. The other characteristic feature that the Ambootia landslide presented was that the event took place in pulses or phases with quiescence in between. The two evolutionary functions of chaos have been well brought out by the Ambootia landslide as well as by the sudden flood in Dallas and floods in the Mississippi River Basin. That chaos avoids entrainment or mode lock-in (chaos helps to break the existing moulds) is amply borne out by the events of the Dallas city and the Mississippi River Basin. Moreover, the above three events reveal that chaos allows relevant systems to explore the entire range of behaviour available to them. This is because systems in chaotic phases bounce around the phase space, exploring every possibility for new and alternative behaviour. Uncertainty and unpredictability typical of chaotic periods are thus created. Every point (in the chaotic system) on its trajectory acquires instability. The characteristic of the Ambootia landslide marked by mass movement in pulses with quiescence in between suggested that in the phase plane the attractor bounced within the limits between zero and one. At the centre, when the attractor was at zero, there was a period of calm. But when it moved towards the boundary, it was nearing the position of one, away from zero. At that time the system became unstable and the landslide was initiated. However, it is purposeful to reflect that the system here is chaotic and hence has no possibility of a quasiperiodic behaviour. (The mathematical explanations are entailed in the concluding pages.)

Let us take the Lorenz model[7] as a laboratory model for numerical work on deterministic dissipative chaos and the equations can be described as:

$$\frac{\mathrm{d}x}{\mathrm{d}t} = \sigma(y - x),$$
$$\frac{\mathrm{d}y}{\mathrm{d}t} = rx - y - xz, \qquad (1)$$
$$\frac{\mathrm{d}z}{\mathrm{d}t} = xy - bz,$$

σ, r, $b > 0$ where σ, r, b are parameters. σ is the Prandtl number, r the Rayleigh number and parameter b has no value.

The system (eq. (1)) above has only two nonlinearities – xy and xz – and a symmetry.

Taking any volume $V(t)$ of initial condition $[S(t)]$ (the surface) in phase space, we have a patch of area dA sweeping out a volume $(\vec{f}\cdot\vec{n}\,\mathrm{d}t)\mathrm{d}A$ in time dt.

$$\therefore V(t+\mathrm{d}t) = V(t) + \iint_s (\vec{f}\cdot\vec{n})\mathrm{d}A,$$

and

$$\frac{\mathrm{d}V}{\mathrm{d}t} = \frac{V(t+\mathrm{d}t) - V(t)}{\mathrm{d}t} = \iint_s \vec{f}\cdot\vec{n}\,\mathrm{d}A.$$

Transforming the integral by the Gauss theorem, we get

$$\frac{\mathrm{d}V}{\mathrm{d}t} = \iint_s \nabla\cdot\vec{f}\,\mathrm{d}v, \qquad (2)$$

where ∇ = nabla, an operator. For the Lorenz system,

$$\nabla\cdot\vec{f} = \frac{\delta}{\delta x}\left|\sigma(y-x) + \frac{\delta}{\delta y}\,|\,rx - y - z\,|\, + \frac{\delta}{\delta z}(x'y - bz)\right|$$
$$= -\sigma - 1 - b < 0.$$

Divergence being a constant, eq. (2) reduces to

$$\frac{\mathrm{d}v}{\mathrm{d}t} = -(\sigma + 1 + b)V,$$

giving a solution

$$V(t) = V_0 \cdot \mathrm{e}^{-(\sigma+1+b)t}.$$

The volume in phase space shrinks exponentially fast. Consequently, an enormous solid blob of initial condition eventually shrinks to a limiting set of zero volume. Since the Hausdorff dimension of this volume is greater than the topological dimenion (zero here), the ultimate point on which trajectories end, constitutes what is called a ‘strange attractor’, which is obviously a fractal. The strange attractor is Hausdorff-measurable and has a non-integral Hausdorff dimension.

It can be shown that depending upon the values of the parameters σ, r, b, the limit may be a fixed point, a limit cycle or a strange attractor.

Suppose $x(t)$ is a point in the initial volume of initial condition at time t and consider a nearby point, say $x(t) + \delta(t)$, where δ is a tiny separation vector of initial length $||\delta_x|| = 10^{-15}$.

In numerical studies of the Lorenz attractor, one finds that

$$||\delta(t)|| \sim ||\varepsilon_0||\mathrm{e}^{\lambda t},$$

where λ, the Liapunov exponent = 0.9 and its value varies along the attractor.

The exponential divergence must stop when the above tiny separation is comparable to the diameter of the attractor – obviously the trajectories cannot get any further than that.

There are n Liapunov exponents of an n-dimensional system.

Considering a small perturbation of an n-sphere of initial conditions, this dynamics will lead to an n-dimensional ellipsoid with n major axes defining the n-Liapunov constant.

Let $\delta_k(t)$ $[k = 1, 2, \ldots, n]$ be the kth principal axis of the ellipsoid. Then,

$$\delta_k(t) \sim \delta_k(0)\mathrm{e}^{\lambda}k^t.$$

λ_k $(k = 1, 2, \ldots, n)$ are the Liapunov exponents.

λ depends slightly on the trajectory under focus. We then have to average over many different points on the same trajectory to get a true value of λ. After a time t, the discrepancy grows to

$$||\lambda(t)|| = ||\lambda_0||e^{\lambda t}.$$

Let a be the measure of our tolerance, i.e. if a prediction is within a of the true state, we consider it acceptable. Then our predictions become intolerable when

$||\delta(t)|| \geq a$, occurring at a time

$$t_{\text{horizon}} \sim 0\left(\frac{1}{\lambda}\ln\frac{a}{||\lambda_0||}\right).$$

Thus the landslide in the Ambootia Tea Estate may be an instance in point when

$||\delta(t)||$ became $> a$.

No matter how hard we work to reduce the errors in the initial measurement, we cannot predict the occurrence of the landslide at Ambootia longer than a few multiples of $1/\lambda$. It might explain the apparent regularity in the landslides of Ambootia. Obviously computer-aided analyses of the database collected would help enumerate the exact multiple of $1/\lambda$. The exercise has to be repeated every time after the landslide takes place. From the management point of view, therefore, the disaster management team may have enough time to prepare for the proposed response system to save human life and prevent other damages as much as possible.

Finally, it is pertinent to point out with reference to the model used, that the system discussed above being dissipative ($V_t = V_0 e^{-(\sigma+1+b)t}$), any phase volume will exponentially shrink fast. Quasiperiodicity is possible only on the phase space of a torus.

$$d\theta_1/dt = f_1(\theta_1, \theta_2),$$

$$d\theta_2/dt = f_2(\theta_1, \theta_2),$$

where f_1 and f_2 are periodic in both the arguments.

(A torus will be given by a simple model of a coupled oscillator:

$$d\theta_1/dt = w_1 + K_1\sin(\theta_2 - \theta_1),$$

$$d\theta_2/dt = w_2 + K_2\sin(\theta_1 - \theta_2),$$

where the symbols have the obvious meanings.)

The volume of the torus in a dissipative system will eventually become zero and quasiperiodicity is thus impossible.

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Fossil pteropods (Thecosomata, holoplanktonic Mollusca) from the Eocene of Assam–Arakan Basin, northeastern India

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A small collection of fossil pteropods, including some unidentified species, provisionally referable to the families Limacinidae, Creseidae, and Clioidae (?) is reported from the late Middle Eocene–Late Eocene beds of the Upper Disang Formation exposed near the town of Pfutsero, Phek District, South Central Nagaland (Assam–Arakan Basin, northeastern India). This is the first record of fossil pteropods from this part of India. Although based exclusively on juvenile or incompletely preserved adult shells, documentation of this collection is important from the viewpoint of biostratigraphy as well as palaeoecology. The occurrence of pteropods in the Upper Disang Formation indicates deposition in an open marine basin above the aragonite compensation depth. The combined assemblages of pteropods and previously reported uvigerinid foraminifers from the Upper Disang Formation indicate a palaeobathymetry of ~500 m, i.e. upper bathyal zone, and a tropical–subtropical climate.

Keywords: Assam–Arakan Basin, Disang Group, Eocene, Mollusca, pteropoda.

PTEROPODS or holoplanktonic gastropods (Mollusca), commonly referred to as sea-butterflies because of their parapodia, resembling wings or fins, are an extant group

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