Mountain tunnelling, aquifer and tectonics – a case study of Gran Sasso and its implications for the India-based Neutrino Observatory

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The India-based Neutrino Observatory Collaboration is about to construct an underground laboratory in the Western Ghats within the Idukki–Theni charnockyte aquifer. There are several dams quite close to the structure and the area is prone to hydroseismicity. No geotechnical study has been conducted for this project. A similar observatory in Gran Sasso, Italy, built three decades ago has caused floods and severely impacted the aquifer, leading to a series of tremors and a major earthquake in 2009. The long-term impacts of the project on the aquifer and the reservoirs should be examined before going ahead with the construction.

The India-based Neutrino Observatory (INO) is a proposed underground facility for conducting research in particle physics and other frontier areas of science. According to the promoters, it will be located in Theni district (77°17′5.32″E, 9°56′46.20″N) of Tamil Nadu (TN), bordering the Idukki district of Kerala. It will house a 50,000 tonne magnetized iron neutrino detector (MIND) for detection of neutrinos from the atmosphere and from neutrino factories expected to come up by the end of this decade in USA, Europe and Japan. With a finished volume of 236,000 m^3, INO will be the biggest underground particle physics laboratory in the world, dwarfing the present one – the 180,000 m^3 Gran Sasso National Laboratory (LNGS) in Italy. About 800 k tonnes of rock will be blasted out in 800 days, using about 1000 tonnes of gelatin – all in an area less than half a square kilometre. The project worth Rs 13.5 billion, is part of the mega science projects approved for the XII Five-Year Plan.

The site and the stakeholders

The proposed site is in the Idukki–Theni charnockyte aquifer (ITCA) with an area of about 4500 km^2. The annual replenishable recharge is 10–28 cm for the Theni portion. This aquifer and the surface waterbodies feed three river systems – Periyar, Vaigai and Vaippar. Idukki district, the water capital for six districts of Kerala and TN, has 12 dams storing 5 billion m^3 of water, all within a radius of 50 km from the proposed site. The Idukki Dam on the Periyar River, one of the highest (169 m) arch dams in Asia, is located 30 km from the proposed site. The 110-year-old Mullaperiyar dam, from which the INO will be drawing 400 m^3 of water daily, is at a distance of 50 km from the site. As the hydroelectric projects on these dams account for about two-thirds of the electricity generated in Kerala, more than 50 million people in the two states have a stake in the waters of Idukki.

Aquifer characteristics

The Aquifer mapping report for TN warns that ‘the unscientific development by the affluent is a matter of concern wherein the government has to go in for groundwater governance for protecting the rights of everyone’[1]. A Government of Kerala study cautions that ‘as the potential fracture zones are encountered at shallow depths, drilling should not go beyond a depth of 100 m[2]’. Uthamapalayam, Devikulam and Udumbanchola taluks (sub-districts) which form the core of the ITCA and share the boundaries with INO have been classified as ‘critical’ by the Central Ground Water Board[2,3]. These taluks have also been listed as ‘ecologically sensitive zone 1’ by the Western Ghats Ecology Expert Panel[4].

Seismicity

According to Rajendran *et al.*[5], Idukki reservoir ‘is among the few in India that has a preimpoundment record of the background seismicity’ and is ‘listed as one of the 53 known global examples of reservoir-triggered seismicity... Starting July 2011 microtremors were felt in the area and the sequence included at least three earthquakes of magnitude $M_L \geq 3.0$ and 20 tremors were recorded until November 2011’. They conclude that ‘the recent activity in the vicinity of the reservoir is unusual’[5]. Downstream the dam, people live in fear of a dam break, which has the potential of altering the geography of three districts in Kerala. The proposed site is only 10 km away from Nedumkandam, the epicentre of the 1988 *M* 4.8 earthquake. A 2009 document from INO[6] shows the proposed site in seismic zone 3, but now it is stated[7] to be in zone 2.

Impact on aquifer

Mountain tunnelling is known to disturb the aquifers, the classic example being the LNGS in the Abruzzio Province, Italy, which has been built on the side of a 10 km road tunnel. Both LNGS and INO are located on beautiful mountain ranges rich in biodiversity and water resources. Rainfall at Gran Sasso is 2000 mm/year, as against 3500 mm/year in Idukki. INO will be blasted out from the charnockite rock, while LNGS sitting in a limestone formation was carved out using a boring machine. Abruzzio is a ‘water-surplus’ region with only a million stakeholders, as against 50 million in the case of ITCA.

The Gran Sasso experience

At Gran Sasso, the warning by ecologists that the proposed LNGS site was close to ‘two major and highly active seismic faults and that the construction would interfere with a major aquifer’[8], was proven true in less than six years after beginning the construction. Paul G. Marinos[9] of the National Technical University of Athens narrates the impact thus: ‘one of the tunnels came upon a thrust fault with a heavily sheared zone 25 m of thickness... . An inrush of 900 liters per second (l/s) lasted for 5 days until the real discharge of the faulted zone occurred with 4,000 l/s–6,000 l/s and a peak of 20,000 l/s (!) filling. Additionally, the tunnel was inundated with more than 30,000 m^3 of debris'. Besides killing seven workers, this accident also flooded the nearby villages. The work was called-off for many months. According to the Abruzzio Social Forum, the aquifer level dropped from 1600 m MSL in 1968 to 1060 m MSL in 1990 (ref. 10). Water still leaks from the complex and the drainage now is '1500 l/s (or about 50 million m^3 per year)'[11]. The LNGS website mentions that 'a considerable part of rock waters, which drip from the laboratory's walls are not drinkable and is drained into the Vomano river'[12]. Fermilab's *Symmetry Magazine* quotes from a 2005 study by Italian university geologists: 'tunnels, although being built for different uses, may drain groundwater even after completion of their lining. In some instances, it is extremely difficult or impracticable to restore the original hydrodynamic equilibrium, with consequent risks of exhaustion of springs, change in the relations with adjacent hydro-geological structures, depletion of groundwater reserves, etc. Tunnel construction also can alter water supply for drinking, irrigation and industrial uses, *with major economic and social repercussions on wide neighboring areas*[13]' (emphasis added).

Aquifer anomalies causing earthquakes

The flood, loss of human lives and aquifer deformation were only the beginning of a series of Earth events that would shock the Italian Province. It seems that the fault lines that were quiescent for four centuries have been reactivated. According to Bella *et al.*[14], 'the analysis of the seismicity ($M > 3.0$) in the Gran Sasso area from 1956 to 1995 suggests that after the tunnelling works, not only has the number of earthquakes increased but the epicentres have migrated, gathering at the NW border zone. The foremost events which occurred in this zone in recent years took place on 5 May 1992 (M 3.1). The flow rate data of four springs and water level data of an underground karst pool located at the border of the carbonate structure of the massif show clear anomalies before the occurrence of the earthquakes'. Tremors continued to rock the region and finally the now infamous L'Aquila earthquake swarms began in November 2008 and culminated in the M 6.3 event of 6 April 2009, which killed 309 people and destroyed several buildings. Until 31 May 2009, more than 6500 events with magnitudes greater than 1.0 with depths between 6 and 20 km were recorded[15] in the region lying between 42.00–42.75°N lat. and 12.75–13.75°E long.

Earthquakes damaging the aquifer

The L'Aquila earthquake of 6 April 2009 caused significant changes in the hydrogeology of the fractured aquifer leading to: (a) the sudden disappearance of some springs, (b) an immediate increase in the discharge of the drainages of other springs and (c) a progressive increase of the water table elevation at the boundary of the aquifer. Antonella *et al.*[16] proposed a conceptual model of the consequences of the earthquake on the aquifer in which 'the short-term hydrologic effects registered immediately after the main shock are determined to have been caused by a pore pressure increase related to aquifer deformation. Mid-term effects observed in the months following the main shock suggest that there was a change in groundwater hydrodynamics. Supplementary groundwater that flows towards aquifer boundaries and springs in discharge areas reflects a possible increase in hydraulic conductivity in the recharge area, near the earthquake fault zone. Simulations by numerical modelling show results in accordance with observed field data, supporting the conceptual model and confirming the processes that influenced *the answer of the Gran Sasso aquifer to the L'Aquila earthquake*'[16]. (emphasis added). In short, the vicious circle is complete.

Aquifer effect at Gran Sasso is not a freak event, caused by some localized anomalies. According to Ugo and Castaldi[17], 'the presence of aquifers is one of the most important problems to be addressed when planning and excavating tunnels. When a tunnel interferes with groundwater, serious problems can arise during the excavation because of water flow, and at the same time, water is drained, which means this resource is lost. Thus, forecasting the drained discharges represents a primary aspect of designing tunnels and subsurface works. In fact the construction of tunnels often conflicts with environmental issues and the interests of populations living in the territory.'

Seismicity during construction

Explosions for constructing the tunnels and caves can also induce earthquakes. Every working day, the United States Geological Survey (USGS)[18] records ~ 50 explosion-induced tremors and the USGS website has a separate account of such events. Nearer home in the Kolar Gold Fields, Karnataka, Srinivasan *et al.*[19] used '100 typical strong motion accelerograms of rockbursts and computed the maximum magnitude to be 4.29'. According to the rapid environmental impact assessment (EIA) of INO conducted by the Salim Ali Centre for Ornithology and Natural History (SACON): 'blasting is known to cause vibrations and *serious damage* to close-by landscape and may have impact on the geological make-up/formation in the surroundings, a subject not under the scope of the present report'[20].

Lack of transparency

The selection of the present site was done without conducting any geo-technical study. 'According to the scientists, a detailed survey by the GSI would take 4–5 months.'[21] The project received final approval from the Government of India in July 2011; nothing has been done at the site during the past 17 months. The EIA focused on impact of construction on the wildlife and even that report was finalized four months after the public hearing. The EIA team did not conduct any field work in the Kerala portion of the study area measuring about 30 km^2, 'as the permission to study the protected areas was obtained by the INO only from the Tamil Nadu forest department'[20]. INO says that 'it *may be* true that the State of Kerala has not been officially informed, however, the project has been *enthusiastically* publicized by local media in the neighboring district of Idukki in Kerala'[22]. Babu Joseph (former Vice-Chancellor of the Cochin University for Science and Technology (CUSAT)) and his colleagues Girija Vallabhan and Moncy John (Breakthrough Science Society) expressed concerns about 'the secrecy over the setting up of the underground lab ... and the suitability of the ecologically fragile Western Ghats region. INO project had so many loose ends and called for transparency'[23,24].

Alternative sites

The INO is the first major construction project in India which enlisted the services of the GSI for its site selection. GSI zeroed in on two sites, one in the Nilgiris in TN and the other in Darjeeling in West Bengal. INO had also considered two other sites – one on the side of a road tunnel in Himachal Pradesh and the other in the Kolar Gold Fields, which housed a laboratory till 1990, where the first atmospheric neutrinos were detected in 1965. As the Nilgiri site was unavailable due to its proximity to the Mudumalai tiger sanctuary, the logical next step was to move to one of the above sites. Using an existing road tunnel or a used mine will be a better option, as this can save about 40% of the cost (over Rs 5 billion), besides avoiding the violence in blasting out and managing huge quantities of rock debris. INO has not stated the reasons for foregoing the other options.

Conclusion

Even though basic science is absolutely necessary for progress of the nation, science research should not be at the cost of lives and livelihoods of people. The Earth is a 'living planet' with acupuncture points and Idukki is one among them. In a big country like India, finding a safe site for this important project in an area with low population density and less vulnerability should not be a problem. If, however, the promoters insist on the present site, all the safety-related studies must be undertaken and a fresh mandate has to be obtained from all the stakeholders.

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ACKNOWLEDGEMENTS. We thank Dr Sreekumar, National Institute of Technology, Karnataka, Surathkal for useful comments, K. Sahadevan, Institute for Total Revolution, Vedchi, Gujarat and Joseph Mathew, Standout IT Solutions Pvt Ltd, Technopark, Trivandrum for support and encouragement.

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