

Environmental Geosciences and Engineering Survey for Territory Protection and Population Safety



CONTENTS

DELEGATE PAPERS

Moscow, 6-8. 09. 2011

**International conference
EngeoPro-2011**



1. ENDOGENOUS GEOHAZARDS AND ENGINEERING PROTECTION

TOHOKU 11-3-11: A MEGA-NATECH

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Abstract: *The 11-3-11 Mw=9.0 earthquake NE off Japan triggered a tsunami hitting eastern Honshu, sweeping away industrial, urban and agricultural zones. High seismic hazard met high vulnerability (investment and development) exceeding the high capacity of Japan. Types of hazardous released emissions call for long-term treatment issues. It is a NaTech so complex that it is very difficult to assess the risks of the synergistic/antagonistic action of pollutants in a variety of environments.*

1. Introduction

On 11 March 2011, the Tectonic boundary between Pacific and Eurasian plate, off the coast of NE Japan, ruptured in a great (Mw=9.0) earthquake, at 05:46:23 UTC (Universal Time Coordinated), 14:46:23 JST (Japan Standard Time) [6, 16]. The hypocenter is calculated at a depth of 32km by JMA and 24 km by USGS. CMT analysis showed a reverse fault type with WNW-ESE compressional axis, corresponding to depth and orientation of the Japan Trench. The size of the main fault is estimated at 450km length and 150km width, confirmed by first day aftershock locations. The main shock triggered a major tsunami that swept the Eastern shoreline of Honshu (main island) [3].

2. Environmental Impact of the Tohoku Disaster

Numerous technological accidents, each of which, having it not been for this major event, would have made it to the front pages of the news, occurred and went off in silence, as whole zones of urban, agricultural and industry development were swept away by the tsunami.

Many coastal zones of Kanto and especially Tohoku regions suffered both the highest earthquake intensities, namely >6- in the JMA scale [6]. Tohoku was also hit by tsunami intensities ranging in the worst cases from IX up to XI (or even XII) in the Papadopoulos-Imamura scale [10]. That is, in the worst of cases (XII intensity tsunami) all masonry buildings were demolished, while from XI intensity up, floodwater backwash has drifted all debris, cars and other objects to the sea, or accumulated objects of all sizes as simple sediment into low lying coastal areas with obstacles such as embankments, hills, forested areas, elevated roads etc, or into newly subsided areas below sea level. Draft measurements along the low lying areas showed numerous debris accumulation sites sizing from 1.000 to 500.000 m², corresponding to average volumes of raw debris concentration of 1.000 to roughly more than 1.000.000 m³ per site (Fig. 1, 2). In these sites, the average composition of unprocessed urban solid waste was accumulated, along with all building materials from the tsunami hit area [7].

A major difference between the aftermath of the Indian Ocean tsunami in Indonesia 2004 [11, 12] and the Tohoku tsunami, is mainly due to the different level of development in the hit areas. As expected, the number of deaths was multiple in Sumatra in comparison to Japan and the economic impact is reversely proportional. However, this is directly related to the environmental impact in the compared areas, once the level of development of Japan had posed at risk highly evolved industry and technology, as much as a consumer society using more complex and hazardous materials [4], which can be easily shown by comparing the composition of urban solid waste [9, 15] (Fig. 3). As a result, larger quantities of more hazardous and toxic substances were released in the Tohoku disaster, than in Indonesia.

At the same time, seismic fires hit not only constructions on site, such as industry, houses warehouses, ports etc. but also the floating mixture of debris and fuel leaks.

As a result, all types and phases of emissions hazardous for the environment have been released to land and sea, especially in the areas of Miyagi, Fukushima and Iwate prefectures, and secondarily to Chiba and Tokyo, inevitably following all pollution pathways through floodwater, air, surface water and groundwater.

The main source of direct deposition on land is the debris consisting of building materials including

metals, asbestos etc, organics, metals, paper, plastic, fuel, medicines, corpses, sludge etc. Direct disposal may release toxic metals such as Cd, Hg, As, Zn, dioxins, aldehyde and formaldehyde into soil and aquifers [2]. This happened in almost all areas hit by high shock intensity and high tsunami inundation, in the coastal zones of Iwate, Miyagi, Fukushima and Ibaraki prefectures [8].

Combustion of floating household and building debris and burning of fuel leaks or stored raw material and industrial installations are the main sources of pollutants direct release into the atmosphere. In these cases there was definitely release of PAHs, heavy metal vapors, dioxins from combustion of crude oil, plastics and petrochemicals in general. For example, fire at Cosmo Refinery, Chiba and at JX Nippon Oil & Energy, Sendai, fire on floating debris during backwash in Sendai, fires at Shiogama bay and Hitachi port, etc.

Surface water along the coastal zone and sea water was primarily affected by backwash, while groundwater was certainly affected soon after. Backwash was full of household and industrial debris, while there were also sewage system failures. As a result, industrial waste, raw sewage, household hazardous waste, detergents, pesticides, heavy metals, toxic chemicals (persistent organic pollutants, solvents etc) were washed along the tsunami affected zone. Another issue, rather of secondary importance at this time but a long term concern for the locals will be the issue of salinization of coastal aquifers due to saline floodwater. Backwash over agricultural areas (phosphates, nitrates, organics etc) also carried along sums of pollutants. The large number of ports hit by the tsunami and/or fires, resulted at a direct disposal of pollutants into the ocean, through stored or combusted products and waste, as it happened in Hachinote, Kuji, Kamaishi, Ofunato, Ishinomaki, Sendai, Shiogama, Hitachi etc.



Fig. 1. Minamisoma coastal area (Fukushima prefecture). Total erosion of shoreline, total deforestation of vegetation in low lying area, submergence of low lying cultivated area into a lagoon-like form, functioning as a retention pond for water backwash after the tsunami. Debris accumulated behind the road embankment and into the newly formed lagoon. Treatment Plant in nearby industry is devastated, as much as the tanks which may also have been set on fire during the disaster.



Fig. 2. Namie coastal area before and after the tsunami. Areas in yellow (before) depict settlements. Areas in red (after) depict debris concentration and areas in green depict spread of sea pollution plume.

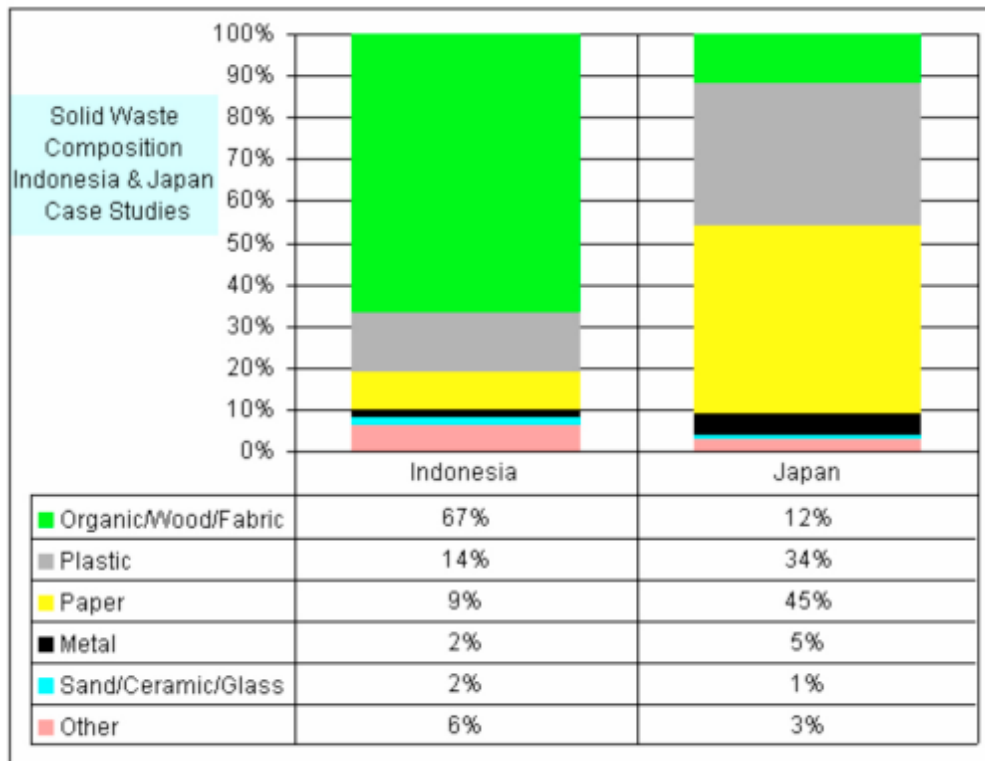


Fig. 3. Urban solid waste composition in Indonesia and Japan. Japanese waste contains less organics and larger amounts of paper, plastic, metals, etc .

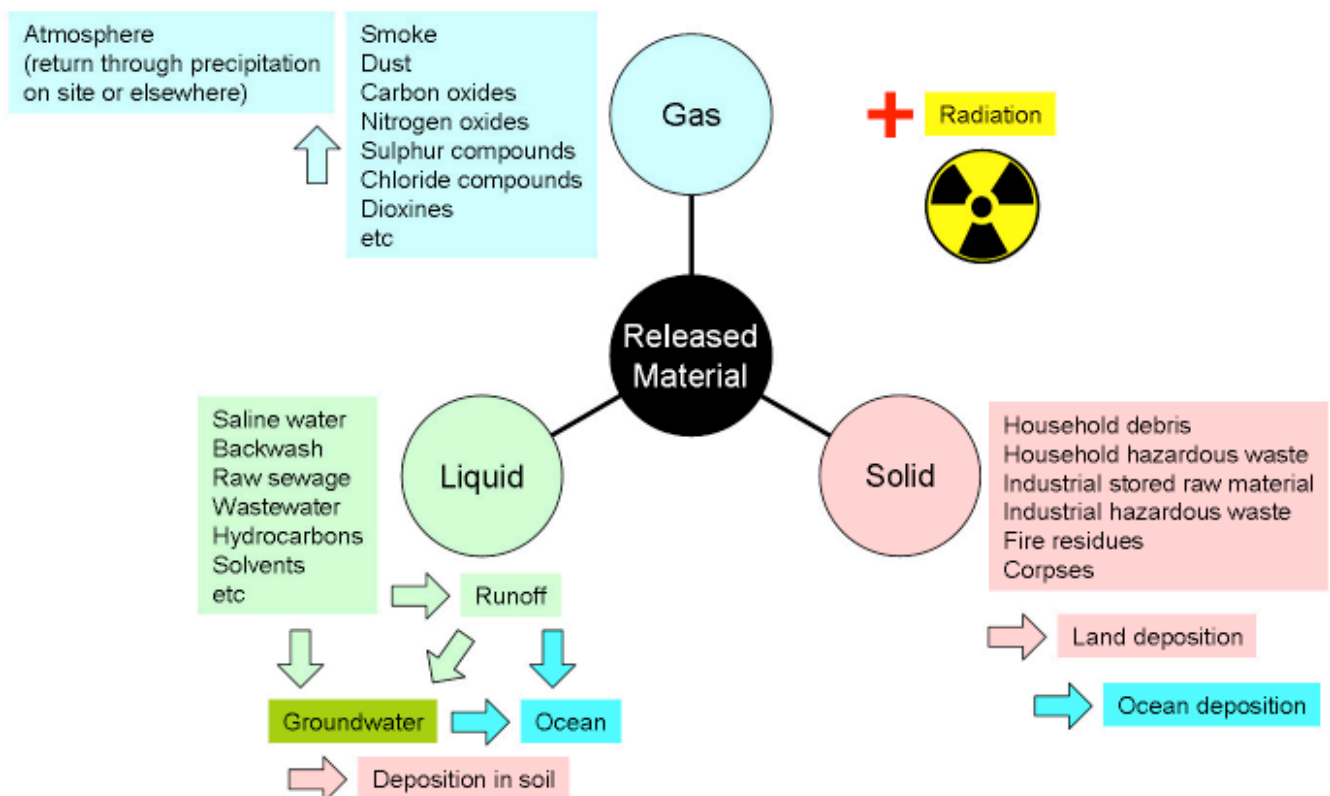


Fig. 4. This is definitely the most complex NaTech of all times. All sectors of human activity were turned into waste in a few hours over a large zone along Tohoku Pacific coast, either directly, or after combustion. All kinds of pollutants, otherwise inconceivable to dispose of without prior processing and strict measures, were released as raw unprocessed waste and dispersed randomly into the atmosphere, land, surface water and groundwater and into the ocean. Radioactive pollution is a major technological and environmental disaster on its own.

3. Radiation contamination

Following the March 11 earthquake, the tsunami hit the 6-reactors of Fukushima Daiichi nuclear power plant and cut the supply of off-site power to the Fukushima Daiichi nuclear power plant. Diesel generators, intended to provide back-up electricity to the plant's cooling system were also disabled by tsunami flooding. 4 out of 6 reactors had suffered damage to their cooling systems and the pressure was rising inside the reactors' containments. A series of hydrogen explosions, fires and smoke were reported and, despite heroic efforts to resolve the nuclear crisis, contamination in food products, surface, drinking water, and soil was detected. This resulted in restrictions at drinking water consumption for infants in Fukushima, Ibaraki and Tokyo Prefectures and, later, the restriction was delimited in Fukushima as levels dropped.

Radionuclides were present at water in 8 Prefectures in total. Food contamination spread in 6 Prefectures (Fukushima, Gunma, Ibaraki, Niigata, Tochigi and Yamagata), after I-131, Cs-134, and Cs-137 radionuclides were detected. Beta-gamma contamination was measured at high level 16-58km from the plant at 2-160 μ Sv/h compared to a natural level of 0.1 μ Sv/h and showed increased levels even 200km away. Seawater contamination was reported also, as offshore levels reached 50000 Bq/l of I-131, 7200 Bq/l of Cs-137, 7000 Bq/l of Cs-134 with other short lived radionuclides being measured as well. Soil samples from Daiichi NPP confirm contamination from Pu-239/240 5/5 and Pu-238 at 2/5 samples respectively [14]. On April 12th, IAEA [5] confirmed that NISA has submitted a provisional INES Level 7 rating for the accident at Daiichi NPP, revised from separate provisional INES Level 5 to 3 reactors, considering the accidents at Units 1-3 as a single event.

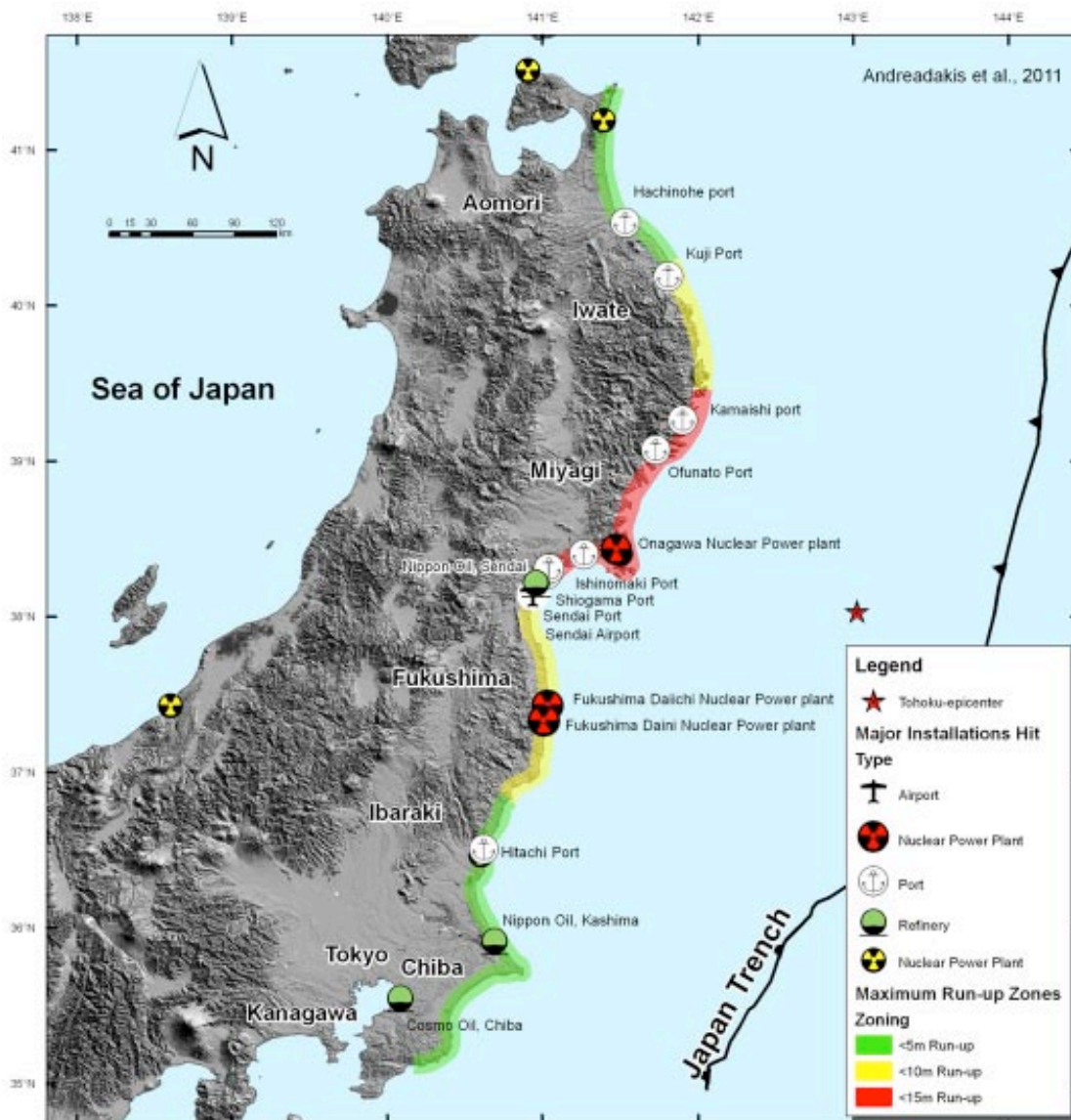


Fig. 5. Map indicating major hit installations along the coast of Honshu.



Run-up zones after Lekkas et al. 2011 [8]

Fig. 6. Floating debris on fire during the tsunami backwash in Sendai, Miyagi (left) and burnt debris (houses, cars, etc) in Otsuchi, Iwate (right)



Fig. 7. Oil leak from Nippon Oil refinery in Shiogama bay, Miyagi (left) and fuel on backwash water at Sendai, Miyagi (right)

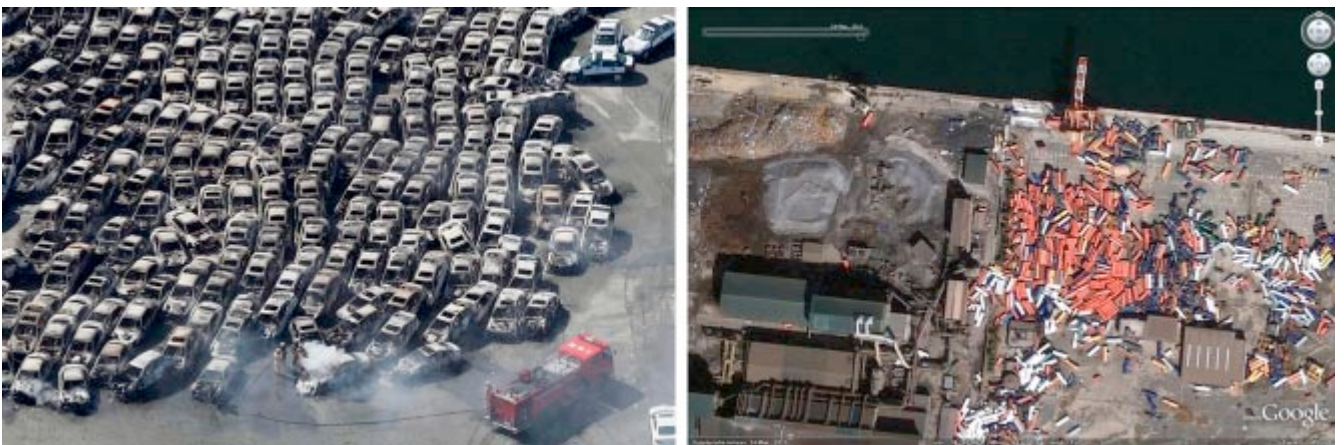


Fig. 8. Combusted cars at Hitachi port, Ibaraki (left) and containers, scrap, slag and incineration residues other raw at Sendai port, Miyagi (right)

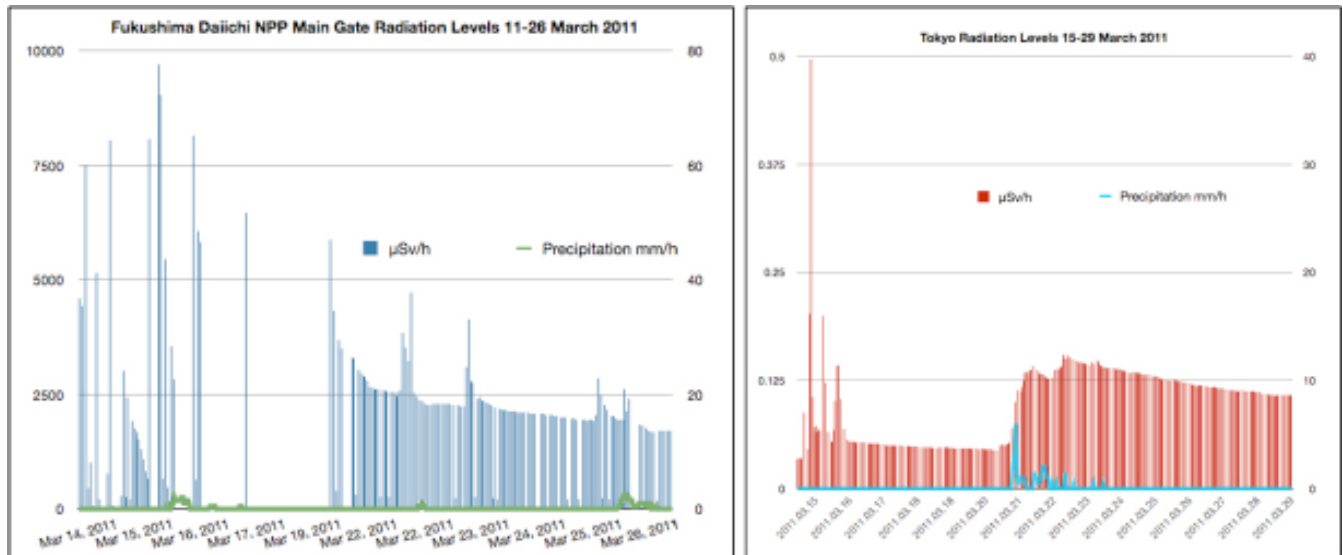


Fig. 9. Radiation levels at Fukushima Daiichi 11-26 March 2011 (left) and at Tokyo, 15-29 March 2011. The increase of radiation levels in Tokyo are quite noticeably related to precipitation in the area [6, 13].

4. Challenges for recovery and rehabilitation

After the initial phase of crisis management during emergency response, and the efforts for relief and recovery, life cannot go on with “business as usual” in the areas hit by the environmental disaster. In order to achieve rehabilitation and redevelopment in the contaminated areas, a long term and large scale program of environmental monitoring and recovery should take place. All leaks have to be plugged, in levies, sewage networks, etc. Debris should be cleared away and be disposed of, in adequate and appropriate settings, for one more reason. Land filling at this scale should affect land use zoning, even if all other environmental factors had remained intact. The example of the San Francisco earthquakes of 1906 and 1986 showed that a seismic event posterior to a major destructive earthquake, primarily affects all buildings founded on the area filled by the debris of the prior event.

The total mass of building debris accumulated in 3 hardest hit prefectures (Fukushima, Miyagi and Iwate) is estimated to 24.9 million tons by the Ministry of Environment of Japan, (16 million tons at Miyagi, 6 million tons at Iwate and 2.9 million tons at Fukushima), which is 1.7 times the wreckage created by the Great Hanshin Earthquake in 1995. This estimation does not include vehicles and vessels. Parks and athletic fields are planned to initially and temporarily receive large amounts of building debris, and incineration and land reclamation are planned to be the final outcome. This would mean that these sites will be turned to disposal sites, with overwhelming environmental pressure, but, desperate circumstances call for desperate measures. However, a long term solution should be soon applied.

Long term issues, such as treatment of contaminated soil and groundwater, removal of contaminated sediment have to be addressed, as much as the issues of widespreading of harbour mold and viri (viruses) also in non destructed and otherwise habitable buildings. Sand and dust contaminated with pathogenic vibrio species and fecal indicators have to be removed and disposed of, creating an additional problem of space.

It has to be noted that Japan is not new to environmental disasters, not even nuclear related ones, apart from the WWII bombing of Hiroshima and Nagasaki. Serious events, with severe impact on public health, have been recorded from the second half of 20th century till today. Itai Itai disease was caused by cadmium poisoning in Toyama prefecture, that occurred in Japan due to mining for lead, copper and zinc, from the 1910s to 1946. Contaminated water entered into Jintsu River, which was harvested for fish and used for rice field irrigation, drinking water and washing. Chisso-Minamata disease, a lethal neurological syndrome caused by methyl-mercury poisoning, was first discovered in Minamata in 1956. It was due to wastewater from plastic production in the Chisso Corporation chemical factory, and mercury entered the food chain through shellfish and fish, ending up to the local inhabitants. Yusho disease (in Kyushu, 1968) was an incident of mass poisoning caused by PCBs and PCDFs contaminating rice bran oil, which was used by poultry farmers as a food supplement and by consumers for cooking.

5. Conclusions

Two years after Katrina and five years after 9/11, experts in the USA (EPA 2007) stated that even if the environmental and public health risks of complex disasters can be assessed for the majority of environmental hazards one by one, it is very difficult to assess the risks imposed by the synergistic or antagonistic action of pollutants within the hydrosphere, atmosphere and biosphere, in a variety of environments from house and urban to wetlands or open sea/ocean. While rapid and short term effects can be directly observed, slower and long term processes are difficult to monitor closely, even by long term measurement and study projects.

Although the disaster of March 2011 that hit Tohoku region of Honshu Island, Japan, was the result of a disastrous mega-earthquake, the following tsunami that inundated a large part of the east coastal area, created a technological and environmental disaster that hardly resembles the Indonesia tsunami aftermath of Christmas 2004, although their physical characteristics were similar. The development type of the area and the volume of investment in so-called “Superfund” sites, such as the industry parks of Japan, make it incomparable to the latter. In fact, the only precedent disaster that could be counted as analogous to what happened in Japan, in the sense of inundation of highly developed urban and industrial areas, is the disaster of hurricane Katrina in 2005 in the Gulf of Mexico, for the area of Louisiana, USA. Again, the presence of a nuclear accident in Japan makes it out of proportion in comparison to what Katrina caused to New Orleans, but, even if it weren't for the Fukushima nuclear power plant, this would have probably been the most severe environmental disaster ever.

What really matches a rough description of what happened in Japan is a combination of Indonesia 2004, Katrina 2005 and Chernobyl 1986. To make a long story short, mega-Natural Disasters (i.e. mega-earthquakes) can cause mega-NaTechs, when they directly affect highly developed areas, no matter the level of pre-disaster planning and readiness. And, while apparently the financial cost of natural disasters and number of victims (especially deaths) are reversely proportional among developed and developing countries, it is now more evident than ever that, full scale development on highly hazardous areas generates environmental risks that societies will hardly be ready for, even on the highest level of public awareness. This is a well known principal among disaster managers ($\text{Risk} = \text{Hazard} \times \text{Vulnerability} / \text{Capacity}$) [1]. In the case of Japan, it seems that maximum hazard (most seismically active area in the world) and maximum investment and complex development (vulnerability) overwhelmed the high levels of capacity that were realized through readiness, public awareness, pre-disaster planning and early warning.

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MUTUALLY INDUCED SEISMICITY. PROPERTIES AND REGULARITIES

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Abstract: *The paper considers mutually induced seismicity from two perspectives: as a natural phenomenon and as a consequence of artificial interference with seismic processes. The study has produced new data about the properties and regularities of induced seismicity that can be helpful in forecasting hazardous natural phenomena and disasters.*

The seismic activity of the Earth is a natural process. If we assume that an actual earthquake induces a series of the subsequent ones and analyze the frequency-time spectrum of 4–5M earthquakes (the number of earthquakes that occurred within a certain period), we will see that the spectrum resembles a human electrocardiogram, only with a pulse rate of 1.8–2.2 day. The ‘pulse’ is slightly disturbed due to changing lunar phases and, in particular, new moon and full moon (Figure1).

Mutually induced seismicity is a natural consequence of the transformation of external and internal physical processes occurring on the Earth. The change of the time intervals between the peaks of seismic activity, 1.8 and 2.2 days, is the result of the effect of gravitational forces induced by the changing position of the Moon. By analogy with the heart-beat-initiated pulse wave, these peaks may imply that an earthquake or an explosion generates an earthquake activation wave that travels round the Earth and comes again to its epicenter in 1.8 or 2.2 days. Hence, the speed of such wave is 770 to 940 km per hour. This is close to the speed of a tsunami arising in the ocean, and can serve as its visualization.

An analysis of the time intervals and frequency distributions of earthquakes of 5 M and above (3240 earthquakes) showed that:

the frequency-time spectrum had sharp stable peaks with an amplitude attenuating for about 30 days according to $e^{-0.4\sqrt{x}}$;

the between-peak time intervals were 1.8 or 2.2 days and alternated successively for up to 24 days [1, 2].

Changes in solar activity and non-uniform rotation of the Earth can disturb the ‘pulse’ and thus increase the seismic activity and cause catastrophic earthquakes [3, 4]. There emerge variable 3D-wave fields, of various physical natures, that can trigger hazardous processes in the atmosphere, hydrosphere and lithosphere. Within a week of an earthquake of above 5M, there is a rise in the rates of mine explosions, flight accidents, power line failures (Figures 2 and 3) [5].

Analysis of the frequency distribution of the subsequent earthquakes by distance from the epicenter of each initial earthquake of 6 M and above (1230 earthquakes) showed that the form of distance-based earthquake frequency distribution can be interpreted as a system of standing waves with wavelengths of about 833 and 1666 km. These distances can be taken as the basic ones.

Supposedly, this system of standing waves is of electromagnetic nature and reflects the powerful electro-physical processes that accompany the shifts and movements of lithosphere plates, the generation of large electric charges and their interactions with the ionosphere.

Most disastrous effects are those of large solar flares, underground explosions used in oil and gas production, and underground nuclear tests. (Figures 4 and 5) [6, 7]. They all cause disturbances and increases in natural seismic activity and hence various failures and disasters, and globally at that.