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Effects of Anthropogenic Activities on Pore Pressure of the Earth's Crust - A Desk Review

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ABSTRACT

The objective of this chapter is to identify and analyse the major anthropogenic factors affecting pore pressure of the rocks inside the Earth's crust which determines the frequency of earthquakes and is responsible for causing seismic events, eventually leading to seismic movements. These activities include construction of dams, hydraulic fracking, carbon sequestration, and radiations from certain technologies such as the United States' High Frequency Active Auroral Research Program (HAARP) which is now being used for research purposes. It also studies how temperature and pressure are related and trigger earthquakes and how global warming is affecting the Earth's pore pressure. The effects of these factors were assessed on different parts of the world such as in the USA, Pakistan and India, where earthquakes were triggered.

The study is based on desk research, including review of research papers and case studies on the subject. The findings from this secondary review indicated that fracking and building reservoirs have resulted in significant seismic events in many parts of the world, even in areas such as Oklahoma, USA, which were not seismically active, but which witnessed earthquakes after fracking and reservoir projects were initiated (Rubinstein and Mahani 2015). Moreover, there exists a positive correlation between temperature increase and earthquake frequency (Usman et al. 2016). Furthermore, the chapter also studies if the radiations emitted under programmes such as HAARP can cause disturbance in the earth's crust because very low frequency radiations emitted from transmitters towards ionosphere, gets reflected back to the earth, can also trigger seismic movements in the crust (Kim et al. 2002). However, human factors such as building of artificial dams, and hydraulic fracking are also major contributing factors towards increasing the frequency of earthquakes around the globe (Petersen et al. 2016). The chapter discusses how the Sendai

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Framework can play a role to reduce the impacts of anthropogenic activities which can trigger disasters, such as earthquakes.

Key words: Disaster management; earthquake; seismicity; Sendai Framework; High Frequency Active Auroral Research Program (HAARP)

1. INTRODUCTION

A few years back, everyone believed that an earthquake was a natural disaster. It is a way by which earth relaxes itself as energy is released in the form of seismic waves through tectonic plates below the earth's surface. But with the passage of time, as humans became the masters of the world, they have tried to alter many natural processes including the seismicity. These changes are unintentional as well as intentional. So now an earthquake is not just a natural process but has also become anthropogenic or 'human-induced'. Through certain anthropogenic factors, seismic events can also be triggered. Human activities, particularly related to geo engineering which results in the alterations in the earth's crust and can result in the rupture or failure of already present faults, is also termed as geo-mechanical pollution which in simpler words is called induced seismicity (Klose 2010). There exists a difference between the terms 'induced' and 'trigger'. Induced earthquake is comparable in magnitude with shear stress that acts on a fault to cause slip; whereas triggered earthquake means a stress at a smaller level created by some human activity (McGarr et al. 2002). Naturally an earthquake occurs when the tectonic plates collide with one another and consequently because of increased stress, energy is released from the fractures or faults in the crust. However, in induced seismicity, stress is caused by human activities such as building reservoirs, mining and extraction, fluid injection, etc. (Ellsworth 2013). Usually the magnitude of induced earthquakes is small (<6) on the Richter scale but these small shocks can activate or trigger movements in faults that can create earthquakes of magnitude >6 on the Richter scale (Klose 2012). Due to human activities, earthquakes can be triggered in seismically stable continental regions (SCR) (Seeber et al. 2004). The faults in stable continental regions can be more earthquake-trigger sensitive since accumulated stresses have not reached failure conditions (Klose 2007). The earthquakes can be induced or triggered by many human activities such as mining, fracking, building reservoirs, etc. (Bommer et al. 2015). In order to reduce the hazards associated with induced seismic events, the Sendai Framework for Disaster Risk Reduction (2015-2030), which was embraced at the 3rd UN world conference in Japan on 18 March 2015, as a substitute of Hyogo Framework for Action (HFA) 2005-2015 can play a vital role in mitigating the risk of seismic disaster associated with human activities (UNISDR 2015).

1.1. Goals and Objectives

The primary goal of this research is to identify, analyse and relate major influencing factors which are affecting the pore pressure eventually leading to seismic movements.

The pore pressure is affected by many different factors such as the intensity of the induced stress, the location of the underlying faults, the hold of the forces of friction, etc. The shear stress usually causes destruction in case of tectonic movements. In this case, the porosity and permeability of the underlying rock structure is also very important. The specific objectives of this research are:

- Study the effects of human induced stresses on pore pressure.
- Analyse the role of those anthropogenic processes which affects pore pressure and have triggered major earthquakes in the past and will induce more in the future.
- The effects of temperature on pore pressure from different anthropogenic processes.

1.2. Rationale

The significance of this study is that it can provide useful information to the seismologists and disaster management authorities in conducting surveys in those regions which are more seismically active. Moreover, it can help in identifying those human activities which are more particular in creating induced seismicity hazards. The researchers, academicians, seismologists, and geo-mechanical engineers can gather quite useful information for the future studies. This paper can also be useful for policy makers in designing effective policies regarding disaster management.

1.3. Research Questions

- How is pore pressure enhanced due to external stresses created artificially by human activities?
- What are the main human made processes through which pore pressure is affected, resulting in seismic movements?
- Does temperature and radiation have any role in enhancing pore pressure?
- How can Sendai Framework for Disaster Risk Reduction play a role in mitigating hazards associated with induced seismicity?

2. METHODOLOGY

This research is based upon qualitative research methods. Data collection is based upon observations and analysis from previous literature which includes research papers, research journals and articles. Similarly, many case studies have been included which demonstrate the rationale of the study.

3. DISCUSSION

In this paper some of the major factors have been studied which affect the pore pressure in one way or the other. These activities have caused seismic events in many regions in the world and can further increase the susceptibility to disasters associated with induced or triggered seismic events. Following are some of the major anthropogenic reasons that activate seismicity.

a. Artificial dams and reservoirs
b. Fluid injections
   - Waste water injection
   - Hydraulic fracturing
c. CO2 storage
d. Temperature and Radiation
   - HAARP

3.1. Artificial Dams and Reservoirs

When an impoundment is constructed, a lot of pore pressure is developed at depth with increasing water level. It creates stress and as a result of process of diffusion between pore fluids, stress is created and so can trigger an earthquake in the nearby faults by causing brittle failure (Shapiro et al. 2010). The earthquake can occur soon after the reservoir or dam has been filled or the pressure can take time to diffuse in pores and create fault failure (Talwani 2000). History has experienced destruction due to such earthquakes (Table B). The magnitude is related to the amplitude, frequency of the level of water in the reservoir and the location of the fault line in the vicinity. The factors resulting in dislocation of faults or tectonic plates are the increase load due to water level causing pressure on elastic stress and the transfer of water to depths resulting in fracturing of rocks eventually leading to reduced friction inside the pores (Shapiro et al. 2010). Therefore, leads to movement in depths. The seismicity in such cases also depends upon a pre-existing fault because if these faults are affected by load or water pressure then the magnitude can exceed 6 on the Richter scale. One of the massive destruction was caused due to an earthquake in Koyna Dam situated in the state of Maharashtra, India. Prior to the dam construction, seismicity surveys were conducted which proved that the region was seismically stable (Table B). However, just after one year of its construction and filling, Koyna dam encountered an earthquake of magnitude 6.7 resulting in approximately 200 casualties in the vicinity (Gupta et al. 2000). The site has become seismically active since then due to increasing water level in the reservoir. In some cases, the situation can be reversed. Likewise, Tarbela Dam which is constructed on river Indus, in Pakistan, is actually located in one of the most seismically active regions in the world. It is considered to be one of the world’s largest earth filled dams. However, soon after the first filling, the reduction in seismicity was observed. This is because if faults are horizontal, then any type of vertically applied pressure can shift the stresses away, thus resulting in decrease in tectonic movements. But if faults are vertical, then a horizontal shift can occur. Such movements in faults are known as strike slip faults. Also the seismicity is associated with the level of water in the dam. But if water level is reduced in the dam then the pre-existing fault can recover itself (Ibenbrahim et al. 1989).

3.2. Fluid Injections (Waste Water Injections and Fracking)

The phenomenon of fluid injections has become very common nowadays especially in developed countries. It basically involves injecting or transferring fluids which can be either treated waste water (waste disposal), brine or other chemicals from oil and gas fracking (Hydraulic Fracturing) or for hydrocarbon storage (CO2 commonly). These fluids are transferred to deep wells known as injection wells. The seismicity is commonly induced where the rock structure deep down the wells is already under pressure and the diffusion of chemical and water enhances the pressure thus resulting in displacement of faults. However, the magnitude of these earthquakes is usually <2 but earthquakes of >5 magnitude on the Richter scale in the regions have also occurred where fluid injection wells were present (Ellsworth 2013) (Table A). The depending factors which are associated to seismicity in such areas include the distance of the underlying faults from the wells and the time taken by the fluids to reach the pores and build pressure in them. Unfortunately, until now there are no proper methods to determine the time duration of diffusion of fluids because it depends upon the types of rocks present in the region. On the other hand, even if the faults are not present below the injection wells, the fluid can be diffused through rocks to other areas where tectonics are active such as in Ohio State, no earthquakes were recorded until in 2011, when movements were felt because of fluid injection wells (Kim 2013). Resultantly, earthquakes can be triggered there. In 2011, Oklahoma experienced an earthquake of magnitude >5 on the Richter scale which caused some buildings to collapse and it occurred due to waste water induced seismicity (Keranen et al. 2013) (Table B). The rate of seismic events increased in Oklahoma after the injection wells were built in the city (Keranen et al, 2014. Also, if waste water is stored for a longer time in a place with little or no seismic activity, chances are that a severe earthquake can result due to large amount of pressure stored inside the pores and that can result in destruction (Kim 2013).

The process of hydraulic fracking is more commonly used for the extraction of shale oil. Shale is basically a sedimentary rock which has very thin pore spaces and is usually covered by an overlying layer of some other kinds of rocks. For its extraction water or gases is pumped with intense pressure to break that layer of rock in order to allow the pumping of shale oil. This process creates cracks deep inside the earth which allows the energy to be released more frequently as the cracks provide the passage to underlying energy causing micro earthquakes (Warpinski et al. 2012). Similarly, as discussed in the above mentioned cases, pore pressure is also affected which plays its part in triggering micro earthquakes with magnitude 2 or below on the Richter scale (Ellsworth 2013). Moreover, recent studies suggest that the induced earthquakes due to fracking pose little threat than those induced by waste water injections which have even resulted in earthquakes of 5 magnitude on the Richter scale (McGarr 2014). However, the concern is that the rate of earthquakes induced by this process is increasing rapidly.

3.3. Carbon Sequestration

Recently, a phenomenon known as carbon sequestration is gaining wide acceptance as a measure of climate change mitigation. It involves removal of the harmful Carbon Dioxide gas which is a leading cause of global warming from the atmosphere. It can be done through various techniques and one of these is injecting it deep inside the ground. This is also known as geologic sequestration. When it is injected it is trapped by the underground less permeable layers of rocks which do not allow it to escape in the atmosphere. But the main concern is that CO2increases temperature and pressure inside the pores, thus leading to fracturing and tectonic slips. Because temperature and pressure are related, thermal stresses are created which can result in destruction (Table A). The frequency of the occurrence of seismic events due to this process depends upon the pressure of the injecting gas and the tectonic behaviour of the site (Rutqvist 2012). However, very rare events have been reported in the past few years regarding the induced seismicity due to this process as the temperature increases gradually and can take months or even several years. Similarly, the pressure inside pores also takes time to build. Some seismic events related to this phenomenon have been reported such as in Basel, an earthquake of magnitude 3.8 on Richter scale was detected near the carbon sequestration site in 2008 and soon afterwards, this site was shut down (Häring et al. 2008). If the process continues then in the near future the rates of induced seismicity can be increased due to geologic sequestration. Furthermore, no mechanism has been devised which could help in predicting the magnitude and intensity of such tremors, also, where they will occur. Moreover, even micro earthquakes can trigger the larger magnitude earthquakes if the pressure is sustained by the pores over longer period of time (Mazzoldi et al. 2012).

Table A

Study Title	**Findings**	**In Text Citation**	**Reference**
Earthquakes induced by water injection at 3km depth within the Ronqchanq gas field, Chongqing, China	Fracking induces seismicity because it requires higher level of water to be injected in wells with pressure, in order to retrieve oil and gas. Therefore, pressure causes rock failure resulting in earthquakes.	(Lei et al. 2008)	Lei, X., G. Yu, S. Ma, X. Wen, and Q. Wang 2008, 'Earthquakes induced by water injection at ~3 km depth within the Rongchang gas field, Chongqing, China', J. Geophys, vol. 113,(B10310), doi:10.1029/2008JB005604.
Injection Induced Earthquakes	Fracking induces micro earthquakes of magnitude 3 on the Richter scale because it requires creation of fractures by pressure fluids to stimulate recovery of hydrocarbons. The rate of micro earthquakes has increased in those regions of the USA where fracking is being carried out which were seismically stable previously.	(Ellsworth 2013)	Ellsworth, W. 2013, 'Injection-Induced Earthquakes', Science, vol. 341, no. 6142, pp.1225942-1225942.
Earthquake Hazard Associated with Deep Well Injection - A Report to the US Environmental Protection Agency	Since 1900s when the process of deep well injection was introduced, micro earthquakes have increased in the USA and Canada which have also triggered major seismic events in Ohio, Colorado, Oklahoma, etc.	(US. Geological Survey, 1951)	US Geological Survey 1951, Earthquake Hazard Associated with Deep Well Injection- A Report to the US Environmental Protection Agency, US. Geological Survey Bulletin 1951, United States Government Printing Office, Denver, pp.1-86. viewed 18 September 2017 < https://pubs.usgs.gov/bul/1951/report.pdf >

Induced Seismicity Potential in Energy Technologies	Carbon sequestration which is the process of capturing large volumes of Carbon Dioxide from atmosphere and storing it directly under soil by intense pressure causes large magnitude earthquakes. This is due to two major reasons: 1) The intense pressure causes rock failure inside pores 2) The temperature of Carbon Dioxide stored for longer terms increases more pressure on rocks and pores resulting in seismic events.	(National Resaerch Council 2013)	National Research Council 2013, Induced Seismicity Potential in Energy Technologies, The National Academies Press Washington, DC., viewed 18 September 2017 <https://doi.org/10.17226/13355>
Two types of reservoir-induced seismicity	Diffusion of water in the pores after filling of a dam can enhance the pressure and result in rock failure. However, the pressure depends upon the incoming load after filling.	(Simpson et al. 1988)	Simpson, D.W., Leith, W.S. and Scholz, C.H. 1988, 'Two types of reservoir-induced seismicity', Bulletin of the Seismological Society of America, vol. 78, no.6, pp.2025-2040.

Table B

Location	Earthquake Magnitude on the Richter scale	Anthropogenic Cause	Year	Reference
Koyna Dam, Maharashtra, India	6.5	Reservoir Induced Seismicity	1967	Chopra, A.K. and Chakrabarti, P. 1973, 'The Koyna earthquake and the damage to Koyna Dam', Bulletin of the Seismological Society of America, vol. 63, no. 2, pp.381-397.
Monticello Reservoir	4.1	Reservoir induced seismicity	1978	Talwani, P. 1997, 'On the nature of reservoir-induced seismicity', Pure and Applied Geophysics, vol. 150, no. 3-4, pp.473-492.
Xinfengjiang, China	6.1	Reservoir Induced Seismicity	1962	Chen, L. and Talwani, P. 1998, 'Reservoir-induced seismicity in China', Seismicity Caused by Mines, Fluid Injections, Reservoirs, and Oil Extraction, pp.133-149.
Youngstown, Ohio, United States of America	3.9	Fracking	2011	Kim, W. 2013, 'Induced seismicity associated with fluid injection into a deep well in Youngstown, Ohio', Journal of Geophysical Research: Solid Earth, vol. 118, no. 7, pp.3506-3518.
Arkansas, United States of America	4.7	Fracking	2011	Kerr, R. 2012, 'Learning How to NOT Make Your Own Earthquakes', Science, vol. 335, no. 6075, pp.1436-1437.
Oklahoma, United States of America	5.6	Fracking	2009	Kerr, R. 2012 'Learning How to NOT Make Your Own Earthquakes', Science, vol. 335, no. 6075, pp.1436-1437.

Netherlands	5.5	Fracking	1995	van Eck, T., Goutbeek, F., Haak, H. and Dost, B. 2006, Seismic hazard due to small-magnitude, shallow-source, induced earthquakes in The Netherlands', Engineering Geology, vol. 87, no. 1-2, pp.105-121.
Dallas, United States of America	3.9	Fracking	2009	Frohlich, C. 2012, 'Two-year survey comparing earthquake activity and injection-well locations in the Barnett Shale, Texas', Proceedings of the National Academy of Sciences, vol. 109, no.35, pp.13934-13938.
Black Pool, United Kingdom	3.7	Fracking	2011	Hammond, G.P., O'Grady, Á. and Packham, D.E. 2015, 'Energy technology assessment of shale gas 'Fracking'– a UK perspective', Energy Procedia, vol. 75, pp.2764-2771.

3.4. Influence of Human Created Temperature and Radiation Effects in Inducing Earthquakes

A lot of controversies exist when it comes to the link between temperature and seismic events. However, recent studies indicate that temperature does affect the frequency of seismic events. Increase in temperature results in receding of glaciers. The glaciers build stress on the earth's crust as they melt, stresses are released which can probably recover the suppressed energy inside the faults and can cause an earthquake (Immerzeel et al. 2010). The melting of glaciers is increasing due to the climate change impacts and specifically the South Asian glaciers are mostly affected by climate change and are receding at a higher rate (Ibid). This phenomenon was also observed in a study in which earthquake occurring frequency was directly related with temperature increase due to climate change in Northern Pakistan (Usman et al. 2016). The study further suggests that this in turn has increased the rate of earthquakes in the region. As climate change is again considered to be the result of anthropogenic activities, there exists a positive correlation between climate change and increase in seismic events. If glaciers melt at a faster pace, then eventually number of seismic events will increase.

Another interesting phenomenon related to seismicity is the electromagnetic radiations. These radiations are observed before and after an earthquake occur but the exact reason that why these radiations are present on seismic site is not known. These radiations are absorbed by the earth and they also travel towards the ionosphere layer of the atmosphere. Therefore, it is also assumed that some of the radiations bounce back to the earth from the ionosphere and are absorbed. These radiations cause fracture in the pores of the rocks, thus resulting in seismic events (Fujinawa and Takahashi 1998). Many large magnitude (>7 on the Richter scale) earthquakes have witnessed the radiation effect which were absorbed by the earth from ionosphere such as Wenchuan earthquake with magnitude 7.9 in 2008 (Pulinets and Davidenko 2014). The same study suggests that most of the radiations which bounce back from ionosphere to the earth are generated by man-made activities and these radiations are often very low frequency (VLF). So waves travelling in the ionosphere are the reason for many seismic events (Johnston 2002). Many such technologies have been developed around the globe; one of such technologies is the United States' High Frequency Active Auroral Research Program (HAARP). It was built in Alaska in 1993 with the purpose of analysing the ionosphere by sending high power Extremely Low Frequency (ELF) electromagnetic radiations and heating a portion of ionosphere. These radiations bounce back to the earth, cause fractures in the rocks and result in earthquakes (Piddyachiy et al. 2008). This technology consists of antennas which transmits electromagnetic radiations. The Noto-hanto peninsula and Niigata-chuetsu-oki earthquakes of magnitude >6 on the Richter scale have been caused due to the ELF radiations that were reflected back to the epicentre from ionosphere and these ELF radiations were injected in ionosphere by some man made antennas operating in Japan

(Ono et al. 2012). In the similar way HAARP can induce earthquakes and whether it has induced earthquakes or not, is still under research but it is certain that if it keeps generating ELF, then definitely it will cause disasters in the near future. The earthquake of magnitude 7.8 which occurred on Pakistan-Iran border in April 2013 was also triggered by ELF reflected back from lower ionosphere and these radiations were enhanced by human made transmitters (Pundhir et al. 2016). It is still not known which transmitters were responsible for this.

3.5. Role of Sendai Framework in Mitigating the Impacts of Induced Seismicity

Sendai Framework for Disaster Risk Reduction (SFDRR) (2015-2030) was adopted as a substitute of Hyogo Framework for Action (HFA), 2005-2015. It was embraced during the 3rd UN Conference in Sendai, Japan. HFA was about creating resilience among nations to disasters and with primary focus on disaster risk reduction and prevention. SFDRR is basically the progression of HFA with some variations such as focus on disaster risk management and strengthening regional and international cooperation for mitigating disaster impacts. The most important objective of SFDRR is to increase the number of nations with disaster risk mitigation strategies at local and regional level (Kelman 2015). This framework focuses on seven global goals and one of these goals is establishment of early warning system while another one focuses on reducing the loss of lives and proper urban planning. The Great East Japan Earthquake of 2011 resulted in a catastrophe due to lack of urban planning. Therefore, the Sendai Framework gives the way forward for reducing such hazards (Okazumi and Nakasu 2015).

Sustainable Development Goals (SDGs), also known as global goals were adopted in 2016 by the United Nations as a follow up for Millennium Development Goals (MDGs) with the objective of poverty reduction, prosperity and public well-being. It consists of 17 goals or targets which focus on food and water security, quality of life and education, climate change mitigation, clean energy, urban planning, etc. (UNDP 2016). Goal 9, which emphasizes on sustainable cities and communities, can be effectively adopted and used for mitigating the risks associated with human induced seismicity. The factors identified in this research which results in seismic events such as reservoirs and fracking operations need to be monitored properly to reduce the risk of earthquakes and this can be done through proper urban planning and infrastructure development. The policies and regulations, if developed by keeping a focus on SDG 9, can be very helpful in disaster risk reduction, management, preparedness and resilience.

When discussing regional and international level cooperation, there exist four priority areas in SFDRR, with the main objective of focused action, policy planning and strategy implementation (UNISDR 2015). The first priority area is about developing understanding of disaster risk. In case of induced seismicity, the communities need to identify the hazard associated with those activities which cause seismic movements by enhancing pressure on pore. Once identified, the communities and authorities can devise policies and strategies which can help in developing better resilience, effective ‘Build Back Better’ response and recovery systems, not only at the local and regional levels but at global scale as well. This can be done by promoting and developing stakeholders’ negotiations at all levels for mitigating and reducing disasters. Moreover, these goals are related with the three priority objectives of SFDRR. Reservoirs and dams can trigger and induce earthquakes, but proper urban planning can help in reducing the hazard such as no urbanization near the dam areas, seismic surveys prior to construction can help in assessing and understanding associated risk and this is what SFDRR aims in priority one. Secondly, in case of fluid injections, again urban planning is important but then proper monitoring of the pressure on pores created by the injection, movement of underlying rocks and the study of history of tectonics on the site can help in mitigating the hazard. As explained in one of the goals of SFDRR, proper monitoring of any factor which can cause disaster risk must be implemented at all levels. In case of climate change relation with seismicity and man-made ELF (Extremely Low Frequency) radiations released from man-made technologies such as HAARP need to be addressed at international level which is also associated with earthquakes. Negotiation between nations, stakeholders, dissemination of relevant scientific knowledge, methods and tools between regions can help in developing disaster risk management strategies in the regions and even at the international level. This is a way forward given by SFDRR in such cases to ‘Build Back Better’ and this complete set of instructions, guidelines, strategies if implemented can certainly reduce the risk of induced seismicity in the world.

4. CONCLUSION

The discussion indicates that anthropogenic activities such as reservoirs, fluid injections especially waste water and hydraulic fracking along with carbon sequestration do induce seismic movements. The two most important factors that induce or trigger earthquakes include reservoirs and hydraulic fracking; reservoirs can trigger and induce earthquake greater than the magnitude of 5 on the Richter scale. However, seismicity associated with hydraulic fracking results in lower magnitude earthquakes of <2 while waste water can induce earthquakes of magnitude <5 on the Richter scale. Also, smaller magnitude earthquakes can trigger the pre-existing faults.

Secondly, in case of carbon sequestration, smaller magnitude earthquakes are induced due to the pressure created by CO_2 gas on pores but again these smaller earthquakes can trigger larger earthquakes. Temperature increase due to climate change from anthropogenic activities causes receding of glaciers, which when melt, release the pressure from the pores and recover pre-existing faults, ultimately leading to seismic movements. Radiations specifically ELF when absorbed in the earth due to the reflection from the ionosphere, causes fractures in the pores, resulting in earthquakes and man-made ELF generating technologies such as HAARP can increase perturbations in the ionosphere, leading to more absorbance of ELF by earth, which in turn, can affect the underlying pores, triggering seismic movements.

SFDRR is a complete set of guidelines and strategies, which if implemented, can prove to be the way forward in designing disaster risk management strategies, at local, regional and international levels for mitigating the hazards associated with induced seismicity. Moreover, by adopting SDG 9, as a priority for improved urban planning, disaster risk resilience can be improved and managed effectively at the local, regional and international levels.

5. RECOMMENDATIONS

Keeping in view SFDRR, some of the recommendations are discussed below:

1. Communities, authorities and experts should identify the key anthropogenic activities which can play a role in inducing or triggering seismic events in their regions. For instance in India, Koyna Dam has induced earthquakes. Authorities should therefore carry out seismic surveys on a regular basis and develop disaster risk preparedness and management strategies with the local communities. The entire South Asian region, which is seismically active, should develop such policies before construction of any dam. Collaborative efforts and negotiations at the local and regional levels can play a vital role in the reduction of seismic hazard due to reservoirs.
2. In case of Oklahoma, USA, where fluid injections and hydraulic fracking has increased the number of earthquakes, authorities should set up monitoring systems in which, the pressure induced by the injection on pores is monitored. The underlying movements of rocks should be properly observed where these injections are being used. The policies related to proper urban planning and infrastructure is very important in this context in such regions. Infrastructure needs to be more resistant to shaking and such activities of fracking and injection fluids should be performed away from the urban settlements.
3. Due to the direct relation between temperature increase, climate change and seismic movements, SFDRR lays primary focus on climate change adaptation for achieving sustainable development (Kelman 2015). Climate change acts as a driving force behind inducing seismicity, hence priority 3 of SFDRR which focuses on building up resilience should be incorporated in the policy making at the local and regional levels.
4. In case of ELF and human made technologies such as HAARP, the negotiation between nations, stakeholders, dissemination of relevant scientific knowledge, methods and tools between regions, can help in developing disaster risk management strategies between regions and even at the international level and this in turn will help to ‘Build Back Better’.

ABBREVIATIONS

ELF:	Extremely Low Frequency
HAARP:	High Frequency Active Auroral Research Program
HFA:	Hyogo Framework for Action 2005-2015
SFDRR:	Sendai Framework for Disaster Risk Reduction 2015-2030
VLF:	Very Low Frequency

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