Analysis on Predicting Earthquakes through an Abnormal Behavior of Animals

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Abstract— This paper presents an abnormal animal behaviour in an earthquake prediction. The earthquake prediction can be done using the abnormal behaviour of animals preceding earthquake occurrence in seismically active region because of their relatively more capability than humans of perceiving certain kind of geophysical stimuli which may precede earthquake. The lead times prior to the earthquake ranged from several seconds to a week, with the most frequent observations occurring between several minutes and several days prior to the earthquake. The implications of these results are discussed with regard to the possibility that some animals may possess sensitivity to certain earthquake precursors, which could serve to help warn people of an approaching earthquake. This survey was done in order to find out how common these observations of unusual animal behavior are among the population of an earthquake-prone region. In the case that animals are actually reacting to precursory earthquake signals, some explanations have been proposed. Most of the methods and models are beyond the scope of the present work and only a few simple methods and models are discussed. Some observations of unusual animal behavior prior to earthquakes have been reported around the world. Further, the data requirement for the earthquake prediction in the Indian context has been discussed.

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Index Terms— Earthquakes, abnormal behavior, prediction, animals and behavior.

1 INTRODUCTION

The first recorded reference to animals predicting earthquakes is found in ancient Greece, attributed to writings from 373 B.C. supposedly weasels, rats, snakes and even centipedes abandoned their normal environments and moved to areas of safety several days before a strong and destructive earthquake. Reports of similar activity have been recorded throughout history. Anecdotal in nature, these reports seem to indicate that many species adapt abnormal behavior prior to earthquake occurrences. Mammals, fish, birds and even insects have allegedly been observed showing strange behavior weeks ahead of a quake, with activity intensifying closer to the time of the event.

One theory pointing to animals exhibiting "predicting" behavior prior to an earthquake relates to lost household pets. One study of the increase in Lost Pet classified ads in a local California newspaper apparently showed an increase in such ads prior to earthquakes in the San Francisco Bay area. If Fido senses that an earthquake is impending, he just might decide that the homestead is not the safest place to stay, and he and his fellow pet buddies head for the hills. An article in California Geology published in 1988 included a statistical analysis of the data that concluded that there was, however, no correlation between Lost Pet ads and later earthquakes.

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In yet another possible indication of animals predicting earthquakes, rare giant oarfish have recently been discovered in the nets of Japanese fishermen and washed ashore on the northern coast of Japan. These snakes like fish normally live in very deep waters, and rarely are seen. Japanese folklore touts the story that the appearances of these fish are predictions of impending seismic activity. Perhaps, according to some theories, these bottom dwellers can sense the changes and activity in deep ocean fault systems, and thus migrate away from these areas. Some Japanese firmly believe that due to the discovery of the oarfish that severe earthquakes are now imminent.

Can animals predict earthquakes? Scientific proof of the ability to base predictions on the observation of certain animal behavior has yet to be documented. Most serious research is being pursued in China and Japan. For now, at least, the mystery remains. Some animals have remarkable adaptations for surviving their environment. This includes sensing things that humans cannot. For example, crabs have hair on their legs to detect water current and vibrations. Fish have sensory receptors that detect changes in water pressure. Mice can hear frequencies between 1,000 and 100,000 Hz. By comparison, humans can hear frequencies between 20 and 20,000 Hz. The hearing range of elephants is between 1 and 20,000 Hz. The very low frequency sounds are in the “infrasound” range, which humans cannot hear. Animals sense even small changes in the environment and this influences their behavior. Through observation of animal behaviour, we can learn about our surroundings. Detailed observation of surroundings can be applied to knowledge acquisition in traditional Native knowledge and Western science. Although the applications of knowledge may vary, it is understood that observation must take place repeatedly over time in order to build a knowledge base that can support pattern recognition, inferring, and prediction. In traditional Native knowledge, observation of sur-

roundings including animal behaviour, often leads to inferences and predictions about weather conditions and sometimes earthquakes. Local Elders, hunters and culture bearers have a sense of the local environment and cues they take from animal behaviour. Although many western scientists are not sure about animals sensing rapid changes to Earth's surface, anecdotes about animals predicting earthquakes and tsunamis have existed for centuries. In 1979, T. Neil Davis of the Geophysical Institute at the University of Alaska Fairbanks reported on observations near Yakutat just before the Lituya Bay earthquake on July 10, 1958. This example shows a keen sense of observing animal behaviour in relation to an earthquake. One person picking berries saw leaves move when they shouldn't have, while nearby others saw birds become disturbed and fly over the trees in unusual numbers. Simultaneously yet another nearby group suddenly started getting bites from fish with every cast into the river. Several minutes later the magnitude 8 earthquake struck. In this instance it seems likely that the birds and fish were responding to vibrations evidenced by the moving leaves but which were not noticed by the people present. Also, it has been suggested that animals may be responding to the release of gases such as methane just before the earthquake. Animal observations were taken into account in China in 1975 when seismologists believed that a large earthquake would take place in Haicheng, a heavily populated area about 400 miles north of Peking. Observations of sudden changes in water well levels, abnormal behaviour of domestic animals and even snakes emerging from below ground in subzero weather plus instrumental indications implied the earthquake was imminent. Massive evacuations of nearly one million people were completed just hours before the earthquake struck. There were no deaths but the entire town of Haicheng was destroyed in the earthquake on February 4, 1975 (Holland, 1976). In this paper, we present an abnormal animal behaviour in an earthquake prediction. Most of the methods and models are beyond the scope of the present work and only a few simple methods and models are discussed. Some observations of unusual animal behavior prior to earthquakes have been reported around the world.

2 Review of the Related Literature

Earthquakes are one of the most destructive of natural hazards and to reduce the risk, it is necessary to predict where and when a future large earthquake may occur. Earthquake prediction means the accurate forecasting of the place, size and time of an impending earthquake (Agarwal, 1991). Solutions have been searched in past using earthquake precursors, particularly in China, Japan, and USA by conducting multi parametric regional studies. Many countries have been working on integrated national earthquake prediction research programs (Wyss, 1975; UNESCO, 1984). An endeavour has been made in the present study to review the work done in the earthquake prediction with respect to the abnormal animal behaviour before an earthquake. The present paper consists of basic information of earthquake prediction, its research components being carried out in China, Japan and America with comments on its feasibility in Indian context.

Earthquake prediction is done in three different time frames assigned by scientist as long term, intermediate and short-term predictions (Scholz, 2002). Long term predictions are of very limited use for public safety and by this type of prediction forecasts of earthquake occurrences have not been very accurate. Intermediate prediction consists of prediction for few weeks to few years, and again would not be of great practical usefulness. Short term prediction is specific information of the time and location of an earthquake given within days, weeks, or months and therefore would be more useful for any kind of public safety and evacuation. It is this prediction for which scientific community is trying to use the abnormal behaviour of animals. It has been observed that earthquakes are generally, but not necessarily, preceded by some signals mainly divided into geophysical precursors and others which also contains the unusual animal behaviour. While lot of research work has been carried out for the geophysical precursors, animal behaviour has not been explored to its full capacity for use in earthquake prediction. The following sections review the abnormal animal behaviour observed for earthquake prediction.

The earthquake prediction can be done using the abnormal behaviour of animals preceding earthquake occurrence, because animals are much more capable than humans of perceiving certain kind of geophysical stimuli which may precede earthquake. The main research has been carried out in China, Japan and America. Chinese began to study systematically on the unusual animal's behaviour, and the Haicheng earthquake of magnitude 7.3, on 4 February 1975 was predicted successfully as early as in mid December of 1974. The most unusual circumstance of animal's behaviour was that of snakes that came out of hibernation and froze on the surface of the earth and also a group of rats appeared. These events were succeeded by the swarm of earth of earthquakes at the end of December 1974. In first three days in Feb the unusual behaviour of the larger animals such as cows, horses, dogs and pigs was reported. Chinese have established an operational network in different counties. In 1968 first experimental station for earthquake making use of biological observation established in Hsingtai province. Other similar stations were set up in 1971 in Aksu, Sinkiang province, where earthquake were expected to occur. Whenever unusual event occur and are reported by numerous observers, these are evaluated as a way of predicting earthquakes. In August 1971 the State Seismological Bureau of China started to collect reports of unusual animal be-

haviour for earthquake prediction purposes. Four years later, based on observations of unusual animal behaviour and geophysical measurements, they successfully evacuated Haicheng city several hours before an earthquake **(**M7.3) on February 4, 1975. This earthquake caused considerable damage to existing structures and cultivated lands, and the successful evacuation was thought to have saved more than 100,000 lives. There were also reports of unusual animal behaviour before the Tangshan Earthquake (M8.2) in 1976, but no warning was issued. There were 240,000 casualties (George, 2007). In Japan, unusual behaviour of catfish before the 1855 Edo earthquake was reported. Many fish jumping in a pond just one day before the great Kanto earthquake occurred was reported (Musha, 1957). (Hatai and Abe, 1932) investigated the response of catfish to the earthquake first time. According to (Buskirk et al., 1981 and Ikea et al., 1997) aquatic animals are more sensitive to electric signals than other animals. Some of them have special electro-sensory systems which are used to acquire information for orientation and communication with each other (Lissman, 1958; Knudsen, 1975; Buskirk et al., 1981). These systems may be perturbed by electric field before earthquakes. (Ikeya et al., 1996) investigated the ground electric field effects on behaviour of Albino rats, Mongolian gerbils (sand rats), hair-footed Djungarian hamsters, guinea pigs, and red sparrows. To determine seismic anomalous animal behaviour prior to a major earthquake due to seismic electric signals, an experiment on these animals was organised. The animals were kept in a cage with a wet conductive floor and electrodes. When Voltage between (0.01 to 50) Volt was applied to the electrodes separated by 25 to 30 cm on the floor of cages, between which wet tissue papers with resistivity of 20 K□□were placed. The film was recorded and it was noticed that initially these animals started grooming, nervous looking and field avoidance behaviours, and finally as the ground electric field increased from 1 to 1000 V/m they started running in panic, jumping, tumbling, crying, standing up, biting wires, flying up and some time their behaviour could not be judged. (Ikeya et. al., 1998) established a laboratory by applying a pulsed electric field on silkworms, earthworms, lungworms, mollusc, Japanese minnows, tropical fish, guppies and fresh water loaches and observed as seismic anomalous animal behaviour (SAABs) as electro physiological responses to the stimuli of seismic electric signals (SES).

According to (Ikeya et al., 2000) unusual animal behaviour during the compression of rocks was observed together with the blood analysis. These EM pulses may be used as early warning to reduce the accompanying the disaster though the exact time of earthquakes would still be difficult to predict. Animal behaviour similar to those induced by pulsed electric field and EM exposures and so by lighting in nature could be a useful warning to lay citizens in earthquake prone areas even admitting the difficulties of deterministic earthquake prediction using these EM signals. (Ustundag et al., 2005) proposed a multi layer capacitor model of the Earth's upper crust to explain the behaviour of measurement patterns acquired from network of the earthquake forecast project. This model indicates that change of dielectric features due to structural changes, such as liquid dilatency, requires a change in the electric field at the surface. Amount of variation is locally independent from the area. Similarly the patterns between the model based simulations using approximate parameters and the real data based patterns beside the relatively high correlation between the anomalies and the earthquakes gives hope for the progress of earthquake forecast in future. It is possible to modify equivalent circuit model of the multi-layer capacitor approach with some additional parameters. It has been shown by laboratory experiments that long animals such as snake tends to stay vertical to the electric fields in order to decrease the potential difference on its body. (Bleier and Freund, 2005) claimed that a network of passive sensors (magnetometers) can be used in EP by using the transient change in earth's magnetic field prior to imminent earthquakes. California earthquakes could have been predicted sometime before, if the region were covered by a network of 200-300 ground-based magnetometers (Sevgi, 2006). Ground-based sensors can be used to monitor changes in the low frequency magnetic field as well as to measure changes in the conductivity of air at the earth's surface. Moreover, noise levels at extremely low frequency (ELF)-below 300 Hz can be monitored using satellites, observe the earthquake related infrared light, even use existing GPS system to detect changes in the total electron content of the ionosphere that occur days, even weeks before the earthquakes. Numerous observations also exist of animals displaying panic in the few seconds prior to the onset of strong ground shaking in American case.(Tributsch, 1982) lists many such examples, including dogs barking, nervous cats jumping out of windows, birds screaming, rats running out of their holes, bees swarming, etc. Such behaviour immediately prior to an earthquake is not difficult to explain, as seismic P waves travel faster through the crust than the associated S waves by roughly 2–4 km/ sec. If organisms are sensitive enough to detect vibrations accompanying the arrival of P waves, that sense could provide enough of a warning to trigger a death-avoiding response immediately prior to the arrival of the more damaging S waves. Animals that live tens of kilometers from the epicenter have several seconds after detection of the P wave to escape the effects of the energetic S waves (Pease and Orourke, 1997). (Kirschvink, 2000) suggests the tilt, hygroreception (humidity), electric, and magnetic sensory systems in animals could be linked in to a seismic escape behavioural system. Several testable predictions of this analysis are discussed, and it is recommended that additional magnetic, electrical, tilt, and hygro-sensors be incorporated into dense monitoring networks in seismically active region. The analysis presented here implies that if there are occasional precursors to earthquakes that animals could

detect, behavioural patterns could evolve to minimize associated mortality. (Heaton et al., 1995) suggested that controlled shake table experiments could be done on laboratory populations of burrowing animals from seismically active zones; also some of California's endemic kangaroo rats would establish a baseline of animal behaviour for comparison with reactions of other stimuli. To determine geophysical and geochemical signals, a variety of field based experiments could be done on the same species, and the expatiation model outlined here would predict some similarity in evoked behavioural response between shaking and other stimuli linked to seismic escape activity. The recognition that changes in groundwater level might sometimes provide clues to an impending earthquake suggests that associated changes in local humidity might be detected by animals. The process of humidity reception in animals is known as hygro-reception. Spiders and insects possess hygro-sensensitive sensilla that consist of specialized receptor cells with hygro-scopic hair-like structures that detect humidity and/or temperature fluctuations (Sayeed and Benzer, 1996; Tichy and Loftus, 1996). According to (Vanderwall, 1993) vertebrates appear to detect humidity through their olfactory system and some controlled laboratory experiments have shown that desert rodents are able to detect seed caches buried in dry sand based variations. Therefore animal detection of impending earthquakes through hygro-reception might be possible in arid environment, but it is difficult in rainy areas like Japan which have uniformly high levels of humidity both in the soil and in the air. It is also difficult to understand that how pattern of a pre seismic humidity change would differ from that generated by an impending storm. On other hand, (Tributsch, 1982) observed that some of the behaviours displayed by animals before earthquake resemble their prestorm behaviour. In terrestrial animals, electrical sensitivity is rather low compared to marine or freshwater animals due to the high resistivity of air. High voltages are perceived through the secondary effects of shock and/or the electrostatic action on feathers or hairs. In contrast, aquatic animals such as sharks, rays, and some fish often have exquisite electrical sensitivity due to specialized organs used both for communication and prey location (Bullock, 1982). In the elasmobranch fish (sharks and rays), a specialized receptor system in the ampullae of Lorenzini has, in fact, reached the thermal noise limit with the ability to perceive nanovolt changes in electrical fields (Kalmijn, 1974). (Tributsch, 1982) suggests an electrical link to anomalous behaviour in fish and other aquatic animals before earthquakes. Similarly, nocturnal animals would have no difficulty detecting earthquake lights by simple visual signals. If some of these signals happen prior to significant seismic events, expatiation could link them to a pre-existing escape response.

While lot of research has been carried out in China, Japan, America, very little efforts have been made in India in the area of earthquake prediction. Very few of the unpublished reports sometime shows some abnormal animal behaviour which has not been studied scientifically. Looking at the future prospects of the abnormal animal behaviour in earthquake prediction and the high seismicity faced by most of the regions in India, this science require much more attention than given in the past. The data on geophysical precursors has not been acquired in the past systematically. Recently, Department of Science and Technology has developed multi parametric geophysical Observation at various places in India. The animal behaviour has not been reported from any of the Indian studies. Neethi Bhargava et.al (2009) discussed review of the work done in earthquake prediction using abnormal animal behavior. Recently Otari and Kulkarni (2012) discussed a brief review of application of data mining in the prediction of natural geological calamities.

3 Earthquake Prediction through some animals - Analysis

There is much anecdotal evidence suggesting that some animals have the ability to detect sensory stimuli which humans cannot even with our most sensitive technological instruments. That many animals have access to a perceptual range exceeding those of humans is scientifically well-established, but it also appears that many animals have sensory abilities not currently explained by traditional science. For example, British biologist Rupert Sheldrake has documented on videotape how some dogs appear to anticipate the arrival of their owner. Regardless of the time of day that the owner begins their journey home, some of these dogs appear to sense their human companion coming without receiving any known physical signals, and wait for them next to the door or window. Homing pigeons also have remarkable abilities to navigate to their desired location using abilities that are not fully understood.

Many pet owners claim that they have powerful "psychic" bonds with their pets, and often describe their connection with the animal as "telepathic". Like Dr. Dolittle, a lot of people believe that they can communicate with animals. Some people even claim that their pets have precognitive abilities, while others notice their animals act in peculiar ways just before an earthquake strikes.

Since the beginning of recorded history, virtually every culture in the world has reported observations of unusual animal behavior prior to earthquakes (and to a lesser extent--volcanic eruptions), but conventional science has never been able to adequately explain the phenomenon. Nonetheless, the Chinese and Japanese have employed such sightings for hundreds of years as an important part of a nationally-orchestrated earthquake warning systems, with some success.

Perhaps most significantly, on February 4, 1975 the Chinese successfully evacuated the city of Haicheng several hours before a 7.3 magnitude earthquake based primarily on observations of unusual animal behavior. 90% of the city's structures were destroyed in the quake, but the entire city had been evacuated before it struck. Nearly 90,000 lives were saved. Since then China has been hit by a number of major quakes that they were not as prepared for, and they have also had some false alarms, so their system is certainly not fool-proof. But never-the-less, they have made a remarkable achievement by demonstrating that earthquakes do not always strike without warning.

Helmut Tributsch's beautifully written classic work on the subject of earthquakes and unusual animal behavior when the snakes awake details numerous consistent accounts of the phenomenon from all over the world. Although these behavior patterns are very well-documented, most geologists that I have spoken with at the United States Geological Survey (USGS) don't take it very seriously. The official word from the USGS is that there aren't any earthquake prediction techniques unusual animal behavior observations included which perform any better than chance.

In fact, the notion that odd animal behavior can help people predict earthquakes is perceived by most traditional geologists in the West as folklore, or an old wives tale, and is often cast into the same boat as sightings of poltergeists, Elvis, and the Loch Ness Monster. The ancient Greeks, on the other hand, considered an understanding of the relationship between unusual animal behavior and earthquakes to be an esoteric form of Secret Knowledge. That such strong support for the application of this knowledge exists in the East in long-lived civilizations like China and Japan is testimony to the reality of the phenomenon, as they have witnessed many more earthquakes in their long histories than has a comparatively young country like the U.S.

But not all Western geologists are close-minded with regard to the phenomenon. James Berkland a retired USGS geologist from Santa Clara County, California claims to be able to predict earthquakes with greater than 75% accuracy rate simply by counting the number of lost pet ads in the daily newspaper, and correlating this relationship to lunar-tide cycles. This maverick geologist has been meticulously saving and counting lost pet ads for many years. Berkland says that the number of missing dogs and cats goes up significantly for as long as two weeks prior to an earthquake.

Gravitational variations due to the lunar cycles, he says, create "seismic windows" of greater earthquake probability. When the number of missing pets also suddenly rises, then bingo a quake is likely to happen. Berkland said he thinks the USGS won't accept unusual animal data because it doesn't jive with their current scientific paradigm and hypotheses, to which, he says, their precious egos are overly attached. (Researchers who attempt earthquake prediction are often lumped into the same category as fortune tellers and scam artists by traditional geologists.) It is not surprising then to hear that Berkland was suspended from his position as Santa Clara county geologist for claiming to predict earthquakes such as the 1989 Loma Prieta quake in Northern California, which was preceded by numerous reports of odd animal behavior.

Unusual behavior is difficult to define, and determining if there is a characteristic behavior is not a simple, clear-cut process, although there are some distinct patterns which have emerged. For example, an intense fear that appears to make some animals cry and bark for hours, and others flee in panic has been reported often. Equally characteristic is the apparent opposite effect of wild animals appearing confused, disoriented, and losing their usual fear of people. Some other common observations are that animals appear agitated, excited, nervous, overly aggressive, or seem to be trying to burrow or hide.

Although the majority of accounts pertain to dogs and cats, there are also many stories about other types of animals in the wild, on farms, and in zoos; including horses, cows, deer, goats, possums, rats, chickens, and other birds. The behavior has been reported in many other animal species as well, including fish, reptiles, and even insects. Deep sea fish, for example, have been caught close to the surface of the ocean on numerous occasions around Japan prior to earthquakes (Tributsch, 1982).

Some fish catfish in particular are reputed to become agitated before earthquakes, and at times have been reported to actually leap out of the water onto dry land. Snakes have been known to leave their underground places of hibernation in the middle of the winter prior to quakes, only to be found frozen on the surface of the snow. Mice are commonly reported to appear dazed before quakes, and allow them to easily be captured by hand. Homing pigeons are said to take much longer to navigate to their destination prior to earthquakes. Hens have been reported laying fewer eggs, or no eggs at all, and pigs have been observed aggressively trying to bite one another before earthquakes (Tributsch, 1982).

Bees have been seen evacuating their hive in a panic, minutes before an earthquake, and then not returning until fifteen minutes after the quake ended. Even creatures such as millipedes, leeches, squid, and ants have been reported to exhibit abnormal behavior prior to earthquakes (Miller, 1996).

These strange behaviors generally occur anywhere from moments to weeks in advance of a quake. Most of the people I have spoken with who have witnessed this phenomenon, ob-

served the strange behavior within twenty-four hours of a quake, although some observations occurred more than a week before the quake struck. Berkland has suggested that there are possibly two primary precursory earthquake signals-- one several weeks before, and the other one just moments before the quake. A lot of reports appear to confirm this.

A number of theories have been proposed to explain this phenomenon, and what the precursory signals that the animals are picking up on might be. Because many animals possess auditory capacities beyond the human range, it has been suggested that some animals may be reacting to ultrasound emitted as microseisms from fracturing rock (Armstrong, 1969).

Another candidate is fluctuations in the earth's magnetic field. Because some animals have a sensitivity to variations in the earth's magnetic field (usually as a means of orientation), and since variations in the magnetic field occur near the epicenters of earthquakes (Chapman and Bartels, 1940), it has been suggested that this is what the animals are picking up on.

Marsha Adams, an independent earthquake researcher in San Francisco, claims to have developed sensors that measure low-frequency electromagnetic signals which allow her to predict earthquakes with over 90% accuracy. Adams suspects that low-frequency electromagnetic signals created by the fracturing of crystalline rock deep in the earth along fault lines are "biologically active" and that her instruments are picking up the same signals that sensitive animals do. As a result of this technology (whose details are a corporate secret), she says that her system makes unusual animal behavior observations obsolete.

Fish have a high degree of sensitivity to variations in electric fields, and because telluric current variations have also been noted before some earthquakes, Ulomov and Malashev have suggested that this is what the fish may be reacting to. Some organisms respond to changes in the polarity and concentration of atmospheric ions, and they suspect that this sensitivity enables some animals to detect the air-ionizing effects of radon released from the ground in advance of certain earthquakes.

Tributsch has suggested that a piezoelectric effect may be at work here. When certain crystals, such as quartz, are arranged in such a way that pressure is applied along certain of the crystal's axes, the distribution of positive and negative ions can shift slightly. In this way pressure changes produce electrical charging of the crystal's surfaces. On the average, the earth's crust consists of 15% quartz, and in certain areas it can be as high as 55%. According to Tributsch, the piezoelectric effect of the quartz is capable of generating enough electrical energy to account for the creation of airborne ions before and during an earthquake. This electrostatic charging of aerosol particles may be what the animals are reacting to. Animals, also observed acting unusual in similar ways prior to thunderstorms, may have evolved sensitivity to electrical changes in their environment (Tributsch, 1982).

The effects of radon gas on the level of air ionization explained above can also be expected to change the field gradient, and dozens of animals have been shown to be sensitive to changes in the electric field gradient of the atmosphere (Chalmers, 1967). Other possibilities are that the animals are actually experiencing a form of pre-cognition, or they could be perceiving and responding to stimuli that currently science has no way to measure. (Support for the notion of pre-cognition is increased when one compares the reports of unusual animal behavior described in this article, with the even more puzzling reports of strange animal behavior reported in England during World War II. Dr. Sheldrake told me that animals were said to act unusual prior to aerial bomb raids, long before they could have possibly heard or felt the vibrations from the approaching aircrafts.)

Some people say that they feel an uncomfortable pressure in their head, or a persistent headache that lasts for weeks, which suddenly vanishes moments before an earthquake. Because magnetite has been found in some animal brains, Berkland thinks that it is possible that animals may be reacting to their own headaches caused by changes in the earth's electromagnetic field. He said that a dog was observed chewing on willow bark from which aspirin in derived prior to an earthquake, and he believes that this was an attempt by the dog to self-medicate him for the headache. He also told me that some people with Multiple Sclerosis a disease caused by improper insulation around the electrically-conductive fibers of the nervous system experience an increase in symptoms weeks before an earthquake.

Other mysterious phenomena are often connected with earthquakes. The regular eruptions of geysers have been interrupted. Well levels have been reported to change, or the water in them has been known to become cloudy. Magnets have been said to temporarily lose their power. Many people report that there is suddenly an unexplainable stillness in the air, and that all around them becomes completely silent. Strange lights are often seen glowing from the earth, and unusual fogs have been reported. These phenomena are all consistent with the notion that the odd animal behavior may result from changes in the earth's electromagnetic field, or the release of electrically-charged particles due to intense pressure on crystalline rock. (More puzzling is that a number of people claim to have sighted UFO's hovering around earthquake sites.)

Another possibly related point of interest is that electrically-charged ionic particles have been shown to change neuro-

transmitter ratios in animal brains, and since charged ions may be released prior to some earthquakes, it has been suggested that this may explain the two seemingly-contradictory behavior patterns discussed above, where in normally-calm pets seem to become frightened, and wild animals often appear to lose their sense of fear (Tributsch, 1982). These neurotransmitter changes could possibly help to explain another related phenomenon.

I've noticed that earthquakes themselves (like solar eclipses) sometimes trigger an intense consciousness-altering experience. People often feel energized, emotionally open, and acutely sensitive following earthquakes. Powerful bonding experiences often occur between people in the aftermath of a quake, although this is likely to be true for any natural disaster that people share.

But subjectively earthquake experiences often take on dream-like qualities, or have a sense of unreality about them, perhaps because our most cherished notion of what is safe and solid in the world the very ground upon which we rest becomes wobbly and unstable. Our whole sense of reality is shaken with the earth, as one is suddenly lifted up out of the mundane, and thrust into the center of what seems an immensely important drama.

California and Japanese residents, like other people living along major fault zones on this planet, don't need to be reminded of the devastation that an earthquake can bring, and currently Western science doesn't have any reliable means of forecasting these earth-shaking events. Tens of thousands of lives are lost globally, and billions of dollars in property damage occur on average every year as a result of earthquakes. Any clues that may be used to help us predict when and where the next quake is coming should be approached with an open mind.

4 Some Observations of Unusual Animal Behavior Prior to Earthquakes

Observations of unusual animal behavior prior to earthquakes have been reported around the world since the beginning of recorded history (Tributsch, 1982). In particular, the Chinese and Japanese have recorded these observations for many hundreds of years (Lee, Ando, and Kautz, 1976), and have made attempts to incorporate these reports into an earthquake warning system with some success (Allen, 1976). For example, on February 4, 1975 the Chinese evacuated the city of Haicheng several hours before a 7.3 magnitude earthquake largely on the basis of unusual animal behavior observations (Allen, 1976).

The anomalous behaviors most frequently reported include restlessness or excitability, a heightened sensitivity to mild stimulation, vocal responses, a tendency for borrowing, premature termination of hibernation, and leaving their normal habitats. The precursory lead times vary from just a few seconds to more than several months (Lee, Ando, and Kautz, 1976). These unusual behaviors have been reported in a wide diversity of animal species, including many varieties of mammals, birds, reptiles, fish, and insects (Tributsch, 1982).

However, only a limited number of scientifically credible accounts of this phenomenon are available. The vast majorities of observations are anecdotal, and are usually classified as folklore. One well-researched book on the subject when the Snakes Awake details much of what is known historically and scientifically about earthquakes and unusual animal behavior (Tributsch, 1982). Scientific accounts of this phenomenon through the mid seventies have been summarized in the "Proceedings of the 1976 USGS Conference on Abnormal Animal Behavior Prior to Earthquakes" (Evernden, 1976).

Some compelling evidence comes from Japan, where it has been reported that certain fish develop a heightened sensitivity to stimulation due to electrical changes prior to some earthquakes (Hatai and Abe, 1932; Suyehiro, 1968; Suyehiro, 1972). However, perhaps the most important evidence comes from a five year study conducted by the Stanford Research Institute Project Earthquake Watch which obtained statistically significant results indicating that reports of unusual animal behavior increase prior to some earthquakes (Otis and Kautz, 1985).

5 Comparison of Animals and Behaviors

Dogs were the animal most frequently sited as behaving unusually prior to an earthquake. This is an especially interesting finding considering that there were more cat than dog owners in the study, and a previous survey of this same population found a correlation between this higher number of cat owners and a greater number of believers in "psychic" cats than dogs (Brown and Sheldrake, 1997). This finding of more "psychic" cats had been somewhat counterintuitive as, in general, dog owners tend to have closer relationships with their pets than cat owners, and cats tend to be less sociable and more independent than dogs (Hart, 1995). Unusual behavior is difficult to define, and determining if there is a characteristic behavior is not clear-cut, although there are some distinct patterns. For example, an intense fear that appears to make some animals cry and bark for hours, and others flee in panic has been reported often. Equally characteristic is the apparent opposite effect of wild animals appearing confused, disoriented, and losing their fear of people (Tributsch, 1982). Since there is experimental evidence that charged ionic particles can effect neurotransmitter ratios in animal brains, and that charged ions may be released prior to some earthquakes, it has been suggested that this may explain these two seemingly-contradictory behavior patterns (Tributsch, 1982). In addition

to the stories collected from the respondents in this survey, the authors of this paper have been collecting dozens of detailed accounts of unusual animal behavior prior to earthquakes through requests in newspapers and magazines, as well as on radio stations and internet sites. Many people reported dogs vanishing or barking uncontrollably. A number of pet owners found their ordinarily calm cats suddenly darted off and hid, or paced around crying for a few minutes before the earthquake. There were reports of goats and horses leaping around wildly, noisy birds suddenly becoming silent, or a whole flock of seagulls taking off all at once just before an earthquake. A few people noticed the number of roadkill increasing for several days before an earthquake. Although it's primarily accounts of dogs and cats that have been reported, many other types of animals in the wild, on farms, and in zoos; including horses, cows, goats, possums, rats, chickens, and other birds have been observed acting in unusual ways. The anecdotal evidence presented in this paper does not necessarily imply the existence of earthquake prediction abilities in animals. Some of the mysterious behavior discussed in this paper may ultimately be explainable in terms of reactions to ordinary stimuli. People may sometimes misperceive or exaggerate an animal's abilities, and the anticipatory behavior may be projected upon them in retrospect. However, some of the unusual behavior discussed in this paper may be due to a genuine sensitivity to precursory earthquake signals, and when these results are combined with the results of previous studies and observations, a very strong case can be made for the existence of this phenomenon.

In the case that animals are actually reacting to precursory earthquake signals, the following explanations have been proposed:

(1). Because many animals possess auditory capacities beyond the human range, it has been suggested that some animals may be reacting to ultrasound emitted as microseisms from fracturing rock (Armstrong, 1969).

(2). Fish have a high degree of sensitivity to variations in electric fields, and because telluric current variations have been noted before some earthquakes, it has been suggested that this is what the fish may be reacting to (Ulomov and Malashev, 1971).

(3). Because some animals have a sensitivity to variations in the earth's magnetic field (usually as a means of orientation), and since variations in the magnetic field occur near the epicenters of earthquakes (Chapman and Bartels, 1940), it has been suggested that this is what the animals are picking up on (Otis and Kautz, 1985). Marsha Adams, an independent earthquake researcher in San Francisco, claims to have developed sensors that measure low-frequency electromagnetic signals which allow her to predict earthquakes with over 90% accuracy, although this remains to be substantiated. Adams suspects that low-frequency electromagnetic signals created by the fracturing of crystalline rock deep in the earth along fault lines are "biologically active", and that her instruments are picking up the same signals that sensitive animals do (Brown, 1997).

(4). Some organisms respond to changes in the polarity and concentration of atmospheric ions, and it has been suggested that this sensitivity enables some animals to detect the air-ionizing effects of radon released from the ground in advance of certain earthquakes. (Ulomov and Mavashev, 1967). Tributsch has suggested that a piezoelectric effect may be at work here. On the average, the earth's crust consists of 15% quartz, and in certain areas it can be as high as 55%. According to Tributsch, the piezoelectric effect of the quartz is capable of generating enough electrical energy to account for the creation of airborne ions before and during an earthquake. This electrostatic charging of aerosol particles may be what the animals are reacting to. Animals, also observed acting unusual in similar ways prior to thunderstorms, may have evolved sensitivity to electrical changes in their environment (Tributsch, 1982).

(5). The effects of radon gas on the level of air ionization explained above can also be expected to change the field gradient, and dozens of animals have been shown to be sensitive to changes in the electric field gradient of the atmosphere (Chalmers, 1967).

(6). The animals may be perceiving and responding to stimuli that currently science has no way to measure.

Experiments that can help us decide between these explanations are not easily performed, as studying earthquakes has inherent difficulties, because they are infrequent and unpredictable by their very nature. However, further investigation in this area could help us discover what the animals are reacting to, and to allow us to build sensors to detect the earthquake precursory signals. We suspect that these types of investigations hold enormous potential for understanding animals better, and predicting earthquakes more reliably. If an understanding of what animals are reacting to were to be obtained, it's value would be tremendous. However, even without understanding what the animals are reacting to, it is conceivable that an earthquake warning system could be created by networking people who observe animal behavior on a routine basis as Kautz and Otis did with Project Earthquake Watch, and the Chinese and Japanese have practiced for hundreds of years. Even something as simple as tracking the number of missing animals may prove to have some predictive value with regard to earthquakes. The pool of untapped resources potentially residing right under our noses may be vast. There are between 51 and 58 million households in the U.S. with dogs, and 49 and 60 million households with cats (American Demographics, 1991). This huge untapped and easily accessible population of potentially geo-physically sensi-

tive animals may be holding an enormous wealth of information. Animal experiments in this area hold great promise. Although studying the possible relationship between earthquake precursors and animal behavior may prove challenging, utilizing the animals' apparent sensitivity to precursory signals may not be difficult, and the benefits could be enormous. When one considers the annual and historical devastation wrought by earthquakes in the form of lives, property, and valuable resources, it becomes increasingly clear why studying this apparent sensitivity in animals is so vital.

6 Methods to Predict Earthquakes

Prediction is concerned with forecasting the occurrence of an earthquake of a particular intensity over a specific locality within a specific time limit. Normally prediction is of three types viz. long, medium and short range prediction. While long range prediction is concerned with forecasting the occurrence of an earthquake a number of years in advance, medium term prediction is to be done a few months to a year or so and the short term prediction implies forecast ranging from a few hours to some days in advance. Medium and short range predictions are very useful because they can help in saving the largest population from disaster in terms of life and property. Scientists believe that it is possible to predict major earthquakes by monitoring the seismicity caused by natural earthquakes, mining blasts, nuclear tests, etc. However, no flawless technique has been developed to predict the earthquakes till date. Some of the methods and models are beyond the scope of the present work and only a few simple methods and models will be discussed here.

6.1 Unusual animal behavior

It is a well established fact that animals are endowed with certain sensory perceptions denied to human beings. Some of the animals have much better power of sniffing, hearing, seeing and sensing than the human beings. The unusual behaviour of animals prior to earthquakes received wide publicity after the Haichang earthquake in Liaoning province of China, in February 4, 1975 was successfully predicted. Although fluctuations in water levels and radon content in water were given due consideration, behaviour of animals was not overlooked in the process of earthquake prediction. On the morning of February 4, 1975, a moderate forestock hit the city of Haichang and by 2 p.m. a general alert was proclaimed. Within six hours, the area was rocked by a devastating earthquake of 7.3 magnitude but almost all the one lakh residents were saved. Chinese are considered to be pioneers in recognizing the unusual behaviour of animals preceding a quake as an important indicator to predict an impending earthquake, particularly since the accurate prediction of Haichang quake of 1975. In fact, national war against earthquakes was launched in 1966 with an effective slogan, "Rather a thousand days with no earthquake than one day with no precaution." Chinese report was presented at the Intergovernmental meeting convened at UNESCO, Paris in February 1976. This stimulated considerable interest among scientists. However, it should be mentioned that abnormal behaviour of animals prior to a devastating earthquake was noticed earlier also in different parts of the world. In Japan large number of rats were seen every day in a restaurant in Nagoya City, which suddenly disappeared on the evening prior to Nobi earthquake of 1891.

Similar observations about rats were reported at two earlier occasions i.e., Kanto earthquake of 1923 and Sankriku earthquake of 1933. In China, unusual behaviour of rats was reported before 1966 Hsingtai earthquake in Hopei Province (300 km from Beijing). In 1835 dogs escaped from the city of Talcahuano in Chile before the earthquake struck the city. Flocks of birds flew inland before the Chilean earthquakes of 1822 and 1835. Monkeys became restless a few hours before the Managua earthquake of 1972 in Nicaragua. In summer of 1969, just before the Bahai quake (July, 1969), the custodians of Tientsin Zoo had observed that swans suddenly scrambled out of water and stayed away, a Manchurian tiger stopped pacing, a Tibetan yak collapsed, pandas held their heads in paws and moaned; and turtles were restless. Hens and cocks were reported restless about an hour's before in 1896 Ryakya earthquake in Japan. In Yugoslavia, birds in zoo started crying before 1963 earthquake. Deer gathered and cats disappeared from villages in northern Italy two or three hours before damaging earthquake of 1976. Just before the earthquake which occurred in 1906 along the San Andreas Fault, horses whined and cows stampeded. In other cases cows about to be milked became restless before the shock. Bellowing of the cattle at the time of shock was very commonly reported. Howling by dogs was reported during the night preceding the earthquake. Abnormal behaviour just before an earthquake has also been noticed among animals who live underground, like snakes, insects and worms, and those living in water (fishes). Abundant fishes were caught in just before the 1896 earthquake in north western coast of Japan and the Tango earthquake of 1927. However, in Kanto earthquake (1923) fishes were reported to have disappeared. Just before the Edo earthquake (November 11, 1855), many grass snakes were reported to have come out of the ground near the epicentral areas even though it was severe cold winter. Very unusual behaviour of dogs was reported just before the Turkey earthquake (November 24, 1976). Barry Ralleigh of the U.S. Geological Survey noticed that the horses were fidget just before the earthquake of 28 November 1974 in Hollister (California).

In India, unusual behaviour of animals with respect to earthquake was noticed early in 1892. Animals were noticed to sniff the ground and exhibit nervousness such as a dog shows in the presence of an unaccustomed object, at the time of Govindpur (Manbhoom) a February 19, 1892. During the recent

earthquakes of Uttarkashi (1991), Latur (1993), Jabalpur (1997), Chamoli (1999) and Bhuj (2001) there were isolated cases of unusual behaviour of pet dogs. Extensive research is being carried on all over the world about the unusual behaviour of animals with respect to prediction of the earthquake. China and Japan are fore-runners in this regard. The USA has also shown keen interest in unusual behaviour of animals as a useful indicator of earthquake prediction.

The Stanford Research Institute, California, under the 'Project Earthquake Watch' has a network along the San Andreas Fault. This group keeps a watch on the behaviour of about 70 animal species. Dr. B.G. Deshpande has compiled a list of 87 animals which have been watched all over the world and whose behaviour might sense as an advance indicator of impending quake. Some of these which may be easily observed by the city dwellers are; cockroaches, crows, dogs, donkeys, ducks, fowls, frogs, geese, goats, horses, mice, monkeys, pigs, pigeons, rats, sheep, squirrels, swans and snakes. The Group of Earthquake Research Institutes of Biophysics, China (1979) has arrived at the following conclusions after an extensive survey of animal behaviour before a strong earthquake.

(1). Most animals show increased restlessness before an earthquake.
(2). The precursor time varies from a few minutes to several days, with increased restlessness at 11 hours which becomes still more marked about 2 to 3 hours before the earthquake. In general precursor times of various animals are mostly within 24 hours before the earthquake.
(3). These observations have been noticed predominantly in high intensity or epicentral region close to active faults.
(4). Abnormal behaviour of the animals is observed during earthquakes of magnitude 5 or more.

More intensive response can be noticed with the increase of intensity of earthquakes.

6.2 Hydro chemical precursors

Chemical composition of underground water was observed on a regular basis in seismically active regions of Tadzhik and Uzbekistan. These observations yielded following results.

(1). Concentration levels of dissolved minerals and gaseous components remained almost constant during seismically inactive period.
(2). An appreciable increase in concentration of dissolved minerals was noticed 2 to 8 days before an earthquake. Variations in level of underground water, the pressure of artesian water, the discharge of water sources and temperature of underground water were also noticed during this period. These variations are large in the event of a strong earthquake.
(3). After the earthquake, anomalies in concentrations of the gaseous and mineral components disappear.

According to India Meteorological Department report, significant pre-disaster and post disaster hydro geological changes rendering the ground water turbid were observed during the Jabalpur earthquake in Madhya Pradesh (1997).

6.3 Temperature change

There seems to be some relation between temperature and earthquakes. A considerable rise of temperature by 10°C and 15°C was reported before earthquakes in Lunglin in China (1976) and Przhevalsk in Russia (1970). The epicentral distances of these earthquakes where observations were taken in hot spring/well were 10 and 30 km and precursory periods were 42 and 72 days respectively.

6.4 Water level

There are drastic changes in water level in several wells just before a major earthquake. There was a fall in water level a few days before the Nankai earthquake in Japan (1946). Rise of water level by 3 and 15 cm was reported before Lunglin (China) and Przhevalsk (Russia) earthquakes.

Similarly, water level rose by 3 cm a few hours before the earthquake in Meckering in Australia (1968). In China rise of water level in wells was observed before earthquakes of Haicheng (1975), Tangshan (1976), Liu- quiao and Shanyin (1979).

Experiments in water level variations have been conducted in Kurile Islands to predict the earthquakes of 4 and more on Richter scale. For this purpose wells upto 410-670 metres depth at epicentral distances upto 700 km are used. This is an effective technique for observing the deformation of the earth's crust. The model on which the forecasts of earthquakes is based shows that 3 to 10 days before an earthquake, the water level begins to fall. After a short period, it starts rising when the earthquake strikes.

6.5 Redon gas

Radon is a radioactive gas which is discharged from rock masses prior to earthquake. It is dissolved in the well water and its concentration in the water increases. Such an increase was reported in Tashkent in 1972 where increase in concentration varying from 15 to 200 per cent was noticed about 3 to 13 days prior to an earthquake. In China, 50% and 70% increase in radon concentration was reported 18 and 6 days respectively before the Tangshan (1976) and Luhuo (1973) at Langfang

and Guzan stations which were located 130 and 200 km epicentral distances for two cases. In 1995, a correlation in radon anomalies at four sites in Kangra and one site in Amritsar with the time of occurrence of Uttarkashi earthquake (1991) was reported.

6.6 Oil wells

Large scale fluctuations of oil flow from oil wells prior to earthquakes were reported in Israel, northern Caucasus (Europe) and China. These earthquakes which occurred in 1969, 1971 and 1972 gave rise to increased flow of oil before their occurrence. It has been suggested that when the tectonic stress accumulates to a certain level, the pore pressure within a deep oil bearing strata reach its breaking strength causing oil to sprout along the oil wells.

6.7 Theory of Seismic Gap

Seismicity gap is a region where earthquake activity is less compared with its neighborhoods along plate boundaries. Soviet seismologist S.A. Fedotov studied the seismic record of 12 large earthquakes which rocked northern Japan between 1904 and 1963. By plotting the size of each tremor- struck area, he found that each quake segment abutted the next contiguous one without overlapping, as if each deep seated crack had been shut off by a barrier at the ends of the fracture zone. Each large earthquake was in a segment that was quiet for the last 39 years or so. Fedotov predicted that those segments which were quiet for some time will be hit by earthquake sooner or later. Three of these blocks in Kurile Island were struck where according to Fedotov an earthquake was due. Thus evolved the theory of seismic gap in earthquake prediction.

In India, three seismic gaps have been identified one in Himachal Pradesh which lies along the plate boundary between earthquakes of Kangra (1905) and Kinnaur (1975); the second called 'Central gap' between 1905 and 1934 earthquakes, third called 'Assam Gap' in northeast India between earthquakes of 1897 and 1950. Identification of these gaps can go a long way in predicting the earthquakes in these areas.

6.8 Foreshocks

Generally major earthquakes are preceded by minor shocks known as foreshocks. These foreshocks provide valuable dues to the occurrence of a strong earthquake. Some of the earthquakes have been successfully predicted on the basis of study of foreshocks. In addition to unusual behaviour of animals, the Haichang earthquake in China (February 4, 1975) was predicted by studying the increased seismicity from December 1974 to February 1975.

The Oaxaca, Mexico earthquake of November 1978 was also successfully predicted on the basis of foreshock observations. Foreshocks have been detected a few days to a month in advance with the help of closely located seismic stations in Himachal Pradesh for several earthquakes like Anantnag (1967), Dharmasala (1968), Kashmir (1973), Kinnaur (1975) and a few others. Uttarkashi earthquake of October 20, 1991 was preceded by foreshocks on October 15 and 16 with magnitude larger than 3.5 on Richter scale.

The most recent Bhuj earthquake of January 26, 2001 was also preceded by foreshocks in December 2000. But there are some other earthquakes which are preceded by foreshocks. Therefore, this is not a flawless method and has to be supplemented by other methods of earthquake prediction.

6.9 Changes in Seismic Wave Velocity

We know that P, S, and L waves originate from the focus of an earthquake. P and S are called body waves because they travel through the body of the earth, while L waves are known as surface waves because they move along the upper crust of the earth. P waves are faster than the S waves and reach seismographs first. The time lag between the arrival of P and S waves is called lead time. Russian seismologists found that this lead time began to decrease significantly for days, weeks and even months before the earthquake. But just before the quake hit the area the lead time was back to normal. A longer period of abnormality in wave velocity presaged a larger quake. Taking the cue from the Russians, Lynn Sykes, Scholz and Aggarwal conducted laboratory, experiments on rock samples in 1973. These experiments showed abnormal change of ratio of velocities of P waves and S waves before the earthquake. This ratio is expressed as V_p/V_s. The duration of V_p/V_s anomaly depends upon the fault or dimensions of the aftershock area. After the Garm region of the former USSR, V_p/V_s anomalies were noticed in Blue Mountain Lake earthquake in the USA in 1973. The velocity anomaly period for this earthquake was about 5 days and the decrease in velocity was about 12 per cent. Similar decrease in velocity ratio was reported before the damaging Haichang (February 4, 1975), Songpan-Perigwu (August 16, 1966) and bungling (1976) earthquakes in China. In Japan, 7 to 40% decrease in the velocity ratio ranging from 50 to 700 days before the main earthquakes were recorded. In Tehran 14% decrease in velocity was reported 1 to 3 days before three earthquakes in 1974. Immediately after the Gujarat earthquake of 2001, the Survey of India mooted a network of 300 permanent Geographical Positioning System (GPS) stations all over the country to monitor earth movements round the clock which help in predicting earthquakes.

If the GPS systems are located along the known active faults, it is possible to monitor movements of active faults or breaks in the earth's crust. Though no precise prediction can

be made about the location and magnitude of an earthquake, minor movements are an indication of an impending earthquake because it reflects the force coming from below the crust.

7 Earthquake Prediction in the Indian Context

An understanding of earthquake risk in India requires an understanding of the fundamental characteristics of earthquakes in India, how their associated ground shaking propagates, the effects of local site conditions, the vulnerability of buildings, and the exposure of buildings and people to the ground shaking. To develop new and improved models in these areas requires high-quality earthquake and ground motion data, along with comprehensive building and infrastructure performance data and inventories. By combining these models it is possible to understand the risk, and to minimize the chance of catastrophic losses by improving the design of structures through appropriate building codes.

Management of earthquake risk cuts across all levels of government, non-government agencies and groups, and the general community. The analysis of earthquake hazard and risk requires collaboration between these sectors as each has their own responsibility and role. Gaps in the knowledge and information that is required to achieve these outcomes, particularly in the areas of earthquake source models, ground motion models and vulnerability research, need to be addressed, and the three levels of government, as well as industry and academia, all have important roles to play.

8 Conclusions

Earthquake prediction is a social imperative and there is need to carry out research with respect to abnormal animal behaviour. The review has shown encouraging results of using abnormal animal behaviour before an earthquake for prediction in many countries and it requires its due attention in Indian context. Most of the methods and models are beyond the scope of the present work and only a few simple methods and models discussed. These to Predict Earthquake are 1. Unusual Animal Behaviour, 2. Hydro-chemical Precursors, 3. Temperature Change, 4. Water Level, 5. Radon Gas, 6. Oil Wells, 7. Theory of Seismic Gap, 8. Foreshocks, 9. Changes in Seismic Wave Velocity. Animals are actually reacting to precursory earthquake signals, the following explanations have been proposed.Observations of unusual animal behavior prior to earthquakes have been reported around the world. Many animals have access to a perceptual range exceeding those of humans is scientifically well established. The requirement for the earthquake prediction in the Indian context has been discussed.

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