J. Ind. Geophys. Union (March 2018)
v.22, no.2, pp: 151-162

Forecasting aftershocks of major earthquakes

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ABSTRACT
Aftershocks of highest magnitude of major earthquakes of magnitude ≥ 7.9 can be forecast on certain lunar days when prominent changes are observed in both values of (Ocean) high tides. If main earthquake occurs on the day when both (Ocean) high tides start decreasing or when both high tides are observed as minimum (continue decreasing) then aftershock of maximum magnitude can be forecast during low tide period. If main earthquake occurs on the day when both high tides start increasing or both high tides are observed as maximum (continue increasing) then aftershock of maximum magnitude can be forecast during high tide period.

Key words: Forecasting; aftershocks; major earthquakes, maximum magnitude; Solar-lunar gravitational force, earth tides, Ocean high tides.

INTRODUCTION

Earthquake, in general, is considered an unpredictable phenomenon. It is caused mainly by the interaction of the tectonic plates as they move. The fault lines or borders between the various plates are where most of the world's earthquakes occur. It is also well known that in areas where the tectonic plates collide, one plate is forced either above or below the other, and produces the high magnitude earthquakes, as well as most obvious geographic phenomenon, major mountain ranges for instance. Ide et al., (2016) investigated three separate earthquake records covering Japan, California and the entire globe. For the 15 days leading up to each quake, they assigned a number representing the relative tidal stress on that day, with 15 representing the highest. They found that large quakes such as those that hit Chile and Tohoku-Oki occurred near the time of maximum tidal strain or during new and full moons when the Sun, Moon and Earth align. For more than 10,000 earthquakes of around magnitude 5.5, the researchers found, an earthquake that began during a time of high tidal stress was more likely to grow and become a significantly high magnitude earthquake, at times to magnitude 8 and above. The aim of the present study is to examine the impact of the different phases of the Moon in forecasting aftershocks of major earthquakes by using tide's tables. Ultimate aim of this study is also to indentify the region where an earthquake is expected.

DATA

Year wise/ month wise earthquakes data, for the period 2009 to 29 September 2017 have been collected from National Earthquake Information Center web site, U.S.A (USGS). Also earthquake data have been collected from I.M.D. web site from 2007. Shri Venkateshwar Shatabdi Panchangam (hundred years Almanac: 1944 to 2044 AD) has been used to identify lunar day for all earthquakes. Tide's tables from 2009 to 2017 have also been collected from PNP Maritime Service Private Limited, Mumbai, which has been prepared by Survey of India.

PREVIOUS STUDIES

Fredrick and Becker (1976) mentioned that spring tide occurs when the Moon is New or Full, Figure 1. Because the Moon and the Sun are then attracting from the same or opposite directions, lunar and solar tides reinforce each other. The neap tide occurs when the moon is at quarter phase; then the Moon and Sun are at 90° apart in the sky, so that one set of tides is partly neutralized by the other. When the Moon is New or Full also in perigee (nearest point), the difference in level between low and high tides is especially great (Figure 2). When the Moon is at apogee (farthest point) the tidal range shrinks.

Kolvankar et al., (2010) observed that earth tides trigger earthquakes at all depths and up to magnitude 5.0. The lateral stresses applied during earth tides close to Full Moon phase are found to be more effective than those stresses of earth tide during the New Moon phase. Kolvankar (2011) observed that over 98% of world wide earthquakes faithfully follow the straight-line relationship between the Sun position or GMT timings with Earth-Moon distance (EMD) and Sun-Earth-Moon angle (ESM). It is seen that all these earthquakes are triggered by the Earth tides caused by the positions of the Sun and the Moon and this process seems to be the primary triggering mechanism for all worldwide tectonic earthquakes. He has also mentioned that high magnitude earthquake counts from 00 hours (midnight) to 06 hours and shown a pattern

that is inversely proportional to the daily atmospheric variation. The suggested pattern has shown the influence of the temperature. This position again depends upon the Sun's local position (Kolvankar 2010). During Rig Veda era, people/saints were having knowledge about the influence of the Sun and seven planets Moon, Mars, Jupiter, Mercury, Venus, Uranus, and Neptune over each other and on the Earth. They were also having knowledge of the destructive power of the Moon, which is apparent from their prayer to the Moon: "You do not put us in the hands of death, we should see always the movement of the Sun in the sky, we should always remain alive, every day our senility should be beneficial and keep the death of God away from us" (Paramhans Swami Jagdishwaranand Saraswati (2010). This type of fear had not been expressed while praying to any other planet (God). While appreciating the level of understanding the seers had regarding the impact of terrestrial bodies on the Earth, we need to keep in view one basic reality. The Moon is closer to the Earth compared to any other planet and as such perturbations on the Earth and The Moon can affect each other. Apart from the Moon the impact due to the Sun on the Earth is considerable. The Sun being very powerful in every respect compared to any of its planets, can cause instability on every planet including the Earth. Such an impact on the Earth`s stability is caused through increase or decrease in the magnitude of solar flares. Apart from the Sun any impact or change in surface manifestations and sub surface structure of the Moon due to different reasons can cause instability on some segments of the Earth, leading to occurrence of earthquakes. These abnormalities can be significant basically due to the Moon`s proximity to the Earth. Such impacts from other planets including the biggest planet Jupiter will not affect the Earth unless they are significantly strong and create an amount of instability not only on the Earth and the Moon but also on other planets. Such a possibility happens at times especially on a particular day when the Earth and the Ocean tides increase in magnitude (on certain days including new moon and full moon days).

Tanaka (2010) observed that since tidal forces generate currents in conducting fluids in the Earth's interior, they in turn affect the Earth's magnetic field. Earth tides have also been linked to earthquakes by him. Juan et al., (2000) considered relationship between 21 major earthquakes ($Ms \geq 7.0$) inland and off shore area of Taiwan Island in 20th century and the variance ratio of the lunar-solar tidal force. They observed that the time of these earthquakes is closely related to the variance ratio of the lunar-solar tidal force and therefore that the tidal force plays an important role in triggering earthquakes. Venkatanathan et al., (2005) mentioned that if two or more planets, especially Sun and Moon are aligned more or less in line (0° or 180°) with the Earth, then the Earth would be caught in the middle of a huge gravity struggle involving the Sun and other planets, including the Moon.

When the speed of rotation of the Earth changes the tectonic plate motion also get affected. Thus the planetary forces act as a triggering mechanism for the accumulated stress to be released abruptly at plate boundaries/ intra-plate faults. It is well known that the gravitational pull of the Moon and the Sun creates tides on the Earth. While tides are most commonly associated with Oceans and large bodies of water, gravity creates tides in the atmosphere and the lithosphere (the surface and interior of the earth extending to sub crustal upper mantle of the Earth). The atmospheric tidal bulge extends far in to the space but the tidal bulge of the lithosphere is limited to 12 inches (30 cm) twice a day (http://geography.about.com/od/physicalgeography/a/tides.htm).

Killer tornadoes develop mostly during high tide period (74.1%) under favorable synoptic situations. High tide and low tide periods have been considered from 10th to 3rd and 4th to 9th during each waning and waxing period of the Moon respectively, Kumar et al., 2012.

Bhattacharya (1998) mentioned that the study of Varaha Mihira (Brihat Samhita, 600 AD) gives us a fairly good idea of seismically active areas in India where moderate to large earthquakes occurred. One belt runs north to south along Hazara, Jammu and Kashmir, Punjab, Himachal Pradesh, U.P. hills and western Border areas of U.P., Delhi and Jaipur. Second belt starts at Surat and moves northward to Saurashtra and southern Rajasthan and then runs eastward to Madhya Pradesh, southeast U.P., Bihar, Bengal and Tripura. Third belt is along central Kerala and east coast from Tamil Nadu to southern Orissa through coastal Andhra Pradesh.

It had been mentioned (http://www.contentwriter.in/articles/others/earthquake.htm) that most of catastrophic events of earthquakes are associated with any of these two belts:

1. Western Coasts of North and South America, the Aleutian Islands and the Island groups along the eastern Coasts of Asia, such as Japan and the Philippines and thus borders the Pacific Ocean on the east, north and the west.

2. It includes the Mediterranean, the Alps, the Caucasus and the Himalayas and continues into East Indies, where it intersects the first belt. Uttaranchal, Assam and Andaman Nicobar Island chains fall within the 2nd belt and thus face frequent earthquakes of devastating nature.

Variations in Tidal Range on Different Lunar Days

Continuous changes in the values of both high Sea tides (Arabian Sea) during every fortnight have been put under four different categories. Each specific feature is noticed

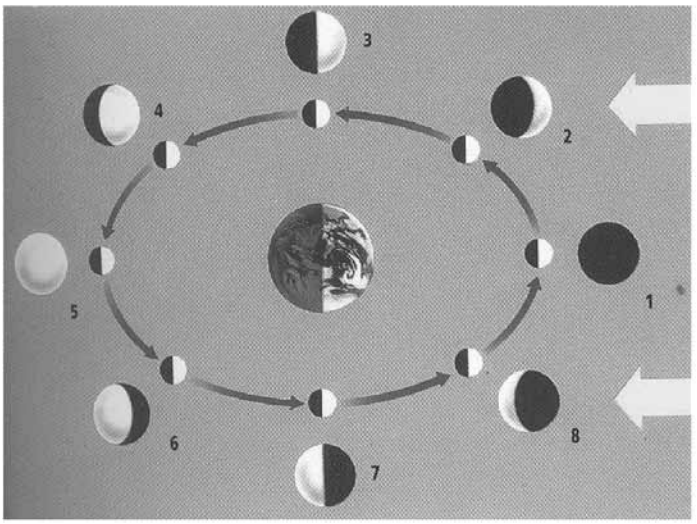

Figure 1. Phases of the Moon**.**

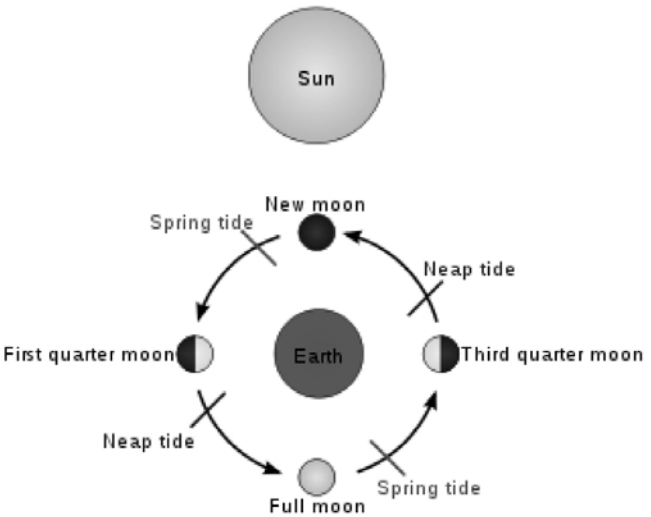

Figure 2. Types of tides.

once in each waning and waxing period in every month and 24 times (normally) in a year. The alphabet 'K' and 'S' denote waning (starts after full moon and up to new moon) and waxing (starts after new moon and up to full moon) period, respectively (Krishna and Shukla Paksha). First day, of the waning and waxing period, has been marked as K-1 and S-1, respectively. It has been observed that when both values of high tides reach maximum on a certain lunar day, then on a certain lunar day both start decreasing. Again both values of high tides go on decreasing daily and on a certain lunar day both values of high tides are observed as minimum. After that on a certain lunar days, both values of high tides start increasing and go on increasing daily. Again on a certain lunar day they reach maximum and the cycle continues. The details of tidal feature, which were found in the tide tables for the years 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016 and 2017 are as under:

Feature Lunar days (total number of occurrence)

Both high tides start decreasing (S.D.):

K-2 (9), K-3 (31), K-4 (50), K-5 (16) and K-6 (1); K (107)

S-1 (1), S-2 (7), S-3 (34), S-4 (41), S-5 (28) and S-6 (2): S (113)

Here K-2 (9) denotes, on nine occasions both high tides started decreasing on 2nd day of the waning period i.e. on Krishana Paksha Dooj. S-1 (1) denotes, on one occasion both high tides started decreasing on 1st day of the waxing period i.e. on Shukla Paksha pariva. So, out of 220 days [K (107) and S (113)] during 9 years period both tides S.D. on maximum occasions during 4th lunar day of both fortnights for 84 days [K-4 (50) and S-4 (34): 38%].

Both tides continue decreasing (C.D.):

K-7 (1), K-8 (46), K-9 (58) and K-10 (5): K (110)

S-7 (1), S-8 (43), S-9 (60) and S-10 (1): S (105)

On these lunar days both high tides reached their minimum heights. So, out of 215 days [K (110) and S (105)] during 9 years period, minimum tides were observed on maximum occasions on 9th lunar day of both fortnights for 118 days [K-9 (58), S-9 (60): 54.8%].

Both tides start increasing (S.I.):
K-9 (2), K-10 (32), K-11 (31), K-12 (34), K-13 (7), K-14 (2), K-15 (1): K (109)
S-9 (1), S-10 (31), S-11 (40), S-12 (25), S-13 (14), S-14 (1), S-15 (1): S (113)
So, out of 222 days (K 109, S 113) during 9 years period, both tides S.I. on maximum number of occasions on 11th lunar day (Aakadashi) of both fortnights for 71 days [K-11 (31), S-11 (40): 31.9%].

Both tides continue increasing (C.I.):
K-1 (21), K-2 (39), K-3 (27), K-4 (3), K-12 (1), K-13 (3), K-14 (3), K-15 (13): K (110)
S-1 (32), S-2 (31), S-3 (31), S-4 (1), S-11 (1), S-13 (2), S-14 (5), and S-15 (12): S (115)

In this case both high tides reached their maximum heights on these lunar days. Out of 225 days during 9 years period, maximum tides were observed on maximum number of occasions during 2nd lunar day in both fortnights of a month for 70 days [K-2 (39) and S-2 (31): 31%].

It is also observed that on 12 and 13 occasions, maximum tides were forecast for full Moon and new Moon's day, respectively during 9 years period. So, out of 225 days [(K (110) and S (115)] during 9 years period maximum tides were observed on only 25 days [K- 15 (13) and S- 15(12)] during new moon's and full moon's day (11%).

METHODOLOGY

Generation and influence of Earth tides have been considered an important triggering mechanism for worldwide occurrence of earthquakes by some seismologists. Researchers in the US have found a link between the position of the Sun and Moon and small tremors deep within the San Andreas Fault - suggesting that the gravitational pull of the astronomical bodies could be causing the Earth's plates to move up and down like the ocean's tides. The San Andreas Fault stretches some 1,287 kilometres (800 miles) through California – is a geological region where the Pacific Plate and the North American Plate meet. To come to that conclusion, the team analysed 81,000 low-frequency earthquakes that occurred between 2008 and 2015 near the Parkfield section of the fault – an area that is constantly jittering with seismic activity. They then compared this data to tidal data from the same timeframe, paying particularly close attention to the two-week 'fortnightly tide', which coincides with the lunar cycle. When all was said and done, the team found that seismic activity in the region increased when the Moon was in its waxing phase, building up to a full Moon. *Proceedings of the National Academy of Sciences*, 2016 (https://www.sciencealert.com/the-pull-of-the-sun-and-moon-can-cause-earthquakes-along-the-san-andreas-fault-study-finds). In a report published by National Geographic News in 2005 it is mentioned that James O. Berkland, California-based geologist in —*An Earthquake Newsletter* believed that the gravitational tugs of the moon, sun, and other planets can influence earthquake activity. He claimed that during the alignment of three celestial objects the Sun, Earth, and Moon that occurs twice a month, at the full and new moons the gravitational forces are at a maximum, especially when the bodies are close together. The Earth and moon are closest together—at perigee—once a month. The Earth and sun are closest together—at perihelion—once a year. Perihelion currently occurs in early January. Maximum gravitation force occurs when perigee occurs on the same day as perihelion. From the seismic data gathered from the Moon, moonquakes occur most frequently at perigee. USGS seismologists negated his theory that influence of celestial bodies on the Earth can lead to seismic activity on the Earth. They opined that though the Earth can trigger quakes on the moon, the moon is too small to trigger any earthquakes. But, the moon is mostly solid and lacks a liquid core like the Earth, which is an active, living planet, and so it is not at all surprising that minor gravitational stresses can trigger earthquakes, Berkland said. Berkland said he accurately predicted several earthquakes, including the October 17, 1989 earthquake in San Francisco, California. At least two major quakes may also support Berkland's theory. The December 26, 2004, magnitude 9.1 in Sumatra, Indonesia, occurred on the day of a full moon. Likewise, the March 27, 1964, magnitude 9.2 earthquake in Alaska occurred on the day of maximum high tide. According to Berkland, such correlations are more than coincidences. They demonstrate a true connection between the moon and earthquake activity (https://news.nationalgeographic.com/news/2005/05/0523_050523_moonquake_2.html).

Ocean tides are linked with earth's tides. Arabian Sea tide's tables from 2009 to 2017 have been studied for forecasting earthquakes aftershocks. An appropriate lunar day has been marked on all day of respective months of the tide's tables. Normally semi- diurnal tides (two high waters and two low waters each day) have been forecast for all the months in the tide's tables. In every month, 3 tides a day have been forecast for three to five days, when two tides were separated by more than 6 hours. In a few cases only two tides were forecast. During 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016 and 2017, it has been observed that mostly both values of high tides S.D. from 3rd or 4th or 5th day of waning and waxing period and C.D. till

8th or 9th day of both fortnights. Again, mostly both high tides S.I. from 10th or 11th, or 12th and C.I. till 1st or 2nd or 3rd lunar day during waning and waxing period. Although earthquakes are observed daily on global basis, yet it is not possible to locate the earthquakes on the basis of tides trend of any Ocean as impact of earth tides on the Earth surface cannot be located. Once a major earthquake struck (≥7.9 magnitude considered), aftershocks can be forecast on the basis of tides trend observed under item "Variations in tidal range on different lunar days". From S.D. trend, K-3, K-4, K-5, S-3, S-4 and S-5; from C.D., K-8, K-9, S-8 and S-9; from S.I., K-10, K-11, K-12, S-10, S-11 and S-12; from C.I, K-1, K-2, K-3, S-1, S-2, and S-3 can be selected for aftershocks forecast as these trends have been observed on maximum number of days. High tides period have been observed from 10th lunar day to 3rd lunar day and low tides mostly from 3rd to 9th lunar day in both the fortnights of the month. 3rd lunar day is observed in both the trends. Lunar days K-3 and S-3, have been observed significantly under trends S.D. (65 days) and C.I. (58 days), as such both have been included for aftershocks forecasting during low and high tide periods. If main earthquake is observed in high tide's period then it would be relevant to consider S.I. and C.I. and for low tide's period S.D. and C.D. trends for forecasting aftershocks. So, for occurrence of aftershocks (≥ 5.0) during high tide's period; K-1, K-2, K-3, K-10, K-11, K-12; and S-1, S-2, S-3, S-10, S-11, S-12 (12 days forecast in a month), and during low tide's period; K-3, K-4, K-5, K-8, K-9; and S-3, S-4, S-5, S-8, S-9 (10 days forecast in a month) can be selected for one month to two months period depending upon the correctness of forecasting and magnitude of earthquake. But if S.D., C.D., S.I. and C.I. trend forecasts are available from the tide's table, these dates should be also included in the forecast if they are not covered by these lunar days. If earthquake occurs on K-3/S-3 lunar day then tide's table has to be consulted to know whether the earthquake has occurred on C.I. or on S.D. If C.I. is observed on K-3/S-3, then forecast for high tide period lunar days should be considered (10th, 11th, 12th, 1st, 2nd and 3rd). If S.D. is observed on K-3/S-3 then forecast for low tide period should be considered. If C.I. has been observed prior to K-3/S-3 and earthquake has been observed on K-3/S-3 then forecast for low tide period should be considered. On the basis of lunar days, forecast can be issued for every 15 days on selected English dates for general public. In Hindu calendar, lunar day starts after Sunrise and continues till Sunrise, whereas English date starts after mid-night. In majority of cases all four trends (S.D., C.D., S.I. and C.I.) observed for Arabian Sea would be observed on the same lunar day for other Seas as spring and neap tides depending upon the position of the Moon. Solar-lunar eclipses are observed on a fixed date for all countries. Any lunar day in U.S.A. will be observed nearly after 12 hours depending upon the difference in time of the two locations in US and the selected country. Earthquake forecast based on lunar days comes into effect on a lunar day, which starts in India after Sun rise and earthquake forecast based on tide table comes into effect after midnight.

Tide's Tables during Aftershocks

Tide's tables for four important cases of aftershocks of major earthquakes have been given below. Ocean tide's trends for different Seas (S.D., C.D., S.I. and C.I.) may differ in terms of dates but here on the basis of Arabian Sea tide's table examples have been given. These four aftershocks can be successfully forecast:

(1) Earthquake struck Chile (36.12°S/072.9°S) on 27 February 2010 at 0634 UTC (1204 IST: S-14) with magnitude of 8.8 at the focal-depth of 22 km. One of the major aftershocks was observed on the forecast date 11th March 2010 near 34.33°S/071.8°S at 1455 UTC (2025 IST) having magnitude 7.0 and focal-depth as 18 km. All timings in the tide's tables have been given in IST (Hour Minute: HM) and height in Meter (M). Tide tables for 9th, 10th and 11th March are as under:

HM	Height (M)	HM	Height (M)	HM	Height (M)
0239	2.57 (9th)	0403	2.32 (10th)	0439	2.05 (11th)
0609	2.70	0832	2.69	0956	2.95
1237	1.76	1409	1.72	1528	1.53
2115	3.25	2211	3.44	2245	3.65

Earthquake occurred on 11th (S-10) when both high tide values S.I. on 11th. It was observed at 2025 IST and 2nd high tide was observed at 2245 IST. On 11th both high tides show increasing trend (S.I.).

(2) Earthquake struck Honshu Japan on 11th March 2011 at 0546 UTC (1116 IST: S-6) near 38.4°E/144.4°E having magnitude 9.0 at 17 km focal-depth. Aftershock of magnitude of 7.4 at 33 km. depth, was observed at 1432 UTC (2002 IST) on one of the forecast date of 7th (S-4) April 2011 when both high tides S.D. on 7th. Tide tables for 5th, 6th and 7th are as under:

HM	Height (M)	HM	Height (M)	HM	Height (M)
0041	4.02 (5th)	1007	4.00 (6th)	0134	3.92 (7th)
0648	0.57	0713	0.53	0741	0.59
1326	4.28	1358	4.29	1431	4.22
1907	1.39	1939	1.47	2015	1.61

Earthquake was observed at 2002 IST and 2nd high tide was observed at 1431 IST. On 7th both high tides values show decreasing trend (S.D.).

(3)A 7.9 magnitude earthquake of 10 km focal depth struck Nepal on 25th April 2015 (S-7) at 0611 UTC (1141 IST), near 28.1°N/084.6°E. Aftershock of 7.3 magnitude at 10 km focal depth struck on 12th May 2015 (K-9) near 27.7°N/086.0°E at 0705 UTC (1203 IST).This occurred on the forecast date. The tide tables for 11th, 12th and 13th May 2011 are as under:

HM	Height (M)	HM	Height (M)	HM	Height (M)
0443	3.37 (11th)	0026	1.84 (12th)	0139	1.63 (13th)
1049	1.38	0610	3.30	0744	3.42
1746	3.91	1206	1.56	1331	1.62
		1852	3.87	2001	3.92

Aftershock devastated already battered region when both high tides values were minimum on 12th. On 12th both high tides have shown minimum values in comparison to 11th and 13th. Earthquake was observed at 1203 IST, which came in between two high tides.

(4) On 8th Sept 2017, an earthquake occurred (magnitude: 8.1 and depth 56.7 km) over Mexico at 0449 UTC (1019 IST). Aftershock of maximum magnitude (7.1) occurred on 19th September at 1814 UTC (2344 IST: K-2) at the focal-depth of 48.0 Km, 17 minutes prior to forecast date of 20th September. Maximum tide was observed on 20th (C.I.). Tides table for 19th, 20th, and 21st are as under:

HM	Height (M)	HM	Height (M)	HM	Height (M)
0451	0.70 (19th)	0534	0.68 (20th)	0024	4.33 (21st)
1125	4.50	1203	4.54	0612	0.78
1724	0.85	1804	0.71	1236	4.47
2346	4.25			1840	0.65

Maximum magnitude aftershock occurred at 2344 IST, just two minutes before the 2nd highest tide on 19th. On 20th maximum value of high tide was observed at 1203 IST. Only three tides were observed during 24 hours. Lunar days are more marked for major aftershocks than timings of the high tides.

DISCUSSION

Earthquakes and aftershocks occurred during 2009 (2), 2010 (1), 2011 (1), 2012 (1), 2015 (2) and 2017 (1) of major earthquakes having magnitude ≥7.9.These earthquakes have been considered for forecasting aftershocks. These have been listed under Table 1. In 2013, earthquake having magnitude 8.3 occurred in Sea of Okhotsk at the focal-depth of 598.1 Km. No aftershocks ≥5.0 occurred after that day, because the earthquake originated from a depth of nearly 600 Km. Aftershocks of some selected major earthquakes (from the list) continued to occur for a period of one to three months. Aftershocks continued to occur almost daily for quite some time. It is expected that on forecast days, aftershock of magnitude ≥ 5.0 would usually strike. Magnitude of these shocks, on any day, is found to be high. On 3rd January 2009 an earthquake having magnitude 8.0 occurred in Indonesia. It occurred on 7th lunar day (S-7), which comes under low tide period. So, aftershocks having magnitude ≥5.0 can be forecast on S-8, S-9, K-3, K-4, K-5, K-8, K-9, S-3, S-4, S-5 and S-8 (11 days) for one month period. Corresponding dates for these lunar days can be found from Hindu almanac/calendar. Aftershocks, which took place on non forecasting days, have been mentioned as other day (O.D.) in the Table 1. Aftershocks have continued for six days i.e. up to 9th January 2009. Aftershock of highest magnitude of 6.0 took place on 6th January on O.D., and aftershocks of magnitude of 5.5/5.7/5.9 have occurred on the forecast day of 4th January. So, difference of just 0.1 has been observed in magnitude of aftershock between forecast day and O.D. On 3rd February 2009, aftershocks occurred nearly 600 km away from the main earthquake epicenter. Also these shocks occurred at relatively deeper focal-depths. Increased distance of epicenters and deeper focal depths suggest that these events are independent of the selected main shock. The above observations helped in discontinuing aftershock forecasting.

Table 1. List of aftershocks from 2009 to 2017.

Date	Time (UTC)	Place	Lat. (Deg.)	Long. (Deg.)	Magnitude (≥5.0)/ Depth (km)	Lunar Day	FCST
03.01.2009	1943	Indonesia	0.41S	132.88E	8.0 (7.7 USGS) /17.0	S-7	Main Eq.
	2149		0.32	132.88	5.6/29.0		
04.01.2009	0714		0.40	132.76	5.9/35.0	S-8	True CD
05.01.2009	1924		0.65	133.28	5.2/17.0	S-9	True
06.01.2009	2248		0.66	133.43	6.0/16.0	S-10	Other day: O.D.
07.01.2009	1502		0.41	132.85	5.2/35.0	S-11	O.D.
08.01.2009	1618		0.41	132.93	5.5/18.0	S-12	O.D.
09.01.2009	1435		0.71	133.78	5.2/35.0	S-13	O.D.
11.01.2009	1813		0.55	132.88	5.2/35.0	S-15	O. D.
12.01. 2009		No Eq.				K-3	False
14.01.2009	1333		0.51	132.95	5.0/35.0	K-4	True SD
15.01.2009	2352		0.30	132.60	5.0/35.0	K-5	True
19.01.2009	0014		0.47	131.90	5.0/32.0	K-8	True CD
20.01.2009	1046		04.67	129.81	5.5/ 143.0	K-9	True
22.01.2009	0315		0.52	127.43	5.1/132.0	K-12	O.D.
29.01.2009		No Eq.				S-3	False

Date	Time (UTC)	Place	Lat. (Deg.)	Long. (Deg.)	Magnitude (≥5.0)/ Depth (km)	Lunar Day	FCST
30. 01.2009		No Eq.				S-4	False
31.01.2009	0318		0.70	133.43	5.0/18.0	S-5	True SD
03.02.2009	1357		6.48	130.14	5.1/164.0	S-8	True CD
		FCST discontinued (DIS)					
29.09.2009	1748	Samoa Islands	15.49S	172.10W	8.1/18.0	S-11	Main Eq.
	2345		16.19	172.55	6.0/10.0	S-11	
30.09.2009	0524		15.34	173.29	5.3/10.0	S-12	True
01.10.2009	0613		15.43	173.25	5.8/10.0	S-12	True
02.10.2009	0107		16.33	173.47	6.1/8.0	S-13	O.D.
03.10.2009	0716		16.91	172.96	5.5/10.0	S-14	O.D.
04.10.2009	0910		16.23	173.24	5.5/23.0	S-15	O.D.
05.10.2009	0922		16.44	173.23	5.1/10.0	K-1	True CI
06.10.2009		No Eq.				K-2	False
07.10.2009	2338		16.74	172.40	5.3/10.0	K-3	True
10.10.2009	1941		15.60	173.06	5.9/13.0	K-7	O.D
11.10.2009	1100		17.59	173.08	5.1/10.0	K-8	O.D.
13.10.2009						K-10	False SI
14.10.2009	1800		14.91	174.82	6.3/10.0	K-11	True
15.10.2009						K-12	False
17.10.2009	0147		14.99	173.75	5.2/10.0	K-14	O.D.
18.10.2009	1202		16.39	173.27	5.4/10.0	K-15	O.D.
19.10.2009	2249		15.36	172.26	6.0/18.0	S-1	True CI
20.10.2009		No Eq.				S-2	False
21.10.2009		No. Eq.				S-3	False
28.10.2009	2356		15.79	173.39	5.5/10.0	S-10	True SI
29.10.2009	1552		15.40	173.21	5.0/10.0	S-11	True
30.10.2009		No Eq.				S-12	False
01.11,2009	2128		15.51	173.75	5.8/105.0	S-14	O.D.
02.11.2009	1706		15.44	173.57	5.5/10.0	S-15	O.D.
03.11.2009		No Eq.				K-1	False
04.11.2009	1835		15.64	171.80	5.2/10.0	K-2	True CI
05.11.2009	0604		17.57	176.89	5.3/35.0	K-3	True
06.11.2009	1735		17.02	173.02	5.1/10.0	K-4	O.D.
11.11.2009						K-10	False
12.11.2009	0213		20.98	178.66	5.8/570.0	K-11	True
13.11.2009	1722		16.07	172.74	5.3/10.0	K-12	True
14.11.2009		No Eq.				K-13	
15.11.2009		FCST DIS				K-14	
27.02.2010	0634	Chile	36.12S	072.90W	8.8/22.0	S-14	Main Eq.
	0801		37.77	075.05	7.4/35.0		
28.02.2010	1125		34.90	071.62	6.2/46.0	S-15	O.D.
01.03.2010	0244		35.04	072.49	5.7/22.0	K-1	True
02.03.2010	0428		36.67	073.30	5.5/35.0	K-2	True CI
03.03.2010	1744		36.61	73.36	6.1/20.0	K-3	True
04.03.2010	0159		33.22	072.12	6.0/24.0	K-4	O.D.
05.03.2010	1142		36.67	073.37	6.6/18.0	K-5	O.D.
07.03.2010	15.59		37.99	073.30	5.9/26.0	K-7	O.D.
10.03.2010	1220		33.56	072.30	5.6/35.0	K-10	True
11.03.2010	1439		34.29	071.89	6.9/11.0	K-11	True SI

Date	Time (UTC)	Place	Lat. (Deg.)	Long. (Deg.)	Magnitude (≥5.0)/ Depth (km)	Lunar Day	FCST
	1455		34.33	071.80	7.0/18.0		
	1458		34.61	071.99	5.6/35.0		
	2011		34.38	071.98	5.6/8.0		
12.03.2010	1650		34.23	071.92	5.8/7.0	K-12	True
13..03.2010	1034		37.55	073.46	5.8/35.0	K-13	O.D.
15.03.2010	1108		35.80	073.16	6.2/14.0	K-15	O.D.
16.03.2010	0221		36.22	073.26	6.7/18.0	S-1	True
17.03.2010	1829		35.44	073.04	5.1/22.0	S-2	True CI
18.03.2010	0157		36.57	072.77	5.2/28.0	S-3	True
19.03.2010	0854		35.84	073.47	5.5/14.0	S-4	O.D.
21.03.2010	1831		36.34	073.16	5.5/36.0	S-6	O.D.
26.03.2010		No Eq.				S-11	False
27.03.2010		No Eq.				S-12	False
28.03.2010	2138		35.39	073.39	6.0/29.0	S-13	O.D.
30.03.2010						K-1	False CI
31.03.2010	0710		33.66	071.86	5.3/29.0	K-2	True
01.04.2010	1253		34.65	071.82	5.1/11.0	K-3	True
02.04.2010	2258		36.23	072.88	6.0/24.0	K-4	O.D.
08.04.2010		No Eq.				K-10	False
09.04.2010		No Eq.				K-11	False
10.04.2010	2129		34.64	071.63	5.0/54.0	K-12	True
11.04.2010		FCST DIS					
11.03.2011	0546	Japan	38.3N	!42.37E	9.0/29.0	S-6	Main Eq.
11.03.2011	0615		36.28	141.11	7.9/42.0		
	0625		38.06	144.59	7.7/18.0		
	1946		40.48	139.05	6.2/10.0		
12.03.2011	0147		37.59	142.65	6.5/20.0	S-7	O.D.
13.03.2011	0126		35.72	141.64	6.1/8.0	S-8	True CD
14.03.2011	0612		37.78	142.46	6.0/14.0	S-9	True
15.03.2011	1523		40.33	143.29	6.1/19.0	S-10	O.D.
16.03.2011	0352		35.9	140.9	6.0/33.0	S-11	O.D.
17.03.2011	0413		40.13	142.17	6.2/29.0	S-12	O.D.
22.03.2011	0944		39.85	143.44	6.4/7.0	K-3	True SD
	1503		35.8	141.7	6.1/10.0		
23.03.2011	1043		36.67	141.46	5.1/35.0	K-4/ K-5	True
25.03.2011	1136		38.77	141.88	6.2/39.0	K-7	O.D.
26.03.2011	1252		39.39	143.29	5.2/21.0	K-8	True
27.03.2011	2223		38.42	142.01	6.2/19.0	K-9	True CD
29.03.2011	1054		37.40	142.29	6.1/15.0	K-10	O.D.
31.03.2011	0715		38.92	141.82	6.0/42.0	K-12	O.D.
06.04.2011	1354		37.65	141.43	5.3/59.0	S-3	True
07.04.2011	1432		38.28	141.59	7.1/42.0	S-4	True SD
08.04.2011	1842		43.72	147.48	5.3/54.0	S-5	True
11.04.2011	0816		37.00	140.40	6.6/11.0	S-8	True CD
12.04.2011	0507		37.11	140.37	6.1/11.0	S-9	True
13.04.2011	1957		39.58	143.34	6.0/22.0	S-10	O.D.
20.04.2011		No Eq.				K-3	False SD
21.04.2011	1337		35.58	140.30	6.2/43.0	K-4	True
22.04.2011	1525		37.23	140.99	5.2/23.0	K-5	True

Date	Time (UTC)	Place	Lat. (Deg.)	Long. (Deg.)	Magnitude (≥5.0)/ Depth (km)	Lunar Day	FCST
05.05.2011	1459		38.18	144.03	6.0/11.0	S-2	O.D.
06.05.2011	1118		38.06	142.20	5.0/11.0	S-3	True SD
07.05.2011	2052		40.24	142.24	5.7/35.0	S-4	True
08.05.2011		No Eq.				S-5	False
11.05.2011	1814		36.1	142.27	5.3/11.0	S-8	True CD
12.05.2011		No Eq.				S-9	False
13.05.2011		Forecast DIS				S-10	
11.04.2012	0838	Indonesia	2.32N	093.06E	8.6/20.0	K-6	Main Eq.
	1043		0.80	092.46	8.2/25.1		
	2356		1.84	089.68	5.8/10.0		
12.04.2012	2021		3.75	092.75	5.3/10.0	K-7	O.D.
13.04.2012	0531		2.65	089.71	5.0/14.0	K-8	True
14.04.2012	1521		0.24	092.14	5.4/22.0	K-9	True
15.04.2012	0557		2.58	090.27	6.2/25.0	K-10	True CD
16.04.2012	1605		0.18	092.24	5.2/10.0	K-11	O.D.
17.04.2012	1944		2.58	092.61	5.0/10.0	K-12	O.D.
18.04.2012	0143		3.33	092.54	5.0/25.0	K-13	O.D.
20.04.2012	2228		3.27	093.82	5.9/21.0	K-14	O.D.
21.04.2012	1104		3.27	093.72	5.2/10.0	K-15	O.D.
22.04.2012	0317		1.38	091.75	5.1/6.0	S-1	O.D.
24.04.2012	1943		1.15	091.72	5.1/10.0	S-3	True SD
25.04.2012		No Eq.				S-4	False
26.04.2012	1921		2.70	094.46	5.6/7.9	S-5	True
29.04.2012	0809		2.70	094.51	5.7/14.0	S-8	True CD
30.04.2012	0800		1.76	089.60	5.7/10.0	S-9	True
04.05.2012	1623		2.00	089.72	5.1/10.0	S-13	O.D.
08.05.2012		No Eq.				K-3	False
09.05.2012		No Eq.				K-4	False
10. 05.2012		No Eq.				K-5	False
11.05.2012		Forecast DIS					
24.05.2013	0544	Sea of Okhotsk, No SIG Eq. after this day	54.9N	153.2E	8.3/598.1	S-14	Main Eq.
25.04.2015	0611	Nepal	28.10N	084.60E	7.9/10.0	S-7	Main Eq.
	0645		28.10	084.80	6.6/10.0		
	0917	China-Nepal	28.30	087.30	5.8/5.0		
26.04.2015	0709	Nepal	27.60	085.90	6.9/10.0	S-8	True
	1626		27.60	085.70	5.3/10.0		
27.04.2015	1235	Nepal-India	26.70	088.10	5.1/10.0	S-9	True CD
07.05.2015		No Eq.				K-3	False SD
08.05.2015		No Eq.				K-4	False
09.05.2015		No Eq.				K-5	False
11.05. 2015		No Eq.				K-8	False
12.05.2015	0705		27.70	086.00	7.3/10.0	K-9	True CD
	0734		27.60	086.20	5.4/15.0		
	0736		27.60	086.10	6.2/10.0		
15.05.2015	0506		27.80	084.70	5.0/10.0	K-10	O.D.
16.05.2015	1134		27.50	086.00	5.7/10.0	K-13	O.D.
20.05.2015		No Eq.				S-3	False SD
21.05.2015		No Eq.				S-4	False

Date	Time (UTC)	Place	Lat. (Deg.)	Long. (Deg.)	Magnitude (≥5.0)/ Depth (km)	Lunar Day	FCST
22.05.2015		No Eq.				S-5	False
26.05.2015		No Eq.				S-8	False
27.05.2015		FCST DIS					
16.09.2015	2254	Chile	31.57S	071.67W	8.3/22.4	S-3	Main EQ
	2318		31.56	071.42	7.0/28.4		
17.09.2015	0355		31.42	071.68	6.5/27.0	S-4	True SD
18.09.2015	0910		32.36	072.22	6.2/8.0	S-5	True
19.09.2015	1252		32.33	072.06	6.2/18.0	S-6	O.D.
20.09.2015	0902		30.23	072.27	5.1/8.6	S-7	O.D.
21.09.2015	1740		31.72	071.37	6.6/35.0	S-8	True
22.09.2015	0713		31.44	071.26	6.0/58.0	S-9	True, CD
23.09.2015	1132		31.61	071.95	5.0/10.0	S-10	O.D
24.09.2015	1613		30.73	071.37	5.2/41.0	S-11	O.D.
26.09.2015	0221		30.81	071.32	6.3/46.0	S-13	O.D.
27.09.2015	2104		31.66	071.70	5.4/36.9	S-14	O.D.
01.10.2015		No Eq.				S-4	False
02.10.2015		No Eq.				S-5	False
03.10.2017	0626		30.30	071.55	5.9/38.0	K-6	O.D.
04.10.2015	0349		30.31	072.10	5.9/5.5	K-7	O.D.
05.10.2015	1633		30.30	071.53	5.9/34.0	K-8	True
		EQ considered up to 3 weeks					
08.09.2017	0449	Mexico	15.02N	93.89W	8.2/47.4	K-2	Main Eq. C.I.
	0501		15.17	094.29	5.7/36.3		
09.09.2017	0454		15.08	094.06	5.5/29.0	K-3	True
10.09.2017	0722		15.39	094.53	5.8/29.0	K-4	O.D.
11.09.2017	2109		14.90	094.01	5.5/27.0	K-5	O.D.
12.09.2017	0508		15.11	093.97	5.4/42.5	K-6	O.D.
13.09.2017	2130		15.61	095.17	5.1/13.3	K-7	O.D.
15.09.2017		No Eq.≥5.0				K-10	False
16.09.2017	14.18		16.09	095.13	5.6/35.0	K-11	True
17.09.2017	0607		15.77	095.31	5.0/10.0	K-12	True
18.09.2017	1419		15.25	094.56	5.6/10.0	K-13	O.D.
19.09.2017	1814	Eq. observed 17 minutes early, prior to midnight (IST)	18.55	098.48	7.1/48.0	K-14	True, C.I. on 20.09.2017, after midnight of 19th (IST)
21.09.2017		No Eq.				S-1	False
22.09.2017		No Eq.				S-2	False
23.09.2017	1253		16.62	95.07	6.1/10.0	S-3	True
24.09.2017	1006		15.31	094.17	5.8/47.4	S-4	O.D.
29.09.2017	0400		14.86	094.23	5.4/11.0	S-9	O.D.

Earthquake struck Samoa Islands on 29th September 2009 (S-11). It`s magnitude was 8.1 and focal-depth at 18 km (Table: 1). The earthquake occurred during high tide period, so aftershocks have been forecast for the lunar days: S-12 (two dates), K-1, K-2, K-3, K-10, K-11, K-12, S-1, S-2, S-3, S-10, S-11, S-12, K-1, K-2, K-3, K-10, K-11, K-12 (20 days) for one and half months period. Aftershock of highest magnitude occurred on 14th October (K-11: 6.3, maximum intensity) on the forecast day. The forecast has been discontinued from 15th November 2009 as failure is getting prominent (aftershocks < 5.0). Earthquake of magnitude 8.8 originating from focal depth of 22 km struck Chile on 27th February 2010 (S-14). It struck during high tide period so aftershocks can be forecast during the following lunar days: K-1, K-2, K-3, K-10, K-11, K-12, S-1, S-2, S-3, S-10, S-11, S-12, K-1, K-2, K-3, K-10, K-11 and K-12. Aftershocks, which occurred on the O.D. having magnitude less than 5.5 have not been included in the

Table 1 to reduce the entries. Relatively high magnitude aftershocks occurred on 11th March (K-11: magnitude: 5.6/ 6.9/ 7.0) and on 16th March (S-1: 6.7), which were forecast days. So, aftershock of highest magnitude, 7.0, occurred on the forecast day. Aftershocks of magnitude ≥ 5.0 continued almost daily till 29th March and extended intermittently till the month of May. Aftershocks forecast have been discontinued after one and half months as more errors (intensity < 5.0) were observed during the last 16 days.

Earthquake of magnitude 9.0 devastated Japan on 11th March 2011 (S-6). It`s focal-depth was 29 km. It occurred during low tide period. Aftershocks can be forecast for the lunar days S-8, S-9, K-3, K-4, K-5, K-8, K-9, S-3, S-4, S-5, S-8, S-9, K-3, K-4, K-5, K-8, K-9, S-3, S-4, S-5, S-8 and S-9 (22 days). Aftershocks having magnitude < 6.0 have not been considered in the Table 1, which occurred during non-forecasting days. Significant high magnitude aftershocks occurred correctly on 7th April 2010 (S-4: magnitude: 7.1), 11th April (S-8: magnitude 6.6) and 21st April (K-4: 6.2: ≥ 6.0 magnitude after a break of 7 days) on forecast days. The forecast has been discontinued after 12th May as errors (magnitude < 5.0) were noticed.

Earthquake of magnitude 8.6 a focal-depth of 20 km (0838 UTC) occurred in a vulnerable segment of Indonesia on 11th April 2012 (K-6). Major aftershocks having magnitude 8.2 originated from a depth of 25 km at 1043 UTC on the same day. Earthquake struck during low tide period. Aftershocks can be forecast for K-8, K-9, S-3, S-4, S-5, S-8, S-9, K-3, K-4 and K-5. Aftershock of highest magnitude of 6.2 occurred on 15th, on the day when both tides were observed as minimum on 10th lunar day of waning period (C.D., K-10). Significant aftershocks occurred on 24th (O.D. 5.9), 26th (S-5: magnitude 5.6), 29th (S-8: magnitude 5.7) and 30th (S-9: magnitude 5.7) April 2012. The forecast has been discontinued on 11 May as aftershocks of magnitude less than 5.0 have been observed frequently.

Earthquake of magnitude 7.9 and focal depth of 10 km struck Nepal on 25th April 2015 (S-7) ,during low tide period. Aftershocks can be forecast for S-8, S-9, K-3, K-4, K-5, K-8, K-9, S-3, S-4, S-5 and S-8 during one month period. A sequence of relatively moderate magnitude aftershocks occurred after a lapse of 14 days; out of them the 7.3 magnitude earthquake was correctly predicted to occur on 12th May 2015 (K-9; magnitude: 7.3). Couple of other aftershocks occurred with magnitudes of 5.4 and 6.2. More casualties occurred in Bihar on 12th May rather than on 25th April. As earthquake magnitude was7.9, aftershocks having magnitude less than five were very much prominent. The forecast has been discontinued from 27th May 2015 as aftershocks after 16th May were observed frequently with less than 5.0 magnitudes.

Earthquake of magnitude 8.3 occurred in Chile on 16th September 2015 (S-3). On 13th both tides were observed as maximum (C.I.). So, main earthquake occurred during low tide period. Aftershocks can be forecast for S-4, S-5, S-8, S-9, K-3, K-4, K-5, K-8 and K-9. Aftershock of highest magnitude (6.6) was recorded on 21st September (S-8). The forecast was continued for 21 days.

On 8th September 2017 (K-2) an earthquake of magnitude 8.2 struck Mexico. Both tides were observed as maximum on this day (K-2). So, main earthquake occurred during high tide period. Aftershocks can be forecast for K-3, K-10, K-11, K-12, S-1, S-2 and S-3. As both tides were observed as maximum (C.I.) on 20th September (K-15), this date was also included in the forecast. Aftershock of maximum magnitude (7.1) occurred on 19th September at 1814 UTC (20th date started after 16 minutes -IST). So, earthquake struck 17 minutes early of the predicted forecast period.

Highest magnitude aftershocks have been observed in 7 out of 8 cases during forecast period of major earthquakes from 2009 to 2017 (magnitude ≥7.9). It has been also observed that earthquakes having magnitude ≥ 8.0 have not occurred even once on 4th lunar day during either of the two fortnights in 42 cases from 1934, Bihar, India to 2017, Mexico (Table not given).

CONCLUSIONS

(i) Mostly both values of high tides start decreasing (S.D.) from 3rdor 4th or 5th day of waning and waxing period of the Moon and continue to decrease (C.D.) till 8th or 9th day of both the fortnights (minimum value).It is observed that mostly both the high tides start increasing (S.I.) from 10th or 11th, or 12th and continue to increase (C.I.) till 1st or 2nd or 3rd during waning and waxing period (maximum value).

(ii) Heights of Ocean tides will differ from Sea to Sea. In majority of cases all four trends (S.D., C.D., S.I. and C.I.) observed for Arabian Sea would be observed on the same lunar day for other Seas as spring and neap tides depend upon the position of the Moon. This is universally true as lunar day would remain same for all the countries. Solar-lunar eclipses are observed on a fixed date for all the countries.

(iii) In Hindu calendar, lunar day starts after Sunrise and continues till Sunrise, whereas English date starts after mid-night.

(iv)High or low ocean tides, initiated by earth tides, exhibit the intensity of solar-lunar gravitational force on a particular day. Moon's gravitational influence on Ocean tides (including spring and neap) is visible during its different phases.

(v) If an earthquake occurs during low tide period (after CI to 9th lunar day) aftershocks can be forecast for K-3, K-4, K-5, K-8, K-9, S-3, S-4, S-5, S-8 and S-9 during one month period. If CD is observed on 7th or 10th lunar day then this has to be included as an additional day. If it is observed between high tide period, aftershocks can be forecast for K-1,

K-2, K-3, K-10, K-11, K-12 and S-1, S-2, S-3, S-10,S-11, S-12 during one month period. If CI is observed on any other day this has to be included as an additional day.

(vi) Aftershocks (magnitude ≥ 5.0) can be forecast for earthquakes having magnitude ≥ 7.9 for 3 to 8 weeks.

(vii) Aftershocks of highest magnitude earthquakes have occurred as predicted in 7 cases out of 8 cases (87.5%) during forecast period. Lunar days are more marked for major aftershocks than timings of the high tides. Since one could argue that such a correlation is more an accident than a normal activity it is essential to look at various alternative theories, including the proposed in the present study.

(viii) As short term earthquake prediction is not yet achieved unequivocally, in spite of significant efforts by international seismological community, we do believe that the present study would help in introducing a significant input to achieve needed outcome in coordination with other inputs like Spatial and temporal variations of total electron content (TEC) and outgoing long wave radiation (OLR) during the period of greater earthquakes. Before, accepting the present theory as an important one it should be strongly backed up by physical models /processes (with clear quantification). Also in co-ordination with experts, as suggested by one of the learned reviewers some relevant statistical analysis or Wavelet power spectrum using Morlet wavelet analysis needs to be carried out as part of the extension study.

ACKNOWLEDGEMENTS

Authors are thankful to National Earthquake Information Center web site (USGS), USA, IMD web site for using earthquakes data, Survey of India for using their tides tables for the years 2009 to 2017 and PNP Maritime Services Private Limited, Mumbai for publication and providing these tide tables. The authors are thankful for access to "The Definitive Guide, Astronomy" and using the figure-1. They acknowledge with thanks Wikipedia, Google websites for using Figure 2. Authors express their sincere thanks to the reviewer, Dr. Vinayak Kolvankar for his critical comments and useful suggestions. Thanks are also due to Dr.Vineet K Gahalaut for suggesting further work using some important processing methodologies. Authors thank Dr.P.R.Reddy, Chief Editor for proper guidance, suggestions, refined restructuring of the manuscript and apt final editing.

Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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"The great earthquake shall be in the month of May; Saturn, Capricorn, Jupiter, Mercury in Taurus; Venus, also Cancer, Mars in zero."

Nostradamus

Received on: 18.11.2017, Revised on: 1.12.17; Re revised on: 10.12.17; Accepted on: 12.12.17