Spatial relationship between earthquakes, hot-springs and faults in Odisha, India

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Abstract. Odisha is famous for Mineral rich Eastern-Ghat mobile belt, hot springs and cultural Heritage. The hot springs are known for centuries and are used by public as a place for worship. Odisha falls under the II and III seismic zones in India. Most of the seismicity in Odisha is due to motion along some active normal faults along the Mahanadi Graben. Therefore, it is necessary to identify the active faults and understand spatial distribution of seismic activity in Odisha. It is also important to understand the Earthquakes and their relation with the Geology of Odisha and understand the neo-tectonic activity. There are 7 major hot springs found along the North Odisha Boundary Fault and Mahanadi Shear Zone. The hot water percolates deep into the Earth through porous and permeable fractured rocks along the fault. Depth of source for most of the hot springs in Odisha must be some few feet to few meters; however most of these observations are not based on scientific geophysical data. Therefore, spatial relationship between thermal springs, earthquakes, and geology of Odisha may provide better understanding of the hot-spring setting. By using the earthquake and fault data, the sense of motion along faults can be easily interpreted. All these information can explain the spatial distribution and inter-relation between hot-springs, faults and earthquakes in Odisha.

1 Introduction

Odisha has experienced very few moderate to large earthquakes. Some events with magnitudes in excess of 5.0 have originated in the Bay of Bengal off the coast of the state. The Mahanadi Graben is a narrow elongated belt covering parts of Odisha, Chatisgarh and Madhya Pradesh along Mahanadi river valley with a NW-SE orientation [1, 2]. It meets the Narmada-son river valley on the North West in Madhya Pradesh and lies hidden beneath the coastal alluvium in Odisha [1]. The Graben lies between two important fault zones, North Odisha boundary fault [3] on the north and the Mahanadi shear zone [2] on the south.

The important sediment filled depressions are IB Basin, Talcher basin, Jaypur-chandbali basin which are lying on the northern part and the Athgarh and Salepur basin on the southern part of Mahanadi Graben. The faults have shown evidence of movement during the Holocene epoch. The Brahmani Fault in the vicinity of Bonaigarh is among them. The Mahanadi also flows through a Graben structure [3]. Several deep-seated faults are situated beneath the Mahanadi Graben. However, it must be stated that proximity to faults does not necessarily translate into a higher hazard as compared to areas located further away, as damage from earthquakes depends on numerous factors such as subsurface geology [4].
The geo-tectonic setup of India, the fault map zones and the epicentre of seismicity indicate about the anomalous nature of different types of geothermal distributions [5, 6]. GSI [7] had identified 340 Hot-water springs which are characterized by Organic activity. A total of about 10,000 MW could be generated from Himalaya, Naga Lushai, Andaman-Nicobar Islands, West Coast of Cambay Graben, Aravalli, Son-Narmada-Tapti, Godavari and Mahanadi, South Indian Cratonic geothermal provinces in India. However, the geothermal reservoirs in India are low to medium enthalpy type where surface temperatures vary from 80 to 105°C thus used to convert their geothermal energy into electricity. All the Hot-Springs of India were classified on the basis of their geo-tectonic setup and grouped into six Geothermal Provinces as follows: (a) Himalayan Province-Tertiary Organic belt with Tertiary magmatism; (b) Areas of Faulted blocks Aravalli belt, Naga-Lushi, West coast regions and Son-Narmada lineament; (c) Volcanic arc-Andaman and Nicobar arc; (d) Deep sedimentary basin of Tertiary age such as Cambay basin in Gujarat; (e) V. Radioactive Province Surajkund, Hazaribag, Jharkhand; and (f) Cratonic province peninsular India.

The Geology of Peninsular India mainly comprises Precambrian assemblages with Jurassic to Quaternary sedimentary rocks and volcanic of Cretaceous-Eocene [8]. The on-shore and off-shore regions of East coast are mainly younger sequences with prospects of hydrocarbons. The Coastal areas have undergone repeated cycles of sea level changes during Quaternary. The Coastal risk along Peninsular Coast has been worked out prior to the advent of cyclone of 2004. Later Inter-mitten seismic activity along parts of East coast is reported around the following places from reports during the period.

1) Off. Odisha coast, May, 2014.
2) Off. Visakhapatnam, Jan., 1996.
3) Off. Pondicherry, Dec., 2001.

The shallow depth origin and possible rejuvenation of faults are either on shore or off-shore. Evidences of uplift and subsidence are reported. Furthermore, there are evidences of disturbances in the top layers of sediments along parts of East Coast by way of displacements in the layers as seen in the sub-bottom profiles. There are also rise-like structures. Presence of hot springs and field evidence showing displacement on a small scale are noticeable. There are evidences of coarse sized sand and pebbly rich aggregates of sediments on the deep sea floor at around 2500m depth beyond slope as observed at off Pennar. Such exotic sediments are possibly seisomogenic turbidities (GSI unpublished sea bed survey reports 1983-2000). Thus, it is prudent to infer seismic activity, neo-tectonism and upper continental crust along East Coast at places [9, 10]. Therefore, the current study aims; to understand the spatial distribution and relation between Earthquakes, Hot-springs and Faults in Odisha; to identify active Faults and understand spatial distribution of Seismic activity; and to interpret the sense of motion along faults by using the Earthquake and Fault data.

2 Study area and dataset

The seismic hazard map of India was updated in 2000 by the Bureau of Indian Standards (BIS). There are no major changes in the zones in Odisha with the exception of the merging of Zones I and II in the 1984 BIS map. Districts that lie in the Mahanadi river valley lie in Zone III, and within Odisha this zone stretches from Jharsuguda along the border with Chhattisgarh in a south-easterly direction towards the urban centres of Bhubaneswar and Cuttack on the Mahanadi Delta (Figure 1).
In this research, three earthquake data were used to prepare a map where all the seismic and active regions can be interpreted especially the periods of 1676 to 2014. The details of the images are shown in Table 1. The selection of the datasets is based on the objectives of the research and literature which explains the spatial distribution of earthquakes [11, 12]. Data of hot spring temperature and location has taken from the geological map of Odisha prepared by GSI. These data can be manipulated to reveal the spatial distribution of earthquakes, hot spring and faults in Odisha and to explain neotectonism including their relation with each other [12-14].

**Table 1. Earthquake Data (ASC Website).**

| No | Year | Magnitude | Intensity | Location | Latitude   | Longitude   | Damage/Loss of Life |
|----|------|-----------|-----------|----------|------------|-------------|---------------------|
| 1  | 1676 | 4.0       | IV        | Balasore Area, Odisha | 21.500N | 86.900E | No |
| 2  | 1837 | 5.0       | VI        | Rambha- Paluru Area, Odisha | 19.500N | 85.100E | No |
| 3  | 1858 | 4.9       | V         | Balasore- Chandipur Area, Odisha | 21.500N | 87.000E | No |
| 4  | 1860 | 4.9       | V         | Karantola area, Odisha | 19.400N | 84.900E | No |
| 5  | 1891 | 4.9       | V         | Near Palmyras Point, Odisha | 20.800N | 87.000E | No |
| 6  | 1963 | 6.0       | VII       | Bijakuli Banei Area, Odisha | 21.700N | 84.900E | Damage of Departmental Building and crop loss |
| 7  | 1979 | 4.7       | V         | Dublabera Majhgaon Area, Odisha | 22.100N | 84.900E | No |
| 8  | 1982 | 5.2       | VI        | Bay of Bengal | 18.510N | 86.310E | Damage of cottages in Village |
| No | Year | Magnitude | Type | Location | Latitude | Longitude | Damage |
|----|------|------------|------|----------|----------|-----------|--------|
| 9  | 1982 | 4.7        | V    | Khajuripada Banigochha Area, Odisha | 20.390N  | 84.420E   | No     |
| 10 | 1985 | 5.4        | VI   | Bay of Bengal | 18.367N  | 88.188E   | Less Damage |
| 11 | 1995 | 4.6        | V    | Laimura Deogarh Area, Odisha | 21.671N  | 84.565E   | No     |
| 12 | 1995 | 4.7        | V    | Kasijodi Nuakoat Area, Odisha | 21.780N  | 85.327E   | No     |
| 13 | 2001 | 4.7        | V    | Kanakjora- Sundargarh Area, Odisha | 22.240N  | 83.918E   | No     |
| 14 | 2014 | 5.9        | VII  | Bay of Bengal | 18.201N  | 88.019E   | Less Damage |

3 Methodology

Literature survey for historical and recent earthquake was conducted to prepare the map of earthquake locations, faults and thermal springs. This step was done for better interpretation and understands the spatial distribution; identifying historical zones and recent seismicity. Modelling of the cross section of Mahanadi Graben creatively design the Gondwana sediments and their relation with normal faults. The Relation with seismic zonation map and earthquake distribution is also important to describe the percentage of hazardous area. Preparing the model explains about the Relation between faults and thermal springs (Figure 2).
Research analysis phase was focusing on the arguments and change detection of the findings. Accuracy of analysis is depends on the study area and data reliability. It was involved with the statistical estimation that obtained from the magnitude vs. year output and the independent references for the probability error measurement of the prepared map. This was to ensure the prepared map and the models are accurate and reliable. For each feature, the data gives the accurate analysis which needs to be established in order to perform good result. The subtracted information from the prepared map explains the features properties. The relation between earthquakes, Hot Springs and faults deliberated in result and discussion section by comparing the features with each other. The details of the analysis will be viewed in the result and discussion section.

4 Result & Discussion

The spatial distribution of earthquakes in India characterized with very high magnitude earthquake zones in Himalayan region, Gujarat and some other places. But earthquakes happened till now in Odisha are generally with low magnitude of 2.5 to 5.5. The districts which are present in Mahanadi Graben are going under II seismic zone. The recent earthquake was during 2003 in Sundergarh area and at a distance of 150 km from the Odisha coast with a magnitude of 5.9. This explains the active movement of normal faults in different regions of Mahanadi Graben. Therefore, it gives the information about neo-tectonic movements in different regions of Mahanadi Graben.

The magnitude vs. year graph explains the (Figure 3);
• Distribution of Earthquakes with Magnitude
• Equal magnitude of earthquakes occurred in same area but year is different and no earthquakes of magnitude higher than 6 and lower than 3.

![Earthquakes Distribution with Year](image)

**Figure 3.** Earthquakes Distribution with year.

There are many regions in India where earthquakes are happening continuously. But some places where very low magnitude earthquakes are happening. Odisha is such a place where the Magnitudes of earthquakes are generally 3 to 5.5, thus making these earthquakes non-dangerous. The 3D model explains the origin of hot spring is at a depth of 15-20 feet from the surface (Figure 4 and 5).
Figure 4. Map of Odisha shows distribution of earthquakes, hot springs and faults.

Hot springs are the sites that discharge hot ground water. The springs usually emerge from the deep faults or fissures of earth along which the ground water comes out.
The high temperature of hot spring water is because of the geothermal energy, exothermic reactions and disintegration of radioactive elements. Here the basement rock is high grade metamorphic gneiss and Granitoids. The cyclic movement of water occurs. Here the water infiltrate into the porous and permeable rocks and come in contact with the country rocks. Reaction takes place where the rock contains pyrite and pyrohrite. Reaction of water occurs with pyrite and pyrohrite which finally gives basic composition of the thermal spring water.

The area is covered with vegetation. The basement rock type of Mahanadi Graben is generally gneiss and the basin is totally covered with Gondwana sediments. There are two main faults present as boundaries known as MSZ and NOBF.
Neo-tectonics is the motions and deformations of Earth's crust that are current or recent in geological time. Geologists refer to the corresponding time-frame as the Neo-tectonic period, and to the preceding time as the Palaeo-tectonic period. Neo-tectonics defining the field as recent tectonic movements occurred in the upper part of Tertiary and in the Quaternary. Active tectonic movements that are expected to occur within a future time span of concern to society. Any fault that moved say the last 35,000 years (10,000 years) is considered as active faults. Active tectonics involved dynamic process operating in the present day regimes. Combining active tectonics and records of reported seismicity new generation maps or models of seismo-tectonics could be framed combing the inputs of geology, geophysics and seismic micro zonation maps. Pertaining the east coasts, for the last 200 years there are some historical records of low magnitude earthquakes. The Extension of the continental crust is well postulated together with active faults or those rejuvenated along pre-existing faults. Therefore, all the earthquakes happened till now in different regions of Mahanadi Graben are due to neo tectonic activity. Neo-tectonic activity is mainly found in central part of the basin because of high thickened and deformed sediments. These loose sediments are also responsible to produce high magnitude earthquakes because it amplifies the earthquake waves.

The focal mechanism of an earthquake describes the deformation in the source region that generates the seismic waves. In the case of Mahanadi Graben fault-related event it refers to the orientation of the fault plane that slipped and the slip vector and is also known as a fault-plane solution. Focal mechanisms are derived from various methods, including first motion analysis and a solution of the moment tensor for the earthquake, which itself is estimated by an analysis of observed seismic waveforms. The focal mechanism can be derived from observing the pattern of "first motions", that is, whether the first arriving P waves break up or down. This method was used before waveforms were recorded and analyzed digitally and this method is still used for earthquakes too small for easy moment tensor solution. Focal mechanisms are now mainly derived using semi-automatic analysis of the
recorded waveforms. Seismologists refer to the direction of slip in an earthquake and the orientation of
the fault on which it occurs as the focal mechanism.

This information was used from seismograms to calculate the focal mechanism and typically
display it on maps as a "beach ball" symbol. This symbol is the projection on a horizontal plane
of the lower half of an imaginary, spherical shell (focal sphere) surrounding the earthquake source.
A line is scribed where the fault plane intersects the shell. The stress-field orientation at the
time of rupture governs the direction of slip on the fault plane, and the beach ball also
depicts this stress orientation. These focal mechanisms explain that all the faults that are present in
Mahanadi Graben are generally normal faults. For a double-couple source mechanism (or only shear
motion on the fault plane), the compression first-motions should lie only in the quadrant
containing the tension axis, and the dilatation first-motions should lie only in the quadrant
containing the pressure axis.

![Diagram of Mahanadi Graben](image)

**Figure 7.** Model of Mahanadi Graben along the cross section [15].

A hot water spring, also known as a thermal spring, is a natural discharge of hot water from the
earth. Such springs normally occur in areas where underground water passes through hot igneous or
metamorphic rocks along faults. They can form pools, geysers or fumaroles. The spatial distribution of
hot water springs and faults explains that the hot springs are the result of the non-active faults.

The relationship is scale-dependent in time and space. Therefore a correlation between location of
hot springs and present day seismic activity is not necessary but the faults were indeed active at some
point in history. Therefore, in Odisha the NOBF and MSZ faults were active but not today. The other
normal faults between these boundary faults must be active because there is no hot springs now and
earthquakes are the result of these active faults.
Water generating from thermal spring is heated by geothermal gradient i.e. heat from earth’s interior. The water percolating deep down into the crust through structural breaks are heated up, while coming in contacts with the host rocks. The source of heat in India for hot springs is generally regional heat flow. Five heat flow zones in India subcontinent are reported where heat flow values are ranges between 30 and 468mW/m2. Odisha falls in zone II (100-180mW/m2 and zone III (70- 100mW/m2) on the basis of heat flow values.

Water in hot springs comes from a depth that is when the porous and permeable rocks get recharged and water passes through the rock up to the basement rock of gneiss. Then water can’t pass through it further. Therefore, by cycling process the water get back to the surface through the faults. Therefore, the depth at which the cycling process starts is called as the depth of hot spring. By using the geothermal gradient and the depth dataset it can be determine that the water is coming from a specific depth of 13-15 feet from the surface of the Mahanadi.

### Table 2. Temperature of all the Hot Springs in Odisha.

| Sl. No | Name of the Hot Springs | Temp. (°C) |
|--------|--------------------------|------------|
| 1      | Taptapani                | 30° - 40°  |
| 2      | Deulajhari               | 40° - 62°  |
| 3      | Atri                     | 55°        |
| 4      | Tarabalo                 | 67°        |
| 5      | Bankhol                  | 40° - 50°  |
| 6      | Badaberena               | 45°        |
| 7      | Magarmuhan               | 55°        |
| 8      | Boden                    | 32°        |

Figure 8. Depth of the Hot Springs.
5 Conclusion

Mahanadi Graben is an active tectonic area where earthquakes are continuously happening. However, these are of small magnitude and not considered as hazardous. The Eastern Coastal areas along the Peninsula witness moderate events as evidenced by the recent reports. The study of outcrop of the whole Graben by using remote sensing techniques for identifying the Hot Springs and faults have great potential for research. Earthquakes related science as an attempt towards progresses of at least the vulnerability criteria could be a worthwhile endeavour with the aid of all modern tools of geology, geomorphology, geodesy, geo physics- geo chemistry and remote sensing. As the only visible marking available is active faults and neo-tectonics for generating new class of seismic hazard zonation maps. The search for hidden faults through geology centred techniques along with geophysics and geochemistry analogies should become a programme of national endeavour Organisations.

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The Earthquake Data used in this study were downloaded from ASC Website.

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