Integrated G3 (Geological, Geophysical and Geochemical) approach for Geothermal Energy Resource Assessment of Manuguru Geothermal Fields in Godavari Graben, India

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Keywords

Geothermal Energy, Manuguru, Godavari Graben, Hot Springs, Net Zero.

Abstract

India set an ambitious target of achieving *Net Zero* by 2070; however, Indian Economy is still predominantly depends on fossil fuels and the share of green energy is still hovering in single digit. It is the need of the hour to exploit the natural and renewable energy resources in a more sustainable manner. Geothermal Energy, earth's natural heat energy, is one of such sustainable, green and renewable energy. In India, GSI has identified **381** geothermal manifestations with an estimated potential of **10,600 MW**. These are grouped into **ten geothermal provinces** i.e. Himalayan; Naga – Lusai; Andaman Nicobar Islands; Son-Narmada-Tapi; West Coast; Cambay; Aravalli; Godavari Graben (Manuguru); Mahanadi and South Indian Cratonic.

For this study, we have chosen Godavari Graben (Manuguru Geothermal Fields). The previous work by various scholars in this region, has been done in siloes by using one or few methods only and the direct evidence of temperature is available till 1000 m depth only and beyond this depth, even GSI in its latest 2022 report has stated that there is a large variation in the temperature values estimated by various scholars. This led to an ambiguity that how much geothermal potential actually exist and whether that is commercially viable or not? To fill this research gap, we have made an integrated G3 approach by employing all suitable geo-scientific methods such as Geological, Geophysical (Gravity, Magneto Telluric and Well Logging) and Geochemical and also analyzed the core samples data collected from GSI.

The study revealed that the highest recorded surface temperature of flowing hot water in artisan condition is **81.1** ^{0}C with water discharge of **800** lpm at Borehole No. GPDW-6A drilled to **618 m** depth. The Reservoir Temperature is around **175** to **215** $^{\mathbf{0}}$**C** at a depth of about **2.5 km**, with an anomalous area of approx. **19 Sq km,** which holds the estimated installed capacity of **122 MW**, for 20 years; to commercially generate the electricity by using Organic Rankin Cycle (ORC), in Pagaderu, Manuguru Geothermal Field of Godavari Graben (Latitude 17.98003 N and Longitude 80.71947 E).

The electricity generated from this field can be easily wheeled through an existing electrical grid network connected to the existing coal based thermal power plants located in this region, with less capital investment. This will address the twin problems of reducing the environmental pollution and sustainably generates the electricity to fulfill the India's energy needs and *Net Zero* targets by 2070.

1.0 Introduction

Geothermal Energy, earth's natural heat energy generates and stores in the rocks and as the temperature and pressure builds up in the sub-surface, water / steam will carry out this heat energy to the surface through fractures and faults present in the sub-surface and forms hot springs, geysers, fumaroles, etc. on the surface. The study area i.e. Manuguru Geothermal Field in Godavari Graben also contains many such fractures and fault in which the perennial Godavari River is flowing since ancient times. The underground aquifer channels present beneath the Godavari River continually recharging

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the sub-surface reservoir which is getting heated up due to the upwelling of magma in this fault zone and this hot water is ejecting in artisan condition to the surface through fractures present in the sub-surface and forms hot springs / geothermal manifestations in Godavari Graben. Among all, notable geothermal manifestations in this region are: namely, Manuguru Geothermal Field, Bugga thermal Spring, Agnigundala thermal Spring.

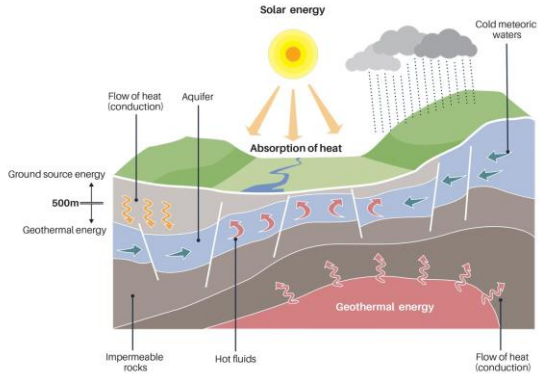

Figure 1: Schematic Diagram of Geothermal Energy

Figure 2: Geothermal Manifestation in Manuguru Geothermal Field of Godavari Graben (Source: GSI Geothermal Energy Resources of Telangana, 2019).

1.1 Geographical Location of the Study Area:

The Study Area i.e. Manuguru Geothermal field in Godavari Graben is located in Manuguru Taluka, Bhadradri (Kothagudem) district of Telangana State, India. It is bounded by latitudes 17°48'57.41" : 18°06'49.82" N and longitudes 80°33'44.29" : 80°55'18.30" E.

Manuguru Geothermal field located on the eastern margin of Godavari Valley extends over a strike length of 14 km from the right bank of River Godavari in the NE to Bugga in the SW. The area consists of several artesian boreholes having temperature in the range of 40 to 81°C and scattered over an area of 35 sq km. The Godavari Valley, a NNW-SSE trending graben filled with Gondwana sedimentary formations fall in zone III (70-100 mW/m2) on the heat flow map of India

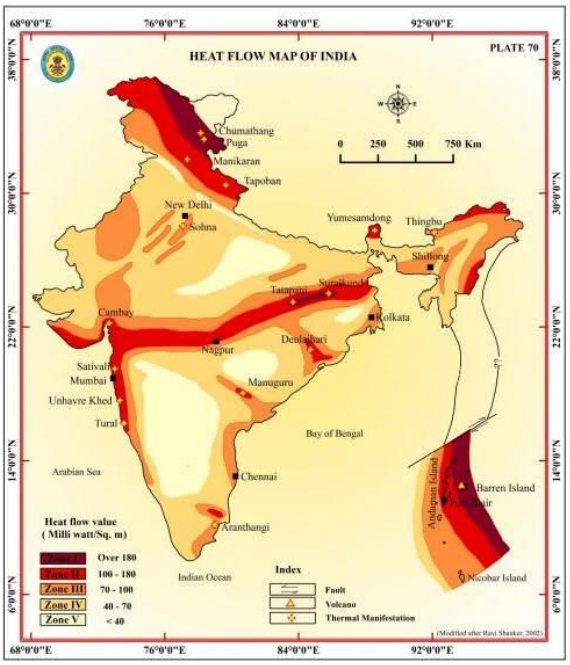

Figure 3: Heat Flow Map of India (Source: GSI Geothermal Atlas of India, 2022)

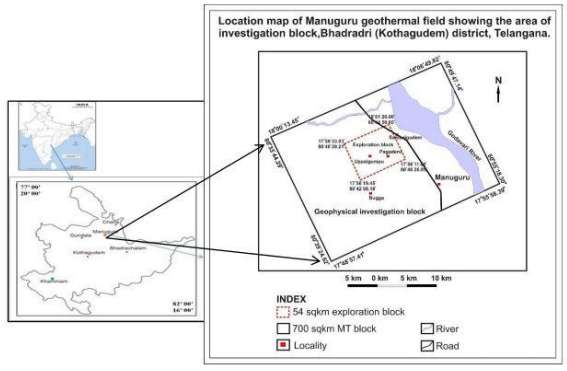

Figure 4: Location Map of the Study Area i.e. Manuguru Geothermal Field in Godavari Graben (Source: GSI Geothermal Energy Resources of Telangana, 2019)

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2.0 Geological Setup of the Study Area:

The litho-units exposed in the study area belong to Pakhal Supergroup and Barakar, Kamthi, Maleri and Kota Formations of Gondwana Supergroup resting unconformably over phyllite / quartzite and phylliticquartzite of Precambrian Pakhal Supergroup. The Maleri is not exposed in the area rather lies in low lying areas covered with drainage and agricultural land.

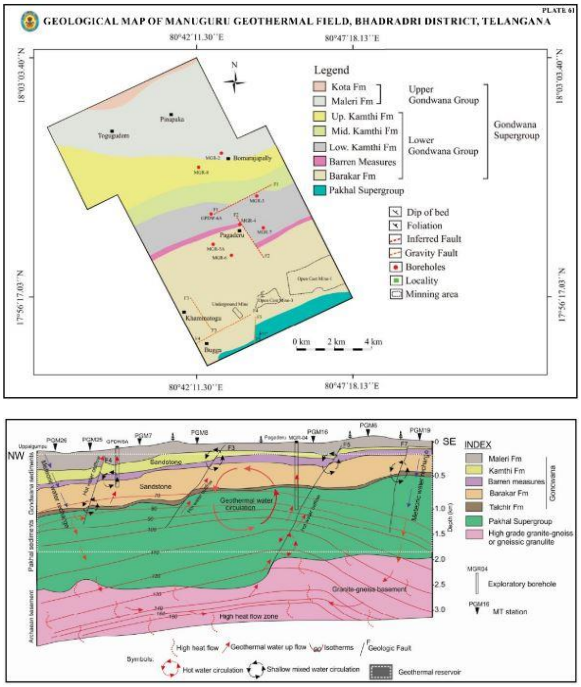

Figure 5 (a) Geological Map (above) and (b) Conceptual Model (below) of the Study Area i.e. Manuguru Geothermal Field in Godavari Graben (Source: GSI Geothermal Atlas of India, 2022)

Geohydrology defined presence of one major basin in the central part hosts streams ranging from 1st to 7th order. Trellis is the most common drainage pattern which is modification of dendritic pattern, with parallel tributaries converging at right angles present. Manuguru is falls under the seismic zone II, as per Bureau of Indian Standards (IS 1893, Part-I, 2002). Most of the seismicity in Bhadradri - Kothgudem district is due to motion along some active normal faults in the Godavari Graben. A major hot spring is located at Bugga which is 6.2 km SSW of Pagaderu village which is a result of neotectonism or faulting. Bugga hot spring is located in a close proximity between the two major neotectonic faults, in north known as Godavari Valley fault while in south known as Kinnerasani-Godavari fault.

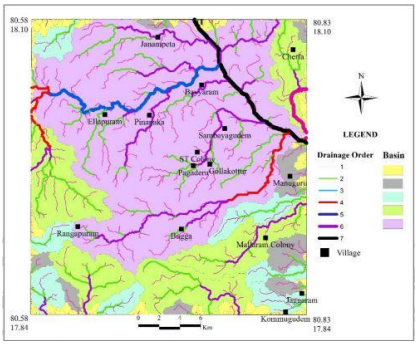

Figure 6: Drainage Basin Map of the Study Area (i.e. Manuguru Geothermal Field in Godavari Graben) generated based on DEM – SRTM Data (Source: GSI Field Report, 2019 -20)

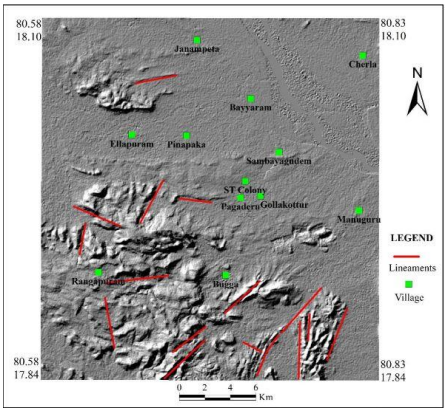

Figure 7: Interpreted structural lineaments over hill shade map of the Study Area (Source: https://earthexplorer.usgs.gov/)

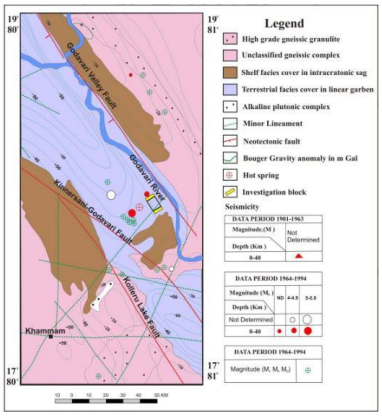

Figure 8: Seismotectonic map of Godavari Valley, Telangana, India. (Source: Seismotectonic Atlas of India and ITES Environs, SEISAT-29-2000)

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2.1 Field Photographs of the Study Area:

Figure 9.1 Exposure of fractured and jointed quartzite, Rathamgutta hill, Manuguru (Left) and Exposure of phyllite with floded silicate vains rocks near Bugga Dolomitic limestone exposed near SCCL, Manuguru Coal Mines (Right)

Figure 9.2 Middle Kamthi Formation, south of Kommugudem (Left) and Upper Kamthi Formation, near Kommugudem (Right)

Figure 9.3 Dolomitic limestone exposed in Manuguru Coal Mines

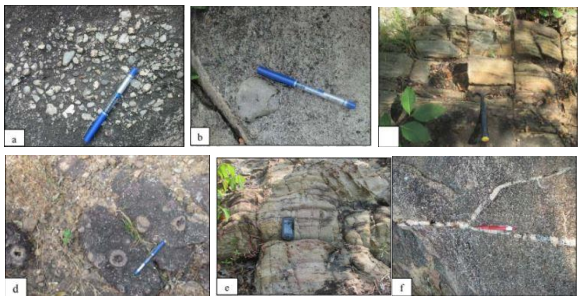

Figure 9.4

(a) Pebbly top in very coarse-grained sandstone, Bugga
(b) Well-rounded quartz clast in coarse grained sandstone, Bugga
(c) Jointed shale and sandstone beds exposed East of Bugga
(d) Iron concretions in very coarse to pebbly sandstone exposed west of Kondapuram SCCL Coal Mines (abandoned OC-3)
(e) Numerous parallel to oblique silicate veins cutting sandstone exposed East of Bugga
(f) Silca vein with iron coating in sandstone exposed SE of Bugga

(Source: GSI Field Reports, 2019 -20)

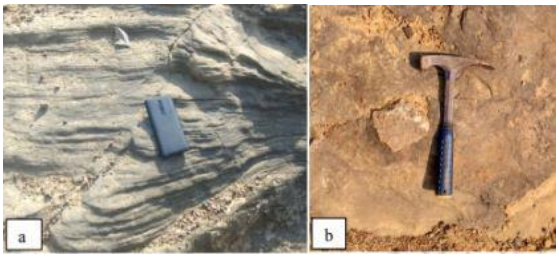

Figure 9.5 Exposure of fractured and jointed quartzite, Rathamgutta hill, Manuguru Talchir Formation exposed in the Motla nala section (a) Shale / siltstone (b) A drop stone of granite-gneiss in siltstone. Coarse grained sandstone of Barakar Formation near east of Muttyalamagutta hills

Figure 9.6 Coarse grained (Left) and Very coarse grained (Right) sandstone of Barakar Formation near east of Muttyalamagutta hills

Figure 9.7 Sandstone / siltstone with iron concretion of Lower Kamthi Formation, exposed in small hill near Uppalagumpu village (Left) and Middle Kamthi sandstone near Garudevipeta village (Middle) and Upper Kamthi sandstone near Sambaigudem village (Right)

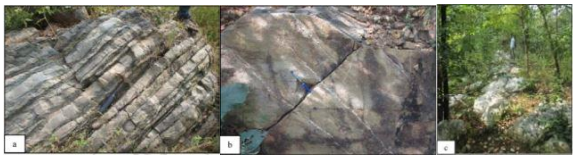

Figure 9.8 (a) Interbedded shale / slate exposed south of Bugga village (b) Parallel to oblique silicate veins cutting quartzite, East of Bugga village (c) Quartz vein exposed near Pakhal and Barakar Contact, east of Bugga

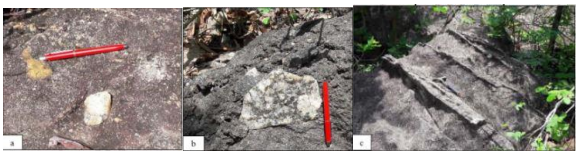

Figure 9.9 (a) and (b) Clay and quartz clasts in coarse to very coarse grained grey colours andstone exposed NW of Pinapaka; and (c) Deformation bands in coarse grained sandstone exposed NW of Pinapaka village.

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3.0 Geophysical Investigations of the Study Area:

3.1 Gravity Survey:

A total number of 144 gravity stations were observed covering an area of 125 sq km by using Autograv Gravimeter CG5 and DGPS GS10 and 15 rock samples were also collected by GSI for physical property (density) measurements. The trend of regional Bouguer Gravity anomaly is following NE-SW direction, which is well correlating with the regional trend of the formations of the study area. It can also be observed that the basement of the study area is dipping towards NW direction and the depth of the Basement ranges from 1.2 to 2.2 km Depth.

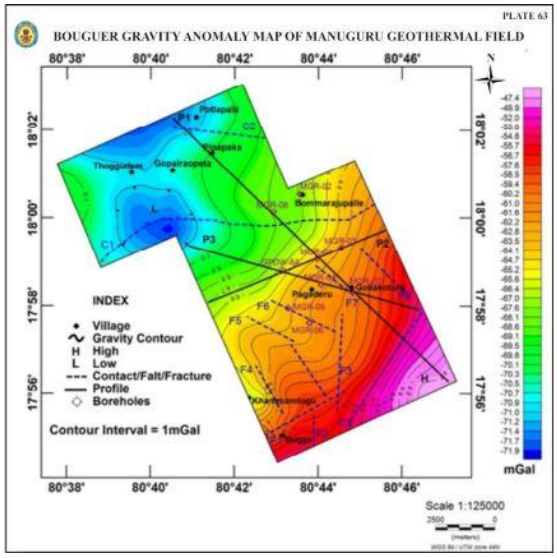

Figure 10. Bouguer Gravity Anomaly Map of the Study Area i.e. Manuguru Geothermal Field in Godavari Graben (Source: GSI Geothermal Atlas of India, 2022)

3.2 Magneto Telluric (MT) Survey:

Magneto Telluric (MT) Geophysical survey was carried out by GSI at 34 sites in an area of 700 Sq km in Manuguru, Bhadradri (Kothagudem) district, Telangana covering Pagaderu geothermal manifestation area by using MT instrument ADU06 - Metronix, Germany for recording MT signals within the frequency range of 20 KHz to DC. The Study identified a distinguished low resistivity zone at a depth of 2.4 KM indicating deep hot water geothermal resource in the area. From the MT survey it is interpreted that the presence of hot water is restricted within the zones near Bandhagirinagar & Chintapalli in northeastern part, Uppalagumpu, Kodichenkuntla and Santhinagar in southern part, ST Colony and Gollakattur in eastern part and Motalagudem in northern part of the investigation block. The MT survey confirms the existence of NW-SE trending fault/fracture running from Kondapuram to Bhandarigirinagar passing through Uppalagumpu. Several faults/fractures and formation contacts are present in Pagaderu geothermal manifestation area. The hot water comes up to near surface through these faults/fractures due to subsurface artesian pressure.

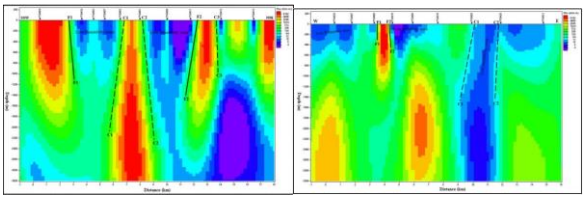

Figure 11. 2-D Inverted model along Profile P1 (left) and P2 (right), Manuguru Geothermal Field (Source: GSI Report, 2022)

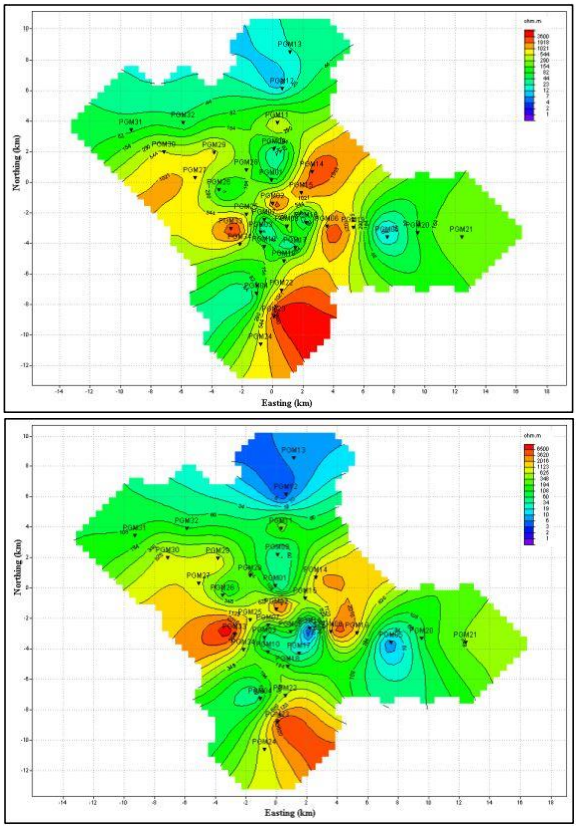

Figure 12. Planar view of inverted model at depth 1500 m (above) and 2000 m (below), Manuguru geothermal field (Source: GSI Report, 2022)

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3.3 Well Logging:

Eight Boreholes were drilled by GSI and the high geothermal gradient with 43.5ºC/km recorded in MGR-4 Well with water discharge of 800 lpm. GPDW-6A is also recorded even more temperatures but logging could not be done due to high artisan condition.

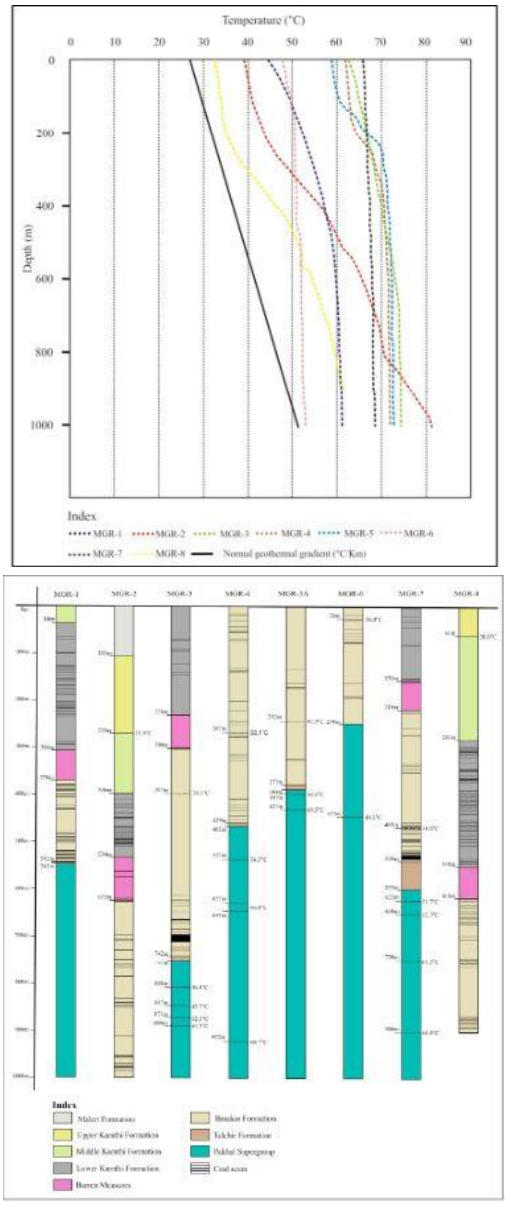

Figure 13. Thermal log (above) & litholog (below) of Manuguru GT Fields (Source: GSI Report, 2022)

4.0 Geochemical Analysis

The monitoring of thermal water from boreholes recorded temperature of 25 °C to 32 °C. Broadly the water samples are classified as Na-HCO3 type (gas enriched meteoric fluid) and mixed type. In Na-K-Mg triangular plot, it is seen that all the thermal water samples fall close to the Mg corner in the 'immature waters' region. Cl-SO4-HCO3 triangular plot indicates peripheral HCO3 rich water. The stable isotope signature (of Hydrogen and Oxygen) of the thermal manifestation reveals meteoric origin and sodium bicarbonate rich water. The indicative reservoir temperature of Manuguru geothermal field is estimated in the range of 65 °C to 100 °C by quartz (Fournier, 1977 conductive) thermometer and 70 °C to 100 °C by quartz (Fournier, 1977 adiabatic) thermometer. Whereas the Reservoir Temp Estimated by the D. Chandrashekaram (1996) is around **175 °C to 215 °C** at a depth of **2.5 KM**.

5.0 Conclusions

The Basement Rock of granite and gneiss present below the phyllite and quartzite of Pakhal Super group could be the heat Source in Manuguru and meteoric origin water deeply circulated to greater depth and comes back to the surface through faults/fractures and the estimated installed capacity of Geothermal Energy is approx. **122 MW**, for 20 years; to commercially generate the electricity by using Organic Rankin Cycle (ORC), at GPDW-6A Borehole in Pagaderu, Manuguru Geothermal Field of Godavari Graben, India (Latitude 17.98003 N and Longitude 80.71947 E).

6.0 References

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7.0 Acknowledgments: Authors Acknowledges GSI for their data and express thanks to Director (E), HoI, Head BRG and I/C UCRG, KDMIPE, ONGC and Head GG, IIT Kharagpur for their valuable support.