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Hydrogeochemistry of Thermal and Cold Springs of Pranhita-Godavari Basin, India

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ABSTRACT

Based on the geological occurrences of the thermal springs, seven geothermal provinces have been identified in India. Godavari geothermal province is in Pranhita-Godavari basin of the Eastern Ghats-mobile belt and its thermal springs are enriched in Ca-SO_4-HCO_3. In this study, we analyze the physiochemical behavior of these thermal waters. Representative water samples were collected from several thermal and cold springs located along both sides of the Godavari River. Rock samples of the gneissic basement and surface sandstone were collected for water-rock interaction study and to understand the evolutionary history of the thermal and cold springs in the area. While the thermal springs of the study area are dominated by Ca-SO_4-HCO_3 rich water, the cold springs are Ca-HCO_3 enriched. While some of the surface and groundwater samples collected from near the Bugga, Manuguru, and Ramagundam thermal springs show their typical Ca-HCO_3 enrichment, others are SO_4-Cl enriched. Likely, this is due to the interaction of water with the pyrite-bearing Gondwana formation and gneissic basement rocks. Enrichment of calcium, magnesium, and enhanced HCO_3/Cl ratio in the thermal springs may have been caused by exchange and/or mixing process during water-rock interaction at an elevated temperature while ascending to the surface. This behavior of water is also observed during the water-rock experimental studies at 100 °C. As a result, thermal springs show shifting towards the bicarbonate field in the piper trilinear diagram. Based on the chemical-geothermometry, the estimated reservoir temperature ranges from 80 to 174 °C.

1. INTRODUCTION

The Pranhita-Godavari (PG) Basin is a Proterozoic basin occurs at the immediate west of Eastern Ghats Granulite Belt (EGGB) of India. The PG Basin, NW-SE trending sedimentary basin, extending from the present east coast of India towards the NW beyond Wardha where it is converted by the Deccan Trap lava flows. Indian geothermal systems are predominantly associated with the continental rifts and continental collision zone. The PG Basin is situated in the southern part of India and shows occurrences of a number of rifts leads to the formation of Godavari basin (Chandrasekharam and Jayaprakash, 1996; Biswas, 2003; Chaudhuri, 2003; Chaudhuri and Deb, 2004). PG Basin is manifested with numerous thermal springs with surface temperature 28 °C to 80 °C (Chandrasekharam and Jayaprakash, 1996; Biswas, 2003) and associated with the high heat flow ranges from 44 – 104 mW/m^2 has been observing in boreholes of depths of 190 – 310m (Rao et al., 1970).

The last few decades the PG Basin has been exploring for the mining of Gondwana coal deposits. The PG basin is appearing to be a promising geothermal field and therefore, has a considerable amount of geothermal power generation capacity. There are many thermal springs within the Pranhita-Godavari basin along sides of the main Godavari River. The occurrences of a number of extinct springs are also reported from this area and they have a relation with the geologic set up of the Pranhita-Godavari basin. The scope of the present work is to understand the geochemical characteristics of the thermal and groundwater and establish a relationship with the subsurface lithology of the Pranhita-Godavari basin.

2. GEOLOGY

The Pranhita-Godavari valley is an NW-SE trending intracratonic rift belt structure which marks the contact of the two Archaean nuclei of Dharwar and Bastar cratons. The lineament extends from the Eastern Ghats Rift in the southeast towards the NW beyond Wardha where it is covered by the Deccan Trap (Figure 1a). The basin-filling sedimentary rocks are exposed along a stretch of about 450 km in the south-eastern part of the basin. The average width of the exposed succession of the PG Valley is about 110 km (Chaudhuri, 2003). Proterozoic sedimentary rocks occur in two linear belts along the southwestern and northeastern margins of the basin separated by a linear belt of younger Gondwana rocks (Biswas, 2003). The proterozoic belts are flanked on their outer margin by Archaean granulites and gneisses of the basement complex. In the western belt, the sedimentary rock succession unconformably overlies the granulites and gneisses, wheres in the eastern belt the former is separated from the basement by a boundary fault. The depositional contact among individual lithological units and between the Proterozoic succession and the basement are broadly liner and follow the trend of the Valley (Chaudhuri and Deb, 2004). Two sub-parallel master faults trending NNW-SSE define the architecture of the basin from Bapatla to Nagpur.

The strikes of the faults follow the Precambrian orogenic trend (Dharwar) and often cut and dislocate the bounding surface. Fault pattern and their extension into the basement suggest control by a preexisting fabric and the reactivation of earlier faults (Biswas, 2003). Uneven extension of the transverse fault in the basement ridge causes the division of the ridge into four sub-basins (Lakshminarayana, 2002). The intersection of the NW trending Pranhita-Godavari ridge and the Eastern Ghat ridge produce Bapatla ridge in the southernmost part of the basin, on the other hand in the northward part the Bhadrachalam and Wamanapalli ridges divide the Pranhita-Godavari ridge into southern Chintapudi (Ashwaraopet), central Godavari (Sironcha), and northern Chandrapur sub-basins. Central Godavari sub-basin has more degree of subsidence than the other and shows maximum tectonic disturbance.

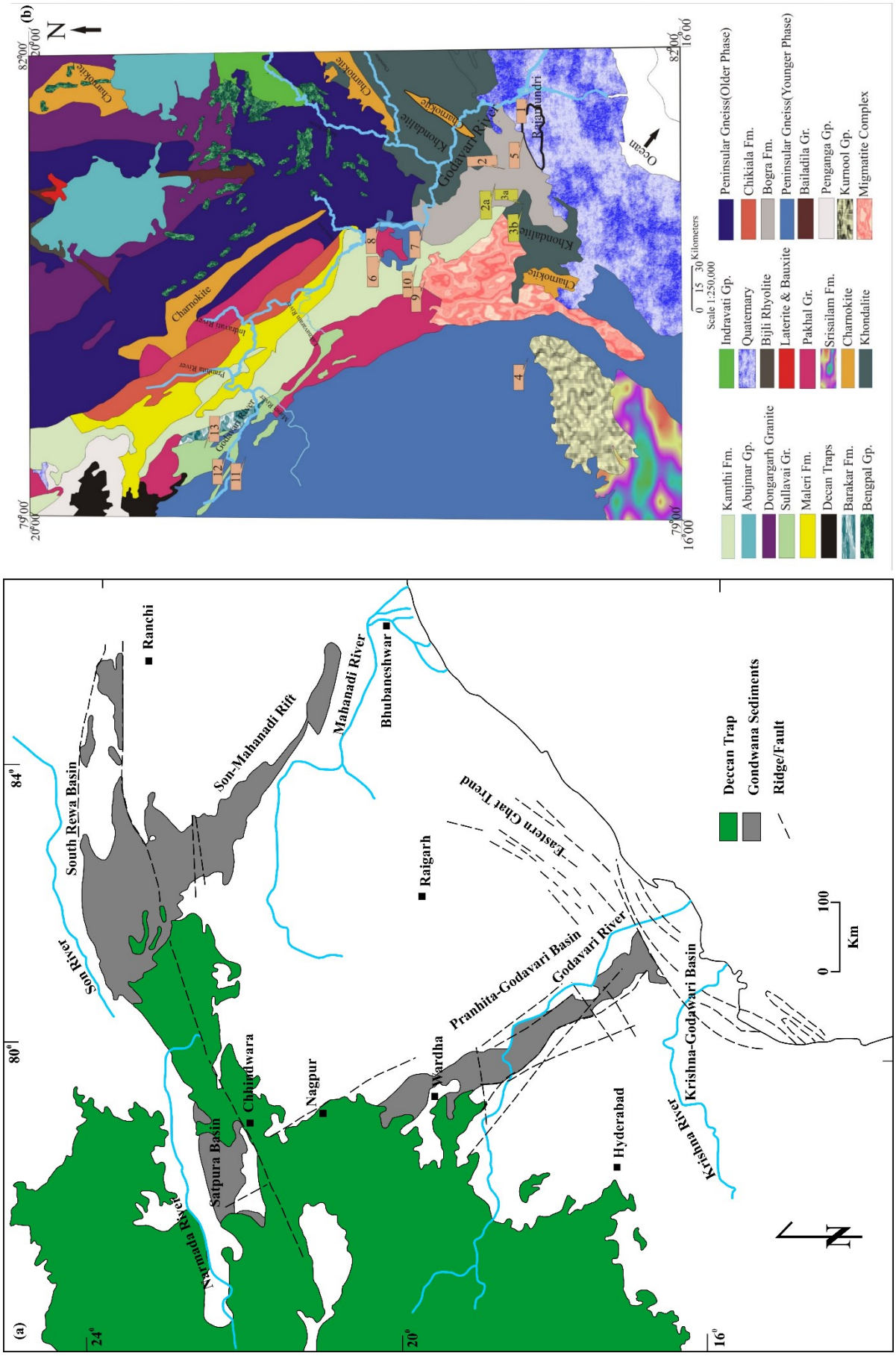

Figure 1: (a) Regional tectonic map of the eastern part of peninsular India, showing Pranhita-Godavari and Son-Mahanadi rift (modified after (Biswas, 2003)); (b) General geological map of the study area (modified after GSI, 2006) with samples collection sites

3. METHODOLOGY

Field investigation has been carried out in the study area for 15 days. A long area along both sides of Godavari River was visited from three successive camps – Rajmundry, Bhadrachalam, and Ramagundam. Five days were allocated for every camp and planned to visit all the nearest geologically important especially important with respect to the present or ancient occurrence of spring. During the fieldwork water samples from thermal springs, rive, groundwater, and rock samples were collected for the chemical analysis (Figure 1b). We followed the procedure for water sample collection as described by Giggenbach and Goguel (1988). One set of water sample was acidified with HNO_3 on-site and the other set was stored at a lower temperature for their geochemical analyses in the laboratories. The water temperature, pH, and electrical conductivity of water samples were measured in the field using Orion 4-Star Meter. Cation and silica were analyzed from the water samples acidified with HNO_3 using ICP-AES at the Department of Earth Sciences, Indian Institute of Technology Bombay. The other set of water samples was used to measure (1) sulfate concentration with the aid of UV spectrometer by turbidimetric method, (2) alkalinity by H_2SO_4 titration method, and (3) chloride concentration by ion-selective electrode method. These analyses were carried out as per the standard procedure set by APHA (2005) and reported in Table 1.

Table 1: Physio-chemical parameters of analyzed water samples from the study area

Sr. No.	WT*	pH	Temp	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	SiO_2
			°C	µS/cm	Mg/L							
1	RW	7.88	25	234.7	21.7	3.1	47.6	7.2	14.8	59.2	130.0	na
2	GW	7.07	27	1292.0	58.2	2.4	87.3	43.3	95.1	190.2	315.0	na
3	GW	7.49	26	754.0	46.6	93.4	79.4	2.4	68.0	136.0	270.0	na
4	GW	7.24	26	2147.0	262.2	11.4	119.0	67.3	245.0	590.0	480.0	na
5	TW	7.28	41	421.0	28.9	8.7	71.4	4.8	43.9	87.8	160.0	112.5
6	TW	7.34	40	610.0	103.4	18.8	71.4	4.8	28.3	56.6	315.0	114.3
7	GW	7.61	27	1169.0	70.0	35.0	63.5	72.1	65.1	130.2	495.0	na
8	RW	8.02	25	311.0	24.5	2.8	71.4	19.2	59.7	119.4	145.0	na
9	RW	8.16	26	307.0	25.7	2.8	79.4	4.8	20.0	40.0	135.0	na
10	RW	7.72	25	102.8	6.8	3.0	55.6	4.8	14.1	28.2	25.0	na
11	RW	8.24	25	949.0	161.7	2.6	103.2	4.8	194.0	388.0	235.0	na
12	TW	6.51	30	88.3	6.5	2.1	39.7	9.6	5.9	11.7	55.0	60.3
13	GW	6.8	27	592.0	43.7	4.3	79.4	19.2	65.2	130.4	250.0	na
14	RW	8.45	26	488.0	45.3	3.4	55.6	24.0	35.5	71.0	190.0	na
15	CW	6.57	24	233.3	12.1	3.1	63.5	9.6	17.1	34.2	125.0	na

*WT: Water-type; RW: River water; GW: Groundwater; TW: Thermal spring water; CW: Cold spring water; EC: Electrical conductivity; na: not analyzed

Furthermore, to understand the evolutionary history of thermal fluid, a water-rock interaction experiment was conducted. To conduct this experiment, the rock samples were crushed to <1mm. The experiment was performed in a glass chamber with fluid/rock ration of 10:1 at 100 °C as shown in (Figure 2). Rainwater was used in the experiment as a leaching fluid. The experiment was run continuously over a period of 90 day and samples were collected after 30 days and 90 days. The analyzed water samples were given in Table 2.

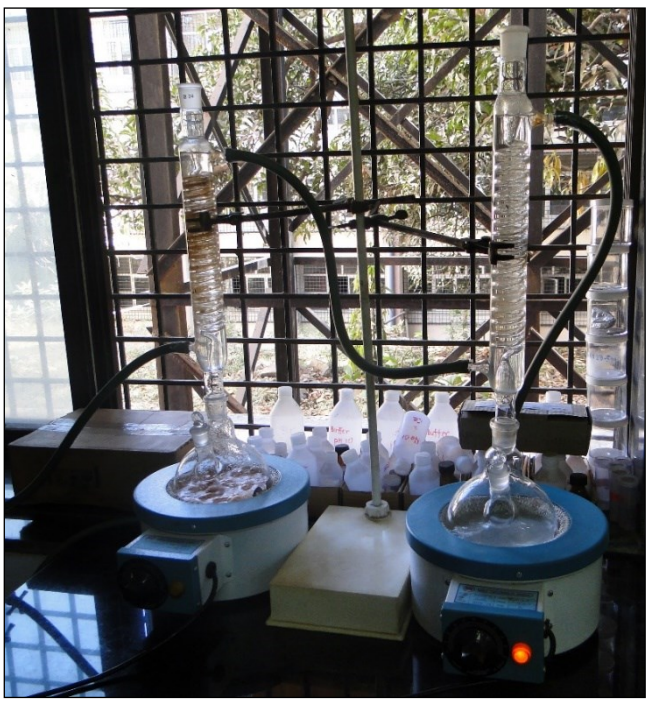

Figure 2: Water-rock interaction experimental setup

Table 2: Data of the major ions from the analysis of the water samples from water-rock interaction experiment (in mg/L)

Sample Name	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	CO_3^{2-}	SO_4^{2-}	Fe^{2+}	SiO_2
S1- 1 Month	7.4	1.1	2.5	0.1	16.7	15.0	160.0	9.3	291.5	126.8
S1-3 month	20.6	2.2	1.5	0.0	14.3	63.0	32.0	4.9	58.9	138.8
G1-1 Month	37.5	3.5	9.0	0.2	9.1	25.0	0.0	2.3	64.2	65.8
G1-3 Month	100.3	5.8	11.8	0.0	19.2	50.0	150.0	4.0	12.8	100.16

*S: sandstone; G: gneiss

4. RESULT AND DISCUSSION

4.1 Hydrogeochemistry

The issuing temperature of these thermal spring ranges from 30 to 41 °C. thermal spring water samples (#5, #6, and #12) are near neutral (pH: 6.51 – 7.34), groundwater is near neutral (pH: 6.8 – 7.61), and cold spring also shows the near neutral (pH: 6.57), whereas river water is slightly alkaline nature (pH: 7.72 – 8.45) behavior (Table 1). The analyzed data (Table 2) of water samples were plotted in the Piper diagram (Piper, 1944) shown in Figure 3. Thermal springs are falling in the secondary alkalinity field dominated by alkaline earth (Ca^{++} and Mg^{++}) and weak acids (HCO_3^-), therefore, characterized them into the Ca-HCO_3 dominated the water. Thus, these thermal springs could be predominantly influenced by the sedimentary rock because the thickness of the sediment in this area goes up to 5 km (Biswas, 2003). Hence, shows different behavior from the other geothermal provinces (Figure 3). Whereas surface water and groundwater show their typical behavior with some amount of SO_4 enrichment and characterized them into the Ca-Na-SO_4 type of water. On the other hand, cold spring of this area falls in Ca-HCO_3 field. The Manuguru thermal spring (Chandrasekharam et al., 1996) is falling in another field of Piper diagram (Figure 3) than the present investigation, suggesting that there might be having a chemical exchange in thermal fluid with the rock while flowing path to the surface with a different time interval.

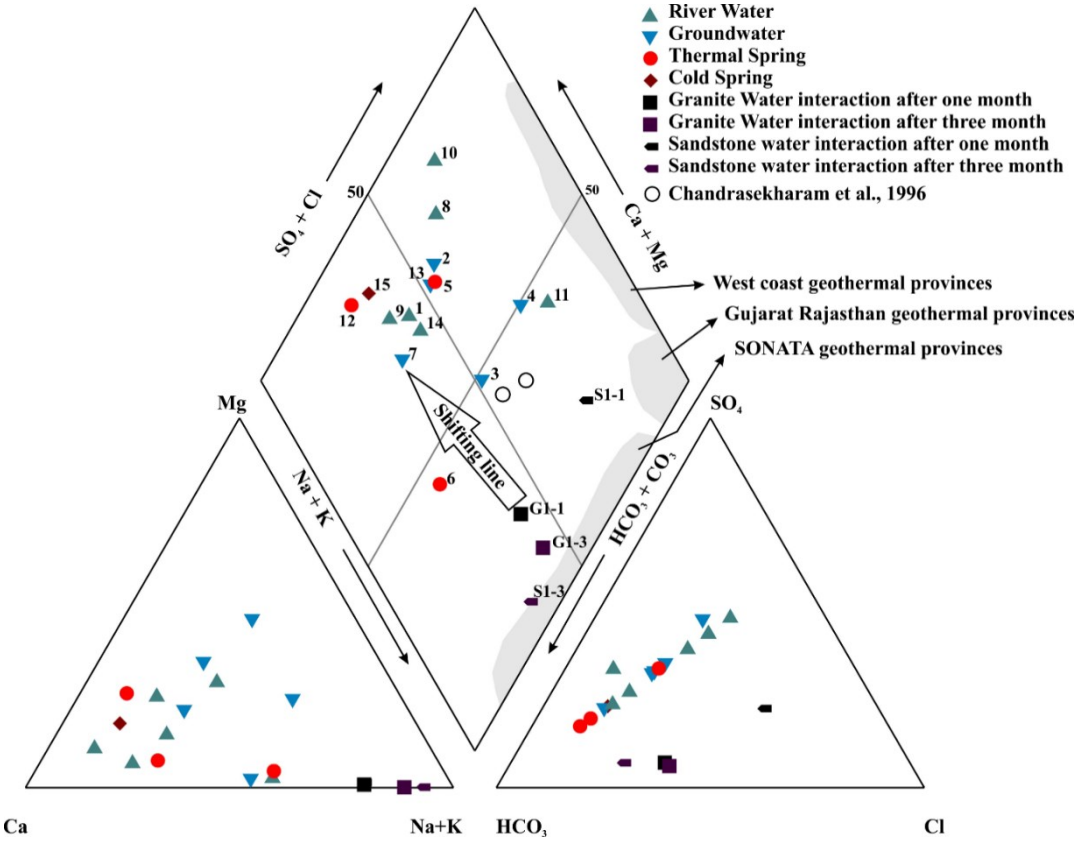

Figure 3: Piper trilinear diagram (Piper, 1944) showing the geochemical variation of different water types from the study area. The Manuguru thermal spring (Chandrasekharam et al., 1996) also presented

4.2 Water-rock Interaction

Figure 3 we can compare interacted water with the thermal springs data. All the interacted samples fall within the low calcium and magnesium field in Piper diagram, whereas all thermal springs have relatively high calcium and magnesium. Therefore, it may be interpreted that either the thermal springs acquires a large amount of calcium and magnesium from the rock by ion exchange process or the springs are mixed with the calcium and magnesium-rich water while ascending to the surface. On the other hand, sulfate and chloride in both water samples (thermal and interacted water samples) shows similar characteristic. Furthermore, this indicates that the deep circulation of meteoric water within the granitic host rock and emerging through sedimentary formation after mixing with the near-surface groundwater rich in Ca-Mg-HCO_3 components.

4.3 Geothermometry

On the basis of silica geothermometry (Fournier, 1973), the estimated reservoir temperature ranges between 110° to 145 °C. However, if we consider Na-K-Ca geothermometry, it provides the reservoir temperature range from 179° to 198 °C. But in some cases, Na-K-Ca geothermometry gave higher reservoir temperature, therefore Fournier and Potter (1979) applied Mg correction for the better reservoir temperature estimation. After applying Mg correction, the estimated reservoir temperature ranges from 93° to 174 °C (Table 3).

Table 3: Estimated reservoir temperature based on chemical geothermometry

	Silica		Cation	
Sample No	No steam loss	Maximum steam loss	Na-K-Ca (Fournier and Truesdell, 1973)	Na-K-Ca with Mg correction (Fournier and Potter, 1979)
5	144	138	198	173
6	145	139	193	174
12	111	110	179	93

The reaction involving K-Na equilibrates at high temperature whereas K-Mg equilibrates at low temperature. Therefore, the calculated temperature from the equations

$$T(^{\circ}C_{kn}) = \frac{1390}{1.75 - \log\frac{K}{Na}} \quad (1)$$

Where 'kn' represents 'K' and 'Na'

$$T(^{\circ}C_{km}) = \frac{4410}{14 - \log\frac{K^2}{Mg}} \quad (2)$$

Where 'km' represents 'K' and 'Mg'

will give different value. Surface geothermal waters can show too low reservoir temperatures by K-Mg geothermometer due to the faster reaction in K and Mg equilibrates, on reverse K-Na geothermometer may show very high temperature due to lack of quick adjustment to the physical environment at shallow depths. So, by combining the two geothermometers Giggenbach (1988) plotted the concentrations of K-Na-Mg obtained from the geothermal water analysis on a triangular diagram to obtain temperatures from both the geothermometers simultaneously. Thermal waters of the study area are falling on the partial equilibrium field (Figure 4), indicates the mixing with water from other sources due course of upcoming samples. Figure 4 shows that these thermal waters falling near to the Mg end, indicating non-equilibrium condition during the ascent to the surface. Therefore, the geothermometry in this case unable to show prominent reservoir temperature. The reservoir temperature found from Na-K geothermometer is 120 °C whereas K-Mg geothermometer indicates 80 °C temperature.

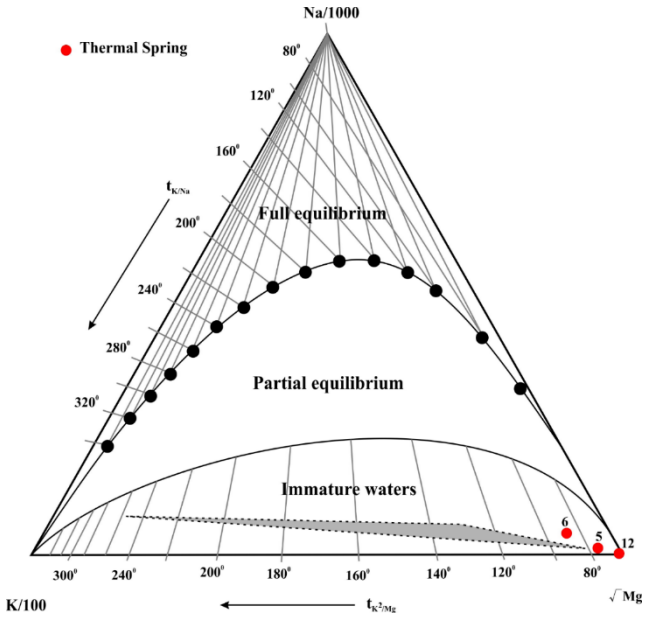

Figure 4: Na–K–√Mg geothermometer ternary diagram of Giggenbach (1988) showing the variation in study area thermal springs.

4.4 XRD analysis of rock

XRD analysis of the initial and the final interacted samples are done to observe the chemical changes in the rock samples due course of water-rock interaction at elevated temperature. Klug and Alexander (1974) suggested that the intensity of one reflection of the phase in the mixture is proportional to the amount of the phase in the mixture. Therefore, the dissolution of secondary minerals including quartz, montmorillonite, and kaolinite in the sandstone sample (S1-F) and on the other hand, quartz, clinoclore, muscovite, and feldspar in the gneiss samples (G1-F) after the water-rock interaction after 90 days as shown in Figure 5.

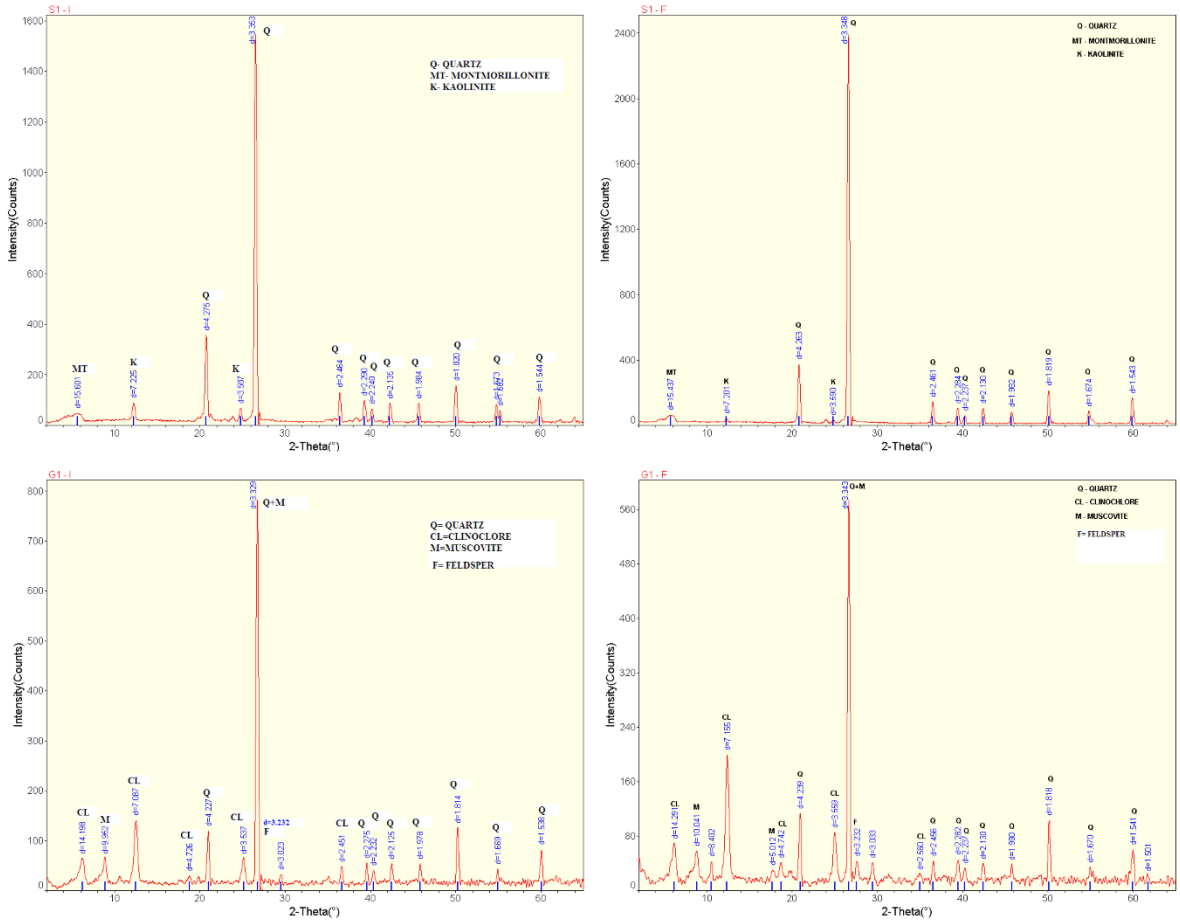

Figure 5: X-Ray Diffraction analysis of rock samples, S1-I: initial sandstone sample; S1-F: Sandstone sample after water-rock interaction; G1-I: initial gneiss sample; G1-F: Gneiss sample after water-rock interaction.

5. CONCLUSION

All the thermal springs are Ca-HCO_3 type of water and their nearest groundwater and river water samples from the study area show similar chemistry. Therefore, it may conclude that the chemistry of thermal fluid is compatible with the chemistry of the surrounding rock through which they flow. As several faults govern the geologic setting of the Pranhita-Godavari basin, the occurrences of the thermal springs and their geochemistry also guided by the fractured basin set up. Water rock interacted water samples have different chemical properties than the spring. Springs are more calcium and magnesium-rich than the interacted samples which suggest that the spring waters are mixes with calcium and magnesium-rich water due course of its ascent to the surface of calcium and magnesium are added to the spring water from the rock through which they are ascending to the surface. With the help of chemical geothermometry, the estimated reservoir temperature could be in the range from 80° to 174 °C. Therefore, this site can be utilized for power generation and other direct application like space heating, bathing, fish farming, etc.

6. ACKNOWLEDGMENT

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