Groundwater Hydrology Studies around a Carbonate Hosted Flatly Dipping Uranium Deposit and Environmental Management

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Abstract

Tummalapalle area in Cuddapah Basin hosts two narrow strata bound parallel uranium bearing lodes in dolostone, dipping at 14-17 degrees from surface to depths beyond 1,000 m and intersected by post-mineralized dykes. These lodes are overlain by a thick band of purple shale, amenable to weathering when exposed to air. This is a low rainfall area with 245-279 dry days a year. The groundwater in this area, classified as 'overexploited' by CGWB, is drawn extensively for drip irrigation for banana cultivation. A steady rise of areas under banana cultivation during the last two decades is associated with sporadic reports of elevated salt concentration in groundwater drawn from borewells drilled for the purpose. A study of the area's hydrology, like groundwater flow directions, and spatial positions of orebodies dykes and agricultural borewells, throws light on possible causes of elevated salt concentration and their associated characteristics. The study also validates the performance and effectiveness of the engineered impoundment facility for the disposal of uranium ore mill tailings by comparing the characteristics of water and salts in the tailings with that of agricultural borewells.

Keywords: Tummalapalle, orebody, borewell, bananas, salts, tailings

Introduction

During the years 2018 and 2019, the Kadapa district in Andhra Pradesh received scanty rainfalls leading to a decline in groundwater level. It affected the banana cultivation in the area, and there were also reports of elevated concentrations of salts in groundwater drawn from some of the borewells used for the purpose. To investigate the root cause of the problem, a systematic hydrogeology investigation was undertaken by 3-D modelling of the uranium mineralized zone dipping at 14-17 degrees from the surface outcrops to depths of 1,000 m and spread almost over the entire area; and also through isotope hydrogeology studies. This paper deals with the findings of this investigation and emphasizes the need for long-term measures for sustainable banana cultivation.

Geology of the Area

Tummalapalle area is located in the southwestern part of the Cuddapah basin and belongs to the Papaghni Group. The rock formations are Gulcheru Formation (~150-200 m thickness) conformably overlain by Vempalle Formation (1900 m thick). The latter formation is overlain by basic lava flows and the Chitravati Group of rocks. The litho-units starting from the base of Gulcheru Formation to the top of Vempalle Formation are basal conglomerate, quartzite and shale of Gulcheru Formation and massive dolostone, conglomerate, Uraniferous dolostone, purple shale constituting the lower 200 m of Vempalle Formation with Cherty dolostone constituting its upper 1700m. The mineralised carbonate rock is designated as "Phosphatic siliceous dolostone" (PSD), as dolomite is the major mineral admixed with impurities like silicate detritus (quartz and feldspar) and phosphate cement (collophane). The main uranium phase in the impure dolostone is pitchblende with a minor amount of coffinite and U-Ti complex. It has two narrow strata-bound parallel uranium-bearing lodes, dipping at 14–17 degrees from surface to depths beyond 1,000 m. The overlain thick band of purple shale is amenable to weathering when exposed to air. The sedimentary beds are gently dipping due-NNE and are affected by E-W trending post sedimentary fractures at places.

Physiography, Climate, and Rainfall

The site in Vemula Mandal (a revenue unit) in the YSR (Kadapa) revenue district of Andhra Pradesh is at the foothill of the NW-SE trending hill range with a peak height of 750 m AMSL in the south and south-west of the site, which extends on either side separating the regional topography. The site is mainly dominated by undulating topography with hillocks and valleys. The average ground level of the site is 360 m AMSL. The remaining sides of the site are almost flat except for a few sporadic hillocks on the western side. The flat terrain is at about 350 m AMSL and the western side hillock is at about 420 mRL. The minimum temperature of the Kadapa district varies in the 28-30 °C range from November to January and its hottest temperature varies in the 40-45 °C range during the April-May period. Kadapa district is a scanty rainfall area with 245-279 dry days in a year. The rainfall trend of the district is given in Table 1.

Drainage & Watershed Map

The drainage pattern of the area is dendritic which facilitates high run-off and seasonal streams flow from the hills towards the east. Fig.1 shows the Google terrain map of the area.

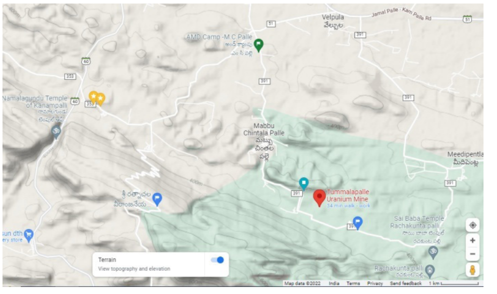

Fig.1: Google terrain map of the Tummalapalle area

The watershed can be broadly divided into two areas, viz. Mabbuchintala Palle (MC Palle) area and the Tailings Pond Area. These two watersheds are shown in the Google satellite map in Fig.2. The tailings pond watershed is represented by a red outline and the MC Palle watershed by a blue line.

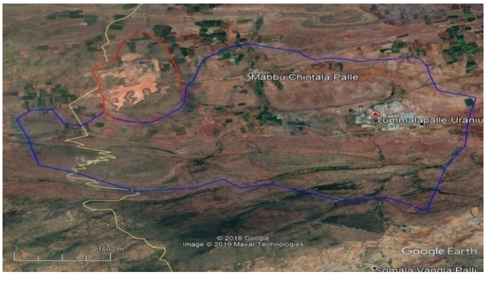

Fig.2: *Watersheds shown on Google satellite map of Tummalapalle area*

Table 1 Rainfall Trend in YSR (Kadapa)

Year	Annual Rainfall (mm)	Year	Annual Rainfall (mm)
June-13 to May-14	654	Jun -17 to May-18	787
Jun-14 to May-15	499	Jun-18 to May-19	326
Jan -15 to Dec-15	1,004	Jun-19 to May-20	689
Jun -16 to May-17	566	Jan -20 to Dec-20	1,420
1999 to 2011 Min. 460, Max. 911, Average 709.5			

Table 2 Banana cultivation statistics

	India					
Year	1991-92	2002-03	2007-08	2008-09	2014-15	2017-18
Area ('000Ha.)	384	475	658	80.1	79.4	89.0
Production ('000 MT)	7,790	13,304	23,823	2,804	3,487	5,003
Yield (MT/Ha.)	20.3	28.0	36.2	35.0	43.9	56.2
		Andhra Pradesh			YSR (Kadapa)	
Year	2008-09	2014-15	2017-18	2008-09	2014-15	2017-18
Area ('000Ha.)	80.1	79.4	89.0	3.82	15.9	15.2
Production ('000 MT)	2,804	3,487	5,003	115.8	953	834
Yield (MT/Ha.)	**35.0**	**43.9**	**56.2**	**30.0**	**60.0**	**55.0**

Table 3 Water requirement for Banana

Period	Planting to 4th month	5th month to shooting	Shooting to 15 days before harvest
L /plant /day	15	20	25

Agriculture

Banana is the principal crop in the area. It is carried out mainly on flatly dipping slopes in hilly terrain as it facilitates proper drainage of water during rains. In a span of 30 months (12 months for planted crop and 9 months each after harvest for the subsequent crops), three crops comprising one planted crop and two ratoon crops are harvested without reduction in yield. The trends of banana cultivation in the district and the state of Andhra Pradesh and India are given in Table 2.

Encouraged by a high return on investment, there is a steady rising trend of conversion of barren lands on gentle hill slopes into agricultural fields for banana cultivation. Assured round-the-year availability of the required quantity of water is a precondition for maintaining productivity. The water requirement for banana cultivation through drip irrigation is given in Table 3.

The drip irrigation system involves a higher investment compared to non-drip systems but offers the benefit of increased productivity and higher return on investment. Since the farmers cannot rely on rainwater, they adopt modern drip fertigation systems by drawing groundwater extensively through agricultural borewells. Though drip irrigation systems decrease water use by 30-70% compared to conventional water sprinkler irrigation, the gross demand for groundwater in this dry area is very high. This has led to the drying up of agricultural bore wells and the farmers are forced to drill new and deeper borewells to draw groundwater from deeper horizons.

Demand of Groundwater

The Central Ground Water Board (CGWB) defines 'Stage of Ground Water Development' as a ratio of 'Annual Ground Water Draft' and 'Net Annual Ground Water Availability' in percentage. CGWB categorizes an area as 'Critical' when the ratio of extracted and extractable groundwater is in the range (>90% - ≥100%) and 'Over Exploited (OE)' when it exceeds 100%. The groundwater recharge and withdrawal statistics of Vemula Mandal for different periods are given in Table 4.

In the Tummalapalle area, agriculture consumes the highest amount of groundwater (97.6% in the year 2019-20). The groundwater consumption for agriculture increased marginally by 5.8% from 1,369 Ha.M in 2008-09 to 1,448 Ha.M in 2019-20.

Rainfall is the principal contributor to groundwater recharge (65% of extractable groundwater in the year 2019-20). The rainfall was 689 mm during the 12 months from June 2019 to May 2020 (@ 57.4 mm per month). However, the rainfall during the 17 months

Table 4 Vemula groundwater recharge & draft

	Description	2008-09	2017	2019-20
Groundwater Recharge (in Ha.M)	**Rainfall**	**-**	**-**	**1,096**
	Canal, Surface irrigation, Tanks and ponds	-	-	6
	Groundwater irrigation	-	-	362
	Water conservation structures	-	-	223
	Total recharge	-	-	1,686
	Environmental flows	-	-	84
	Extractable groundwater	**1,130**	**-**	**1,602**
Groundwater Extraction (in Ha.M)	**Irrigation**	**1,369**	**-**	**1,448**
	Domestic & Industrial	57	-	36
	Gross Groundwater Draft	**1,426**	**-**	**1,484**
Stage of Ground Water Development (%)		126.19	106.13	92.65

Table 5 Groundwater parameters around the tailings pond up to 15 km

Parameter	Total Samples	Unit	Tailings Pond	pH range and average values of parameters of groundwater samples Collected from places outside tailings pond						
				By distance (km)				Relationship with orebody /dykes		
				0 - 1	1 - 2	2 - 3	3 - 15	A#	B#	C#
pH	308	Min.	10.99	6.98	6.66	6.91	6.40	6.98	7.14	7.00
		Max.	11.20	8.04	8.56	7.93	9.10	9.10	8.56	8.29
SO4-2	260	mg/L	9,001	95	316	190	135	145	244	408
Na+1	156	mg/L	6,011	25.41	109.07	86.31	87.38	88.92	71.75	55.00
Mg+2	156	mg/L	3.43	6.93	28.93	35.06	54.46	50.56	29.25	25.00
Ca+2	156	mg/L	9.60	69.77	46.89	71.43	97.08	87.54	159.75	63.00
EC	307	µS/cm	26,627	906	1,402	1,086	1,268	1,231	1,590	1,194
TDS	307	mg/L	13,337	500	843	654	738	709	1,019	763
HCO3	76	mg/L	8,235	401	367	364	342	351	-	-
Total Alkalinity as CaCO3	184	mg/L	-	421	470	358	381	383	474	399
Total Hardness as CaCO3	184	mg/L	-	323	382	398	525	490	361	420

Abbreviations used in this table

A	not modeled	B	intersected	C	not intersected

from January 2018 to May 2019 was only 423 mm @ 24.9 mm per month, which was 57% lower compared to the period from June 2019 to May 2020. It was during this period when reports of a fast decline in groundwater levels in the area started pouring in from various sources. Simultaneously, there were sporadic reports of higher salt concentration in water drawn from some of the agricultural borewells.

Hydrogeological Investigations

To investigate the genesis of the above problem, a hydro-geological study was conducted to understand the 3-D spatial positions of orebodies dykes and agricultural borewells and the groundwater flow directions by developing a 3-D solid model. A total of 378 exploratory boreholes extracted at 200 m intervals have been considered for the orebody modelling. It was observed that some of the borewells had intersected the orebody. Some other borewells had intersected the post-mineralized dykes and others had neither intersected the orebody nor any known dykes. The area has many concealed dykes and only a few of them are mapped. The modelling of the orebody and dykes was restricted to limited areas around the tailings pond but the groundwater samples were collected over a larger radius during the period from August 2017 to August 2021 by various scientific teams. The summary of the findings of the study is presented in Table 5.

From the above study, it is evident that the trends of concentrations of various salts in groundwater samples collected from places within a radius of 1.0 km from the centre of the tailings pond are similar to those collected from places located within radii of 1.0-2.0 km, 2–3 km, and 3-15 km. Similarly, the trends of concentrations of various salts in groundwater for samples collected from borewells intersecting the orebody /dykes, from borewells not intersecting the orebody / dykes, and from other borewells which are not modelled, are also similar. However, there is a sharp contrast between salt concentrations in decanted water samples collected from the tailings pond and those in groundwater samples collected from borewells outside the tailings pond.

The sporadic nature of reported higher concentrations of salts was also examined by studying the distances from the centre of the tailings pond of 5% of the groundwater samples with the measured highest concentrations for each type of salt. This is given in Table 6.

From the above analysis, it is evident that the reported higher concentrations of various salts were sporadic in nature and had no relationship with the tailings pond. This is also evident from the findings of the isotope hydrological investigation carried out by the 'Isotope and Radiation Application Division (IRAD), BARC' that radiocarbon data of groundwater samples varied between 38 to 105 pMC, and their modeled estimated radiocarbon ages varied from semi-modern to 3300 years.

Table 6 *Groundwater parameters around the tailings pond up to a 15 km radius*

Parameter	Unit	Tailings Pond	Position by distance from the centre of the tailings pond (in km)			
			0 - 1	1 - 2	2 - 3	3 - 15
SO_4^{-2}	mg/L	9,001	-	1,401	1,153	1,133
Na^{+1}	mg/L	6,011	-	332	748	316
Mg^{+2}	mg/L	3.43	-	-	-	117
Ca^{+2}	mg/L	9.60	-	-	-	340
EC	µS/cm	26,627	-	3,550	4,071	3,317
TDS	mg/L	13,337	-	2,371	2,111	1,888
HCO_3	mg/L	8,235	-	-	600	520
Total Alkalinity as $CaCO_3$	mg/L	-	610	815	622	-
Total Hardness as $CaCO_3$	mg/L	-	-	-	-	1,199

Conclusion

The investigation validates the performance and effectiveness of the engineered impoundment facility. The impact of over-exploitation of groundwater for bananas and other cultivations needs to be studied in detail to ensure their long-term sustainability as horticulture is the financial backbone of the local agricultural economy.

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