



Structural control on the occurrence of groundwater in granite gneissic terrain, Purulia, West Bengal

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Abstract

Purulia, one of the most drought prone districts of West Bengal, India, is geologically a part of Chotanagpur Gneissic Complex and is mainly a granite gneissic terrain. Scarcity of drinking water has always been a major concern in the area. Thus, a hydrogeological study was carried out in and around Purulia I and Purulia II blocks of the district during lean season. The main objective of the study is to determine the structural control on groundwater flow so that groundwater extraction can be optimised economically in the area. For the purpose, depth to water level zonation map was prepared with flow direction. The lineament data was obtained by analysing satellite imagery of the area and was cross-checked using field data. The orientation of the major joint sets is NE-SW and NW-SE in this area. The NW-SE trending fractures act as conduits and facilitate the flow, while NE-SW trending fractures act as an obstruction to the flow. The lineament density of the area was overlaid on depth to water level map using Surfer and it is observed where fractures form a network, water occurs at shallow level, while in places where fractures are isolated, water flows down to deeper levels. It was interpreted from all the observations that the flow of groundwater in this area depends on the distribution of joints, thus subsurface water being structurally controlled. This type of study has been carried out in various parts of the world but in Purulia district of West Bengal, India, structural control on the occurrence of subsurface water has not yet been established through any major studies. This study will help in divulging structural control on groundwater in this area and identification of areas where constructing tubewells will help in economical extraction of groundwater.

Keywords Water level · Hydraulic gradient · Joints · Structural control

Introduction

Purulia district lies in the western most part of West Bengal, India, between 23° 42' N and 22° 43' N latitude and 86° 54' E and 85° 49' E longitude (Bhaya and Chakrabarty 2016; Haldar and Saha 2015) and is known to be one of the most dry and drought prone districts of the state of West Bengal. The scarcity of water faced by the people here is not only because of extravagant or uncontrolled use of water (both subsurface and

surface water); the fact that the area is a hard rock terrain is also accountable for it. Hydrogeological investigation was carried out during the lean period (a cold season with lack of rainfall allowing for little harvest), i.e., February, considering the physical and chemical aspects of groundwater in this area. The district is extremely dry and also exhibits extremities in temperature. The temperature goes as high as 49 °C in summer and goes as low as 4 °C in the winter. The rainfall here varies from 1100 to 1500 mm. The district is drained by the Damodar river in the North, Subarnarekha river in the South and other tributaries and distributaries such as Kangsabati, Kumari and Darakeshwar play their part as source of water supply in the district.

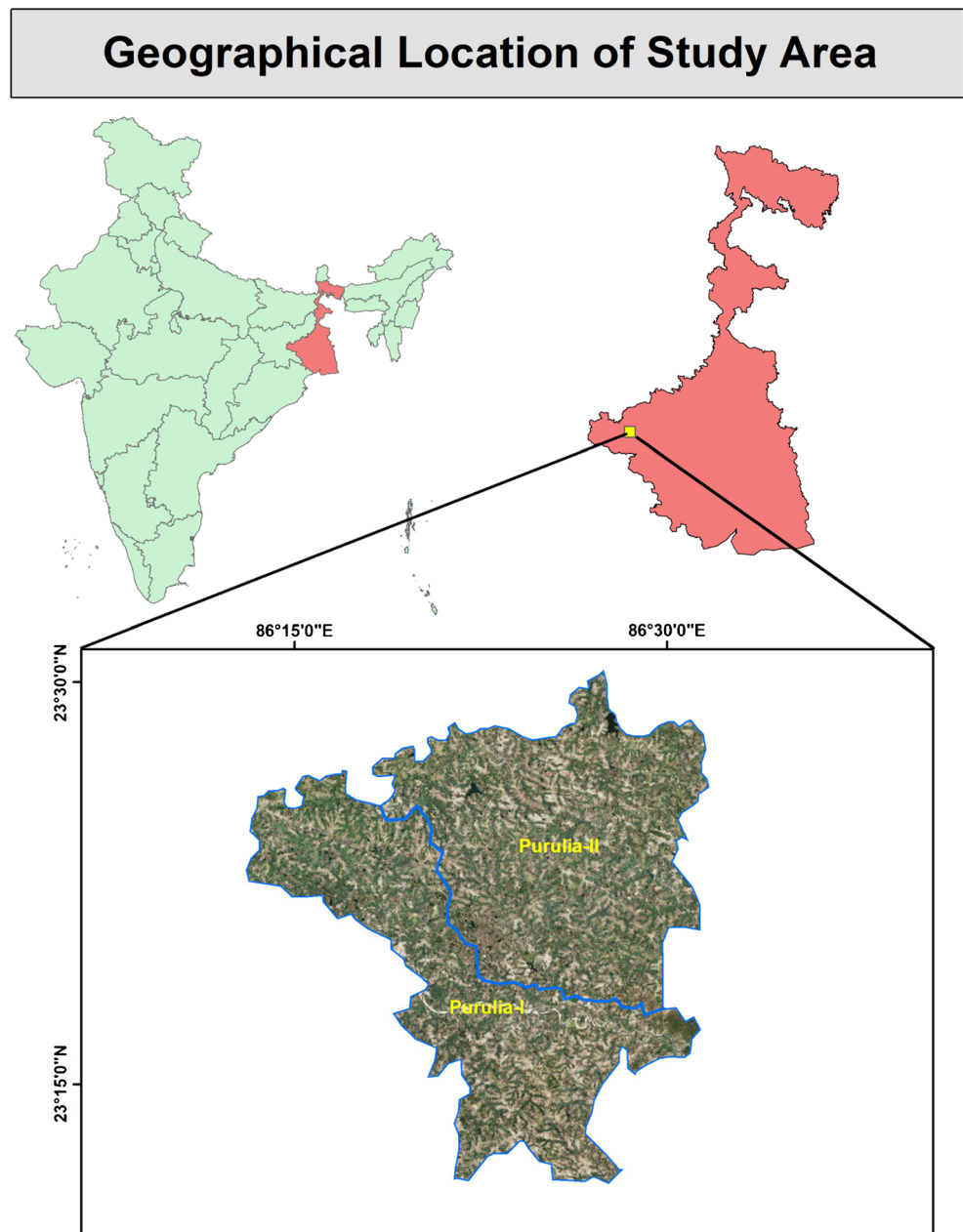
The geology and structure of the area are such that groundwater is mainly confined to the fracture network and weathered mantle as Purulia being a hard rock terrain lacks primary porosity (Acharya and Mallik 2012; Acharya et al. 2014). Groundwater is available in almost all places, but the quantity differs. It is a very reliable source of water mainly in drought prone areas (Hussain and Abed 2019). Decreasing

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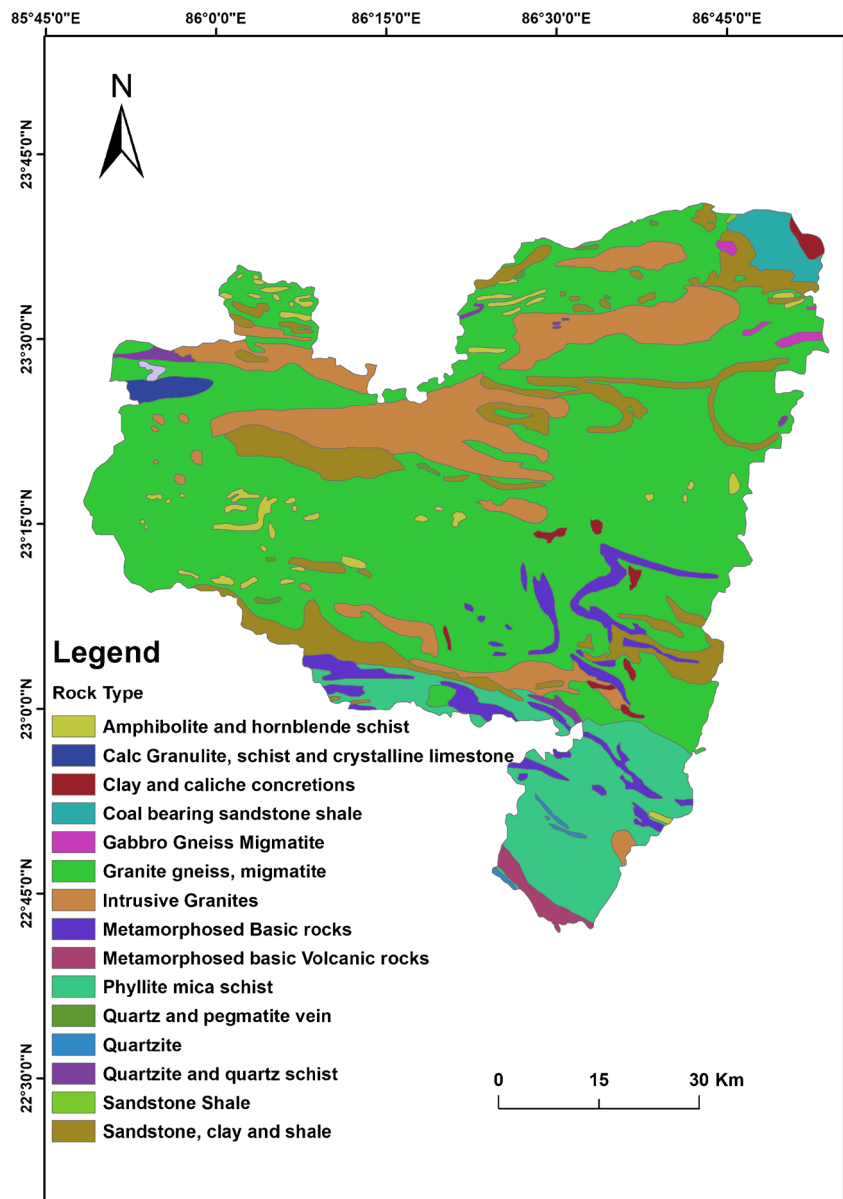
Fig. 1 Study area, covering major portions of Purulia blocks I and II, Purulia district, West Bengal, India



groundwater levels are not always due to drought but inappropriate planning, policy-making and poor management of water resources also play a key role (Pophare et al. 2014). Thus, a proper planning and identification of suitable locations for groundwater exploration is necessary to monitor both depletion of groundwater and problems faced by local people and farmers (Hashemi et al. 2019). In hard rock terrains or basement rocks, groundwater is mainly confined to structural features such as fractures, faults, lineaments and joints (Todd 1980). Places where there is intersection of several fractures, faults or shear zones are considered one of the favourable areas for hosting groundwater in hard rock terrains (Cook

2003; Sonkamble et al. 2014). Hard rocks are susceptible to metamorphism and weathering (Srinivasamoorthy et al. 2011; Bednarik 2019); thus, groundwater can also get stored in the weathered zone. Fault planes and other linear features can be identified by analysing satellite imagery with support of field data (Kumar et al. 2014); on the other hand, a detailed study of fault planes and other structural features can be done using various structural control algorithms. These methods have earlier been used for earthquake related structural identification and can be used for groundwater exploration as well (Pnevmatikos and Gantes 2009; Pnevmatikos 2012; Pnevmatikos and Thomas 2014). The porosity is enhanced

Fig. 2 Lithological map of Purulia district (ref. GSI)



and thus provides a suitable condition for storing groundwater within the basement rocks (Goddard and Evans 1995; Blenkinsop and Kadzvi 2006). The tensional fractures in granitic rocks are wider and contain more water than the compressional fractures. Brittle fault zones usually contain a fine-grained narrow core with low permeability but are surrounded by several subsidiary small faults and fractures which are responsible for enhancing the secondary permeability and porosity (Caine et al. 1996; Caine and Forster 1999). As a result, the low permeability cores of fault are responsible for restricting flow of fluids across the faults, whereas the damaged zone that flanks the fault core is responsible for conducting groundwater flow parallel to the fault zone (Sweetkind et al. 2010). When the fault core lies perpendicular

to the groundwater flow direction, it forms an impermeable barrier to the flow and the flow is channelled along the zone parallel to the trend of the fractures (Elfouly 2000; Hurlow and Bishop 2003). Minor fractures often help in storage of groundwater in an area and increase the permeability where they intersect (Babiker and Gundmundsson 2004). The geological structures such as fractures and lineaments thus have the ability to restrict or allow the flow of groundwater through them (Nilsen et al. 2003; Al-Taj 2008; Perrin et al. 2011; Senthilkumar et al. 2015). The structural control on the occurrence of groundwater has been established in various hard rock terrains across the world, but it has not yet been established in hard rock terrains of Purulia. There have never been any such prominent studies in this area to determine the

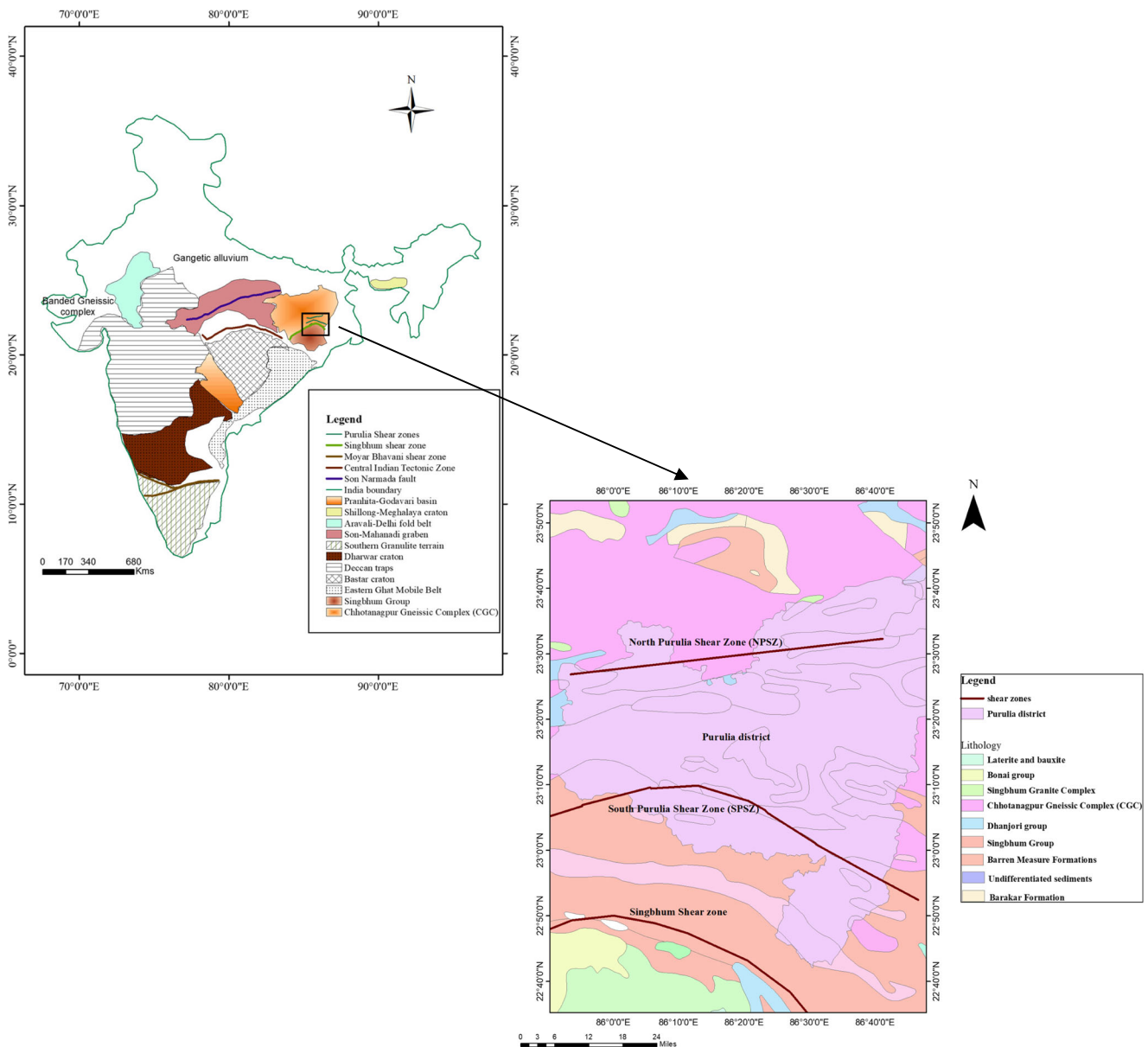


Fig. 3 Geological map of Purulia showing the major shear zones in the area (ref. GSI and modified after Mukherjee et al. 2019)

influences of structural features on groundwater. This study aims to establish the relation between structural features and occurrence of subsurface water in this area. Purulia being a granite gneissic terrain is dominated by fractures, faults and shear zones. So it is very important to see how the disposition of various structural features controls and regulates the occurrence and flow of groundwater in this area.

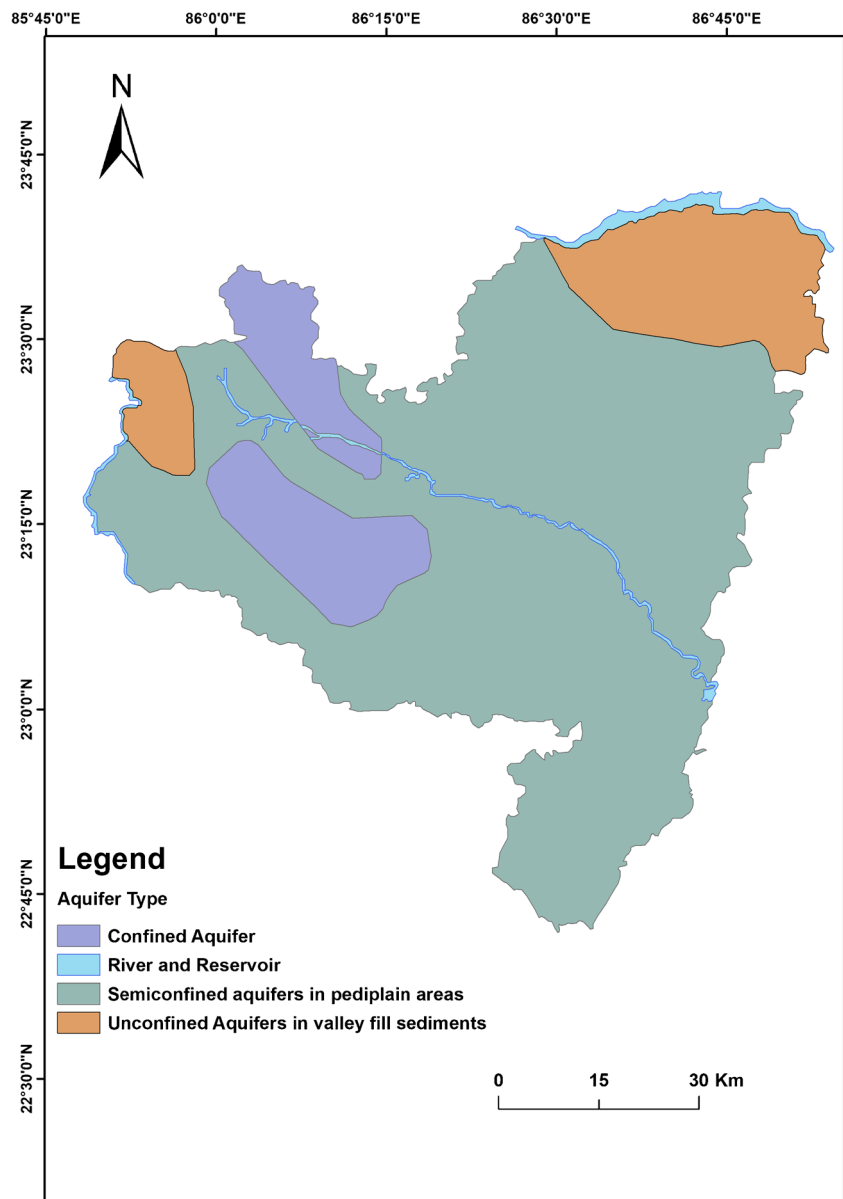
Given the structural complexities in Purulia, this study was largely dependent on developing an understanding of the role of different structural elements (e.g., shear zones and faults) in collecting and channelling groundwater. This objective was achieved by preparing depth to water level zonation map and finding the flow direction of groundwater in the area. Also, delineating the distribution of structural features in the

study area is necessary to identify the fracture sets which help in groundwater flow and the fractures or lineaments which act as barrier to groundwater flow. Developing an understanding of these structural features and their control on groundwater flow will further help in identification of areas suitable for economic extraction of groundwater in this zone.

Study area

Studies related to the impact of structural elements on flow patterns of groundwater are not properly addressed for Purulia district because the entire procedure is quite challenging as it

Fig. 4 Distribution and types of aquifers in Purulia district (ref. CGWB)



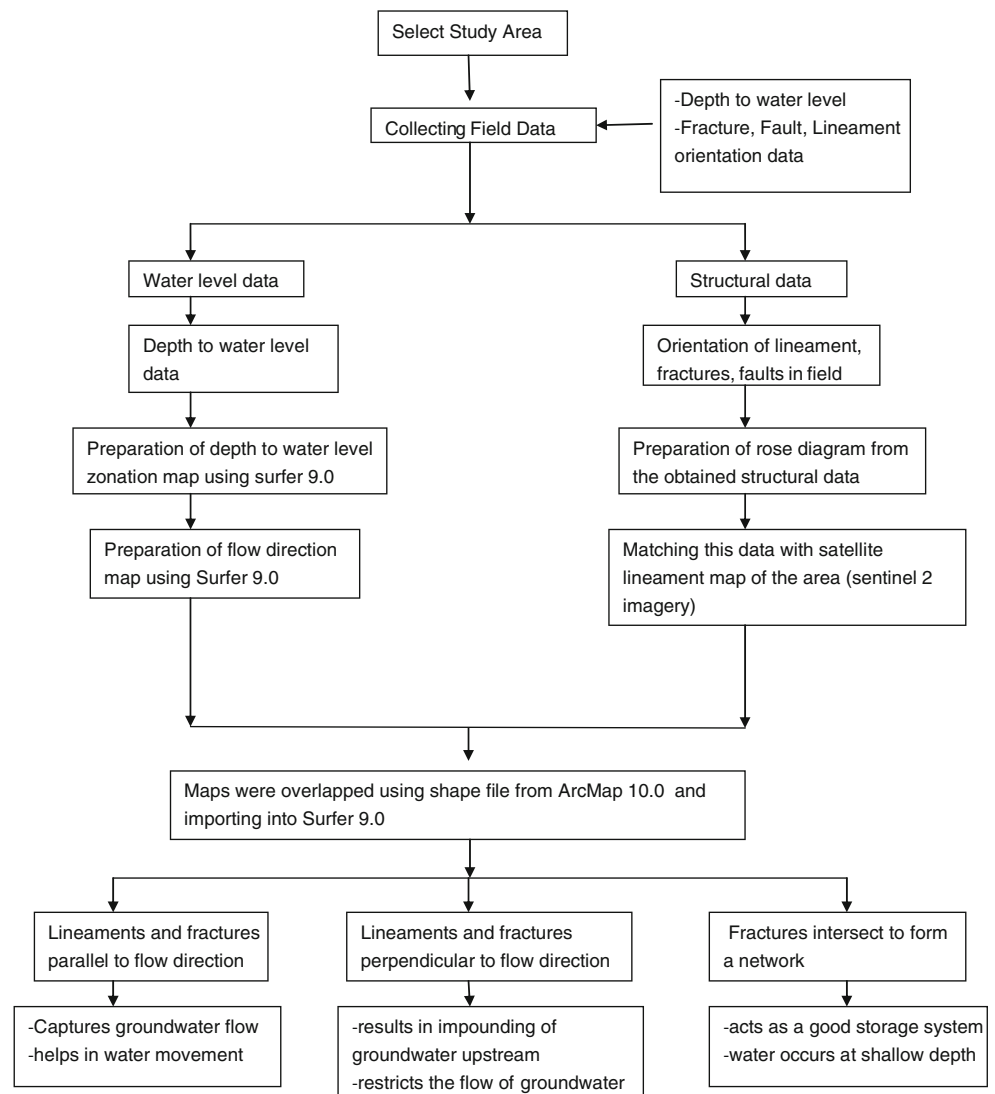
requires combined study of structural and hydrogeologic research efforts. A hydrogeological examination was carried out in and around Purulia town covering a major portion of Purulia I and Purulia II blocks of the district (Fig. 1). The lithological map of the district shows that the study area is mainly composed of amphibolites and hornblende schists (Fig. 2). The soft and flaky mica schist also dominates the area and a large portion of the area is covered with Proterozoic intrusive granites. Some portions of the area are affected by quartz and pegmatite veins. The North Purulia Shear Zone (NPSZ) passes through the upper portion of both the blocks. Physiographically, the two blocks are considered penepplain with slight undulating surface configuration, similar to the rest of the district. The area is drained by river Kangsabati,

popularly known as Kasai river, and it flows from NW towards SE. The study area has low relief and slope.

Geologically, Purulia district forms a part of Chotanagpur Gneissic Complex (CGC) of Eastern Indian peninsular shield (Ghose 1983; Baidya 1992; Gupta and Basu 2000; Ghosh et al. 2016; Acharya and Prasad 2017). It is a craton located to the north of Singbhum orogenic belt and lies to the south of North Purulia Shear Zone (Baidya 1992; Acharya and Prasad 2017) (Fig. 3).

Purulia district shows a great diversity in lithology. The CGC mainly consists of different types of granite gneisses. The main mineralogy of this area consists of phyllite and mica schists belonging to the Singbhum orogenic belt. The presence of garnet porphyroblasts has also been reported

Fig. 5 Research methodology flow chart of this study



(Acharya and Prasad 2017). Augen gneisses occur as small bands in this area. Apart from these, dolerite dykes and veins occur sporadically over the entire terrain (Baidya and Chakravarty 1988; Baidya 1992; Acharya and Prasad 2017). The rheological behaviour of the rock mainly depends on the mineralogical content.

Prior to determining structural control on the occurrence of subsurface water, it is important to know the various structural features present in this area. The district is bound by two shear zones. South Purulia Shear Zone (SPSZ) trending E-W and passes through the south of Balarampur existing along the boundary of CGC and Singbhum granite (SG) (Gour et al. 2014). The NPSZ is also E-W trending and passes through Jhalda and Raghunathpur. It passes through the central part of CGC and is characterised by shear joints, fractures of mafic-ultramafic basic rocks along with quartz veins (Bhattacharya 1989). The area has undergone polyphase deformation giving rise to different structural elements like fold, fault and joints

with varied orientations along with dextral and sinistral minor folds (Sengupta 1964; Sarkar 1977).

The geology of the district suggests that it is a hard rock terrain covered with a thin weathered mantle (regolith). According to the study conducted by Central Ground Water Board, the occurrence of groundwater in Purulia district is confined to four zones: weathered mantle, saprolitic zone, fractured zone of hard rocks and unconsolidated sediments zone (Haldar and Saha 2015). The distribution of various aquifer types in the district is shown in Fig. 4.

In granite gneissic terrains, flow of groundwater is mainly controlled by lithological characteristics, discontinuities that occur due to compositional differences, joints, fractures, topography of the area, depth of weathered zone, nature, size and characteristics of the recharge and discharge area and the spatial relationship between these factors (Neretnieks 1985; Acharya and Prasad

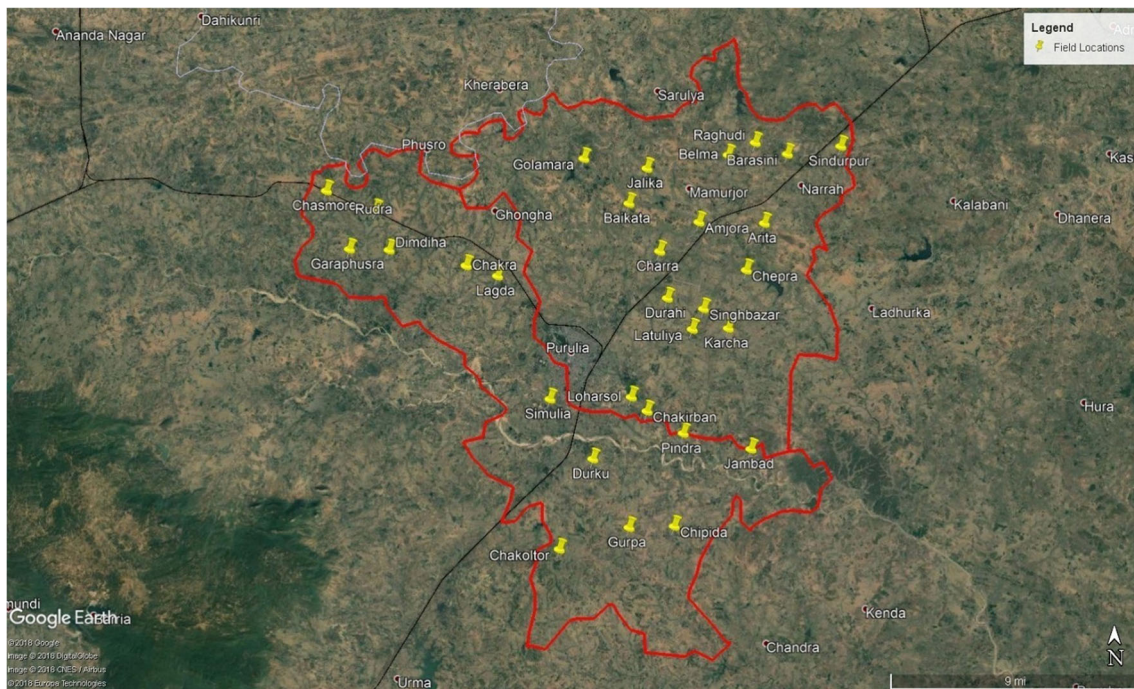


Fig. 6 Map showing location points in the study area

2017). The mentioned fractures are responsible for the secondary porosity and permeability of these areas which allows easy movement of precipitated water (Acharya and Prasad 2017). Higher frequency of fractures corresponds to more potentially transmissive host rocks resulting in an increase in permeability (Henriksen and Braathen 2006; Boutt et al. 2010; Acharya et al. 2012). There is a lack of primary porosity in the district. As the area has interconnected fissures, joints, fractures, faults, bedding and foliation planes, it is necessary to analyse whether the occurrence of subsurface water is controlled by these structural features or not.

Methodology

The work flow of the study is illustrated in Fig. 5. Determination and preparation of depth to water level zonation map help to understand the overall hydraulic gradient in the hydrogeological system. It is controlled by numerous factors such as precipitation, evapotranspiration, surface runoff and season. To determine the depth to water level across Purulia I and Purulia II blocks of Purulia district, the water level was measured in 68 observatory wells which include 43 tubewells (mark II) and 25 dugwells. The location points are shown in Fig. 6.

The depth to water level of the 68 observatory wells is given in Table 1. On the basis of this data, depth to water level zonation map (Fig. 7), and depth to water level map showing

ground water flow direction (Fig. 8), was prepared using Surfer 9 software for the lean period 2016.

The orientation of various planar and linear features was measured directly from the field and the data was recorded in a tabular form (Table 2). The data was then plotted in a rose diagram to show the orientation of joints (Fig. 9). Plane paper map on a mesoscopic scale was prepared at certain locations in the two blocks; these are high-resolution maps which are prepared on a scale of 3 cm = 1 m and 4 cm = 1 m (Fig. 10) after measuring the length and orientation of the joints present in that particular area and it depicts geometrical dispositions of crosscutting joint sets. This was done as field verification in response to the lineament map (source: Sentinel 2 imagery) (Fig. 11).

The fracture-lineament map obtained from Sentinel 2 imagery was overlapped with depth to water level zonation map using ArcMap 10.0 and Surfer 9.0 software (Fig. 12) which helps in determining the control of structural features on groundwater flow and identification of groundwater potential zones.

Results and discussions

Depth to water level obtained from all the observatory wells were plotted in a bar diagram for recording the variations (Fig. 13). It was observed that in the study area, the depth to water level varies from a shallow level of 1.38

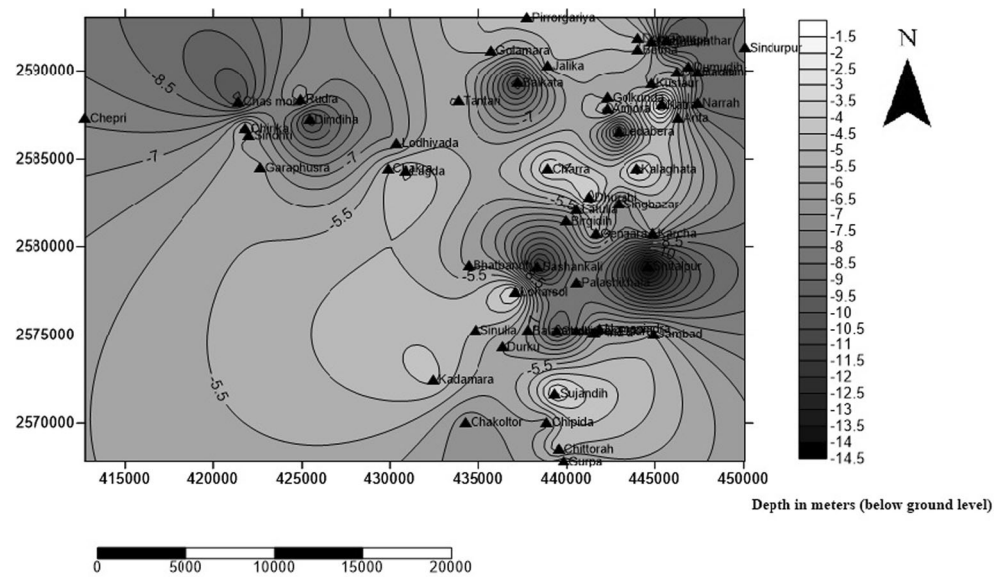
Table 1 The locations and the depth to water level of different observatory dugwells and tubewells in the study area

S.No	Latitude	Longitude	Village	Depth to water level (in meters below ground level)	Type of well
1	N 23° 23' 599"	E 86° 26' 068"	Amjora	3.7	Tubewell
2	N 23° 24' 181"	E 86° 26' 711"	Golkunda	6.2	Dugwell
3	N 23° 24' 454"	E 86° 27' 350"	Kustaur	6.27	Dugwell
4	N 23° 25' 172"	E 86° 28' 496"	Dumudih	7.38	Tubewell
5	N 23° 25' 718"	E 86° 29' 060"	Barasini	8.65	Tubewell
6	N 23° 22' 782"	E 86° 24' 805"	Charra	3.42	Dugwell
7	N 23° 24' 689"	E 86° 27' 577"	Katra	1.38	Tubewell
8	N 23° 26' 058"	E 86° 28' 640"	Kalapathar	8	Dugwell Tubewell
9	N 23° 25' 628"	E 86° 28' 267"	Dumurdih	10.02 7.3 5.89	Dugwell Tubewell
10	N 23° 25' 488"	E 86° 27' 822"	Belma	4.97	Tubewell
11	N 23° 26' 032"	E 86° 27' 364"	Raghudih	5.41	Tubewell
12	N 23° 26' 916"	E 86° 27' 768"	Dobrajpur	5	Dugwell
13	N 23° 20' 309"	E 86° 24' 453"	Birgidih	7.38	Tubewell
14	N 23° 20' 797"	E 86° 25' 442"	Gengara	5.26	Dugwell
15	N 23° 21' 158"	E 86° 25' 320"	Dhurahi	3.05	Tubewell
16	N 23°20' 436"	E 86° 25' 860"	Latulia	6.12	Dugwell
	N 23°20' 527"	E 86° 25' 664"	Latulia	7.21	Tubewell
17	N 23°21' 027"	E 86° 26' 315"	Singhbazar	5.88	Tubewell
18	N 23°20' 820"	E 86° 27' 393"	Karcha	15	Tubewell
19	N 23° 19' 867"	E 86° 27' 301"	Shitalpur	4.05 9.9	Dugwell Tubewell
20	N 23° 23' 174"	E 86° 26' 295"	Ledabera	7.58	Dugwell
21	N 23° 23' 367"	E 86° 84' 461"	Chepri	3	Tubewell
22	N 23° 22' 879"	E 86° 27' 628"	Kalaghata	5.59	Tubewell
23	N 23° 23' 380"	E 86° 28' 334"	Arita	4.54	Dugwell
	N 23° 23' 427"	E 86° 28' 298"	Arita	8.69	Tubewell
24	N 23° 24' 958"	E 86° 29' 628"	Narrah	8.19 7.64	Tubewell Dugwell
25	N 23° 25' 529	E 86° 30' 409"	Sindurpur	5.45 5.15	Dugwell Tubewell
26	N 23° 25' 183"	E 86° 24' 849"	Jalika	4.61	Tubewell
27	N 23° 26' 463"	E 86° 23' 266"	Pirrogariya	10.83	Tubewell
28	N 23° 24' 455"	E 86° 23' 870"	Baikata	5.24	Tubewell
29	N 23° 25' 460"	E 86° 22' 150"	Golamara	4.63 4.26	Dugwell Tubewell
30	N 23° 13' 303"	E 086° 24' 331"	Chittorah	6.67	Tubewell
31	N 23° 13' 726"	E 086° 24' 423"	Gurpa	6.35	Dugwell
32	N 23° 14' 202"	E 086° 24' 949"	Chipida	2.75	Tubewell
33				3.77	Dugwell
34	N 23° 15' 123"	E 086° 24' 252"	Sujandih	6.99	Tubewell
35	N 23° 14' 198"	E 086° 21' 273"	Chakoltor	4.37	Dugwell
36	N 23° 15' 374"	E 086° 20' 227"	Kadamara	6.06	Tubewell
37	N 23° 16' 377"	E 086° 22' 403"	Durku	5.02	Dugwell
38	N 23° 17' 988"	E 086° 21' 468"	Sinulia	6.1	Tubewell
39	N 23° 17' 044"	E 086° 25' 411"	Pindra	6.2	Dugwell
40	N 23° 17' 138"	E 086° 25' 530"	Namapindra	7.94	Tubewell
41	N 23° 17' 975"	E 086° 25' 769"	Upperpindra	5.53	Dugwell
42	N 23° 17' 033"	E 086° 27' 421"	Jambad	6.08	Tubewell
43	N 23° 17' 107"	E 086° 27' 238"		5.48	Dugwell
44	N 23° 18' 371"	E 086° 25' 646"	Palashikala	7.96	Tubewell
45	N 23° 17' 951"	E 086° 23' 303"	Balarampur	6.55	Tubewell
46	N 23° 17' 811"	E 086° 24' 275"	Chakirban	9.45	Dugwell
47	N 23° 18' 209"	E 086° 23' 685"	Loharshol	3.07	Tubewell
48	N 23° 19' 608"	E 086° 23' 497"	Sashankali	11.95	Tubewell
49	N 23° 22' 024"	E 086° 19' 261"	Lagdha	4.41	Tubewell
50	N 23° 22' 544"	E 086° 19' 893"	Lodhiyada	6.94	Tubewell
51	N 23° 22' 732"	E 086° 18' 462"	Chakra	7.43	Dugwell
52	N 23° 22' 711"	E 086° 18' 500"		5.13	Tubewell
53	N 23° 22' 789"	E 086° 14' 351"	Garaphusra	5.86	Tubewell
54	N 23° 23' 363"	E 086° 16' 126"	Dimdiha	10.52	Tubewell
55	N 23° 24' 131"	E 086° 15' 552"	Rudra	6.53	Tubewell
56	N 23° 23' 638"	E 086° 14' 131"	Sindhri	6.35	Dugwell
57	N 23° 23' 191"	E 086° 14' 669"	Chirika	4.7	Tubewell
58	N 23° 24' 887"	E 086° 13' 512"	Chasmore	10.3	Tubewell
59	N 23° 24' 119"	E 086° 21' 098"	Tantari	5.42	Tubewell
60	N 23° 19' 809"	E 086° 21' 314"	Bhatbandh	6.15	Dugwell

mbgl (meters below ground level) to as deep as 11.95 mbgl. Depth to water level zonation map of the study area

(Fig. 7) was prepared using Surfer 9.0 software based on the depth to water level data collected from the field. The

Fig. 7 Depth to water level zonation map of the study area (lean period)



map shows a strong variation in the hydraulic gradient of the study area as indicated by the variation in contour spacing of groundwater. The 3D flow direction map (Fig. 8) shows the recharge and discharge zones as well.

Structural analysis was done to examine whether the occurrence of subsurface water is structurally controlled. The rose diagrams (Fig. 9) clearly infers that there are two major joint sets in the study area striking NE-SW and NW-SE,

respectively, which occur as conjugate pairs and corresponds to the lineament map (Fig. 11) which also shows two major orientations. On overlapping the lineament map in Fig. 11 on the depth to water level zonation map in Fig. 7, we see that the areas where fracture density is more, they form a network for retaining water and thus, water occurs at a shallow depth in these places forming potential aquifers suitable for extraction. Kustaur, Kalaghata, Charra, Kadamara, Sinulia, Lagda and

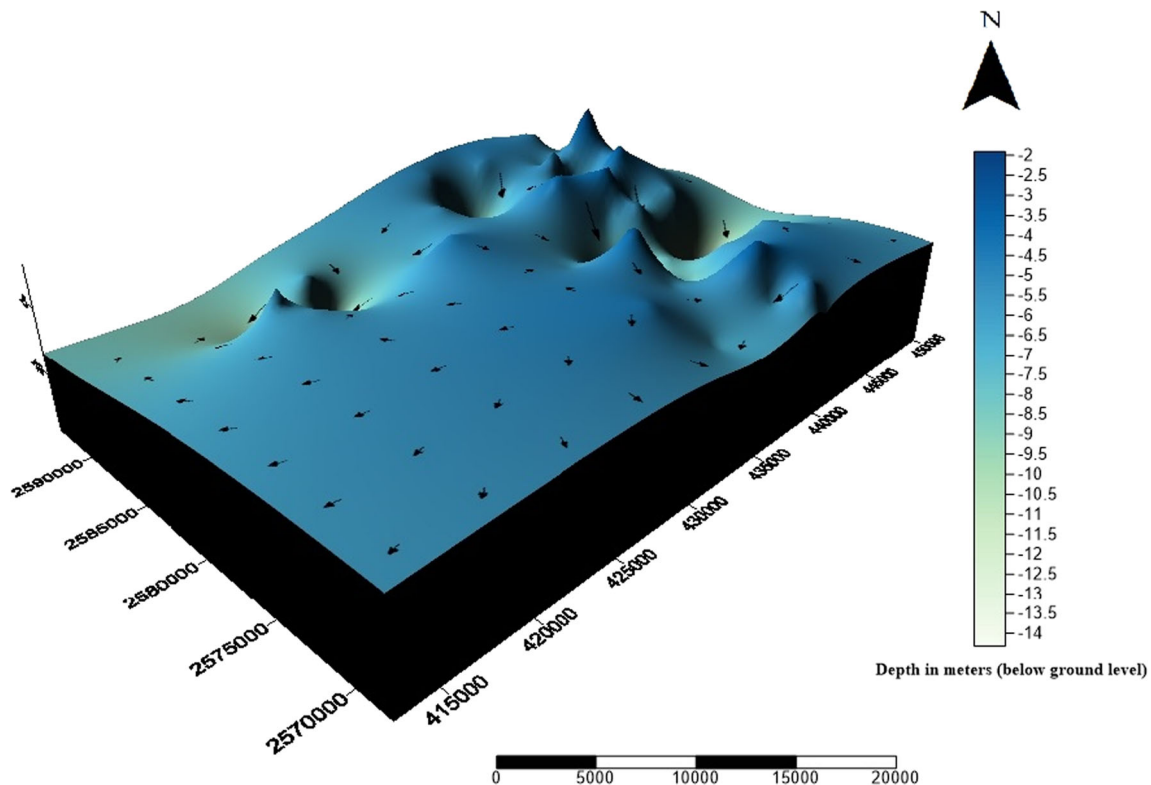
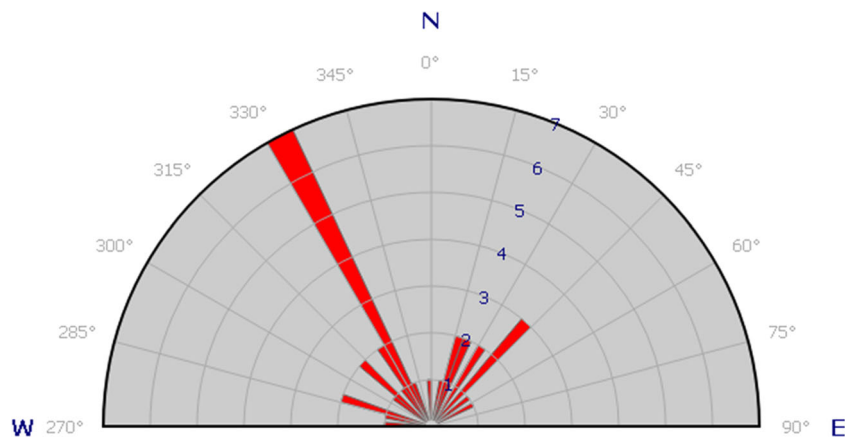


Fig. 8 3D map showing flow direction of groundwater in the study area

Table 2 The orientation of joints observed during the field survey

S.No	Village name		Strike	Dip
1	Shitalpur	Joint1	018°-198°	82° → 108°
		Joint2	106°-286°	90°
		Joint3	150°-330°	86° → 240°
		Joint4	050°-230°	90°
		Joint5	176°-356°	90°
		Joint6	040°-220°	80° → 310°
2	Ledabera	Joint1	034°-214°	88° → 124°
		Joint2	286°-106°	90°
		Joint3	034°-214°	82° → 124°
		Joint4	126°-306°	80° → 216°
		Joint5	130°-310°	86° → 220°
3	Narrah	Joint1	100°-280°	74° → 190°
		Joint2	020°-200°	70° → 110°
4	Kalaghata	Joint1	015°-195°	82° → 105°
		Joint2	060°-240°	78° → 330°
5	Chandradih	Joint1	150°-330°	84° → 240°
		Joint2	152°-332°	70° → 242°
		Joint3	041°-221°	90°
		Joint4	040°-220°	80° → 310°
		Joint5	020°-200°	72° → 290°
		Joint6	090°-270°	90°
		Joint7	011°-191°	76°-281°
		Joint8	156°-326°	79° → 246
6	Anai	Joint1	146°-326°	90°
		Joint2	155°-335°	85° → 065°
		Joint3	150°-330°	85° → 240°
		Joint4	150°-330°	88° → 060°
		Joint5	150°-330°	88° → 060°
		Joint6	133°-313°	86° → 043°
		Joint7	150°-330°	→ 240°
		Joint8	143°-323°	

Fig. 9 Rose diagram illustrating the orientation of joints based on field survey



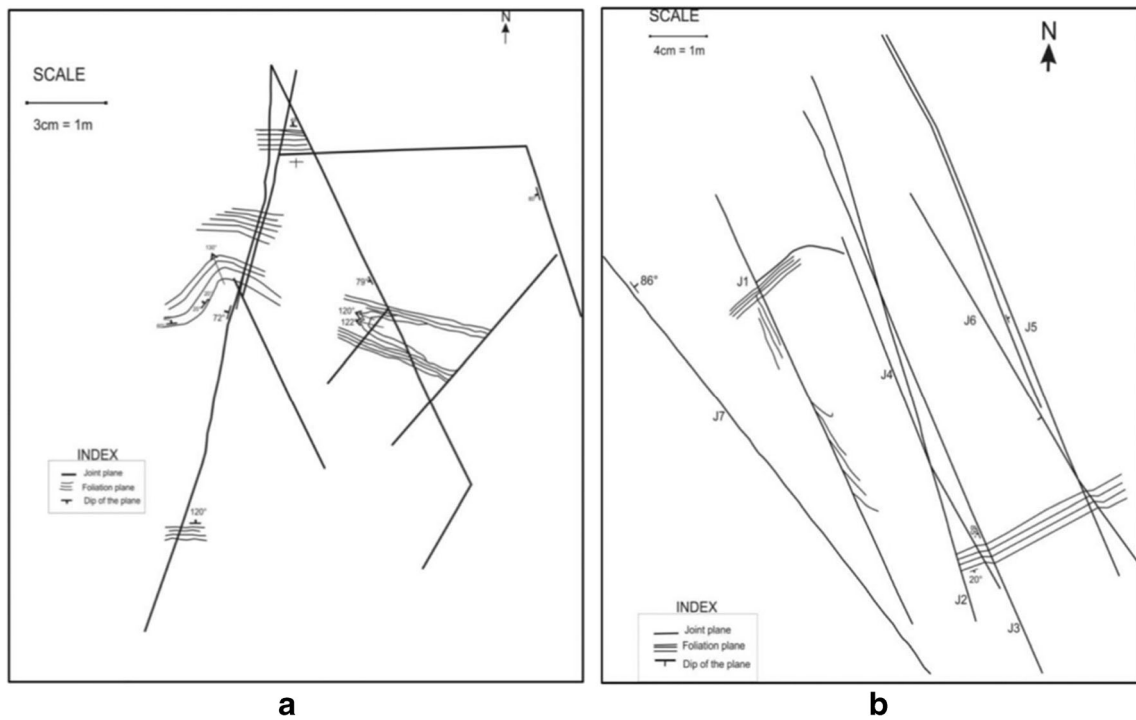


Fig. 10 Plane paper maps from field work showing that the major joints and fractures in the area have NW-SE and NE-SW orientation : (a) an exposure in Purulia block I (b) an exposure in Purulia block II

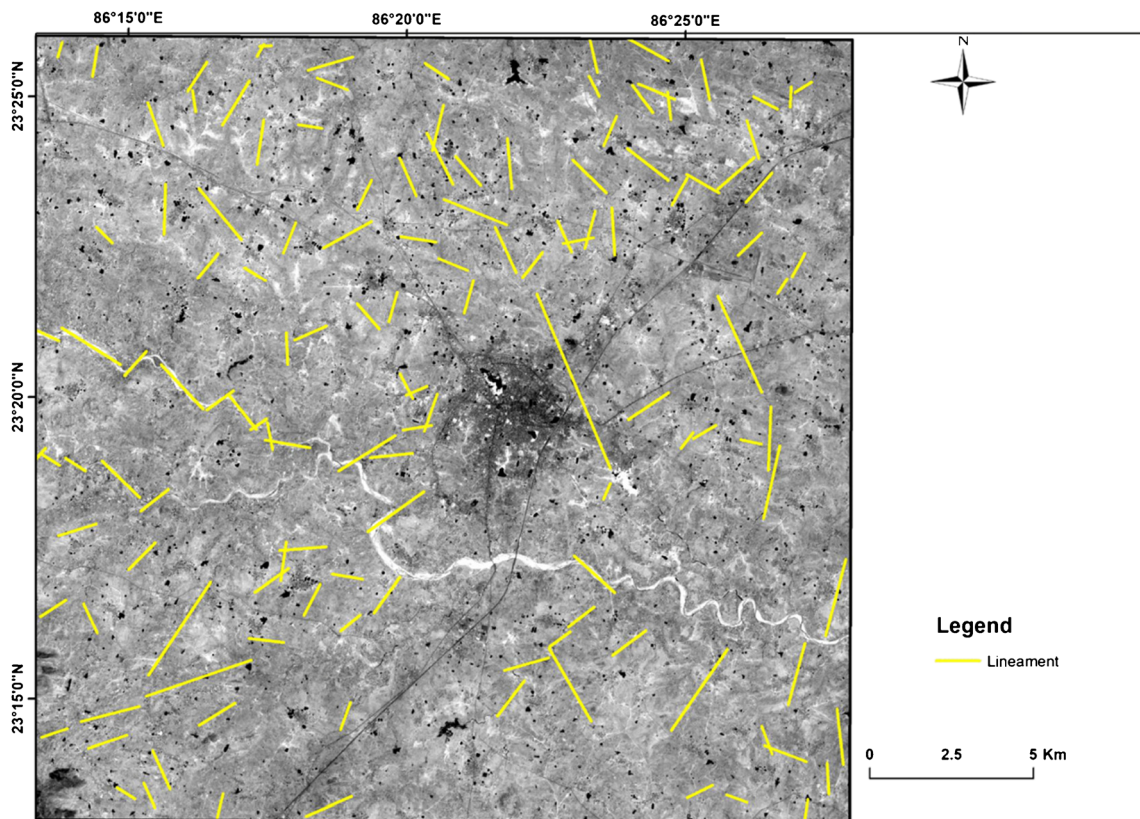


Fig. 11 Lineament map of the study area prepared using Sentinel 2 imagery

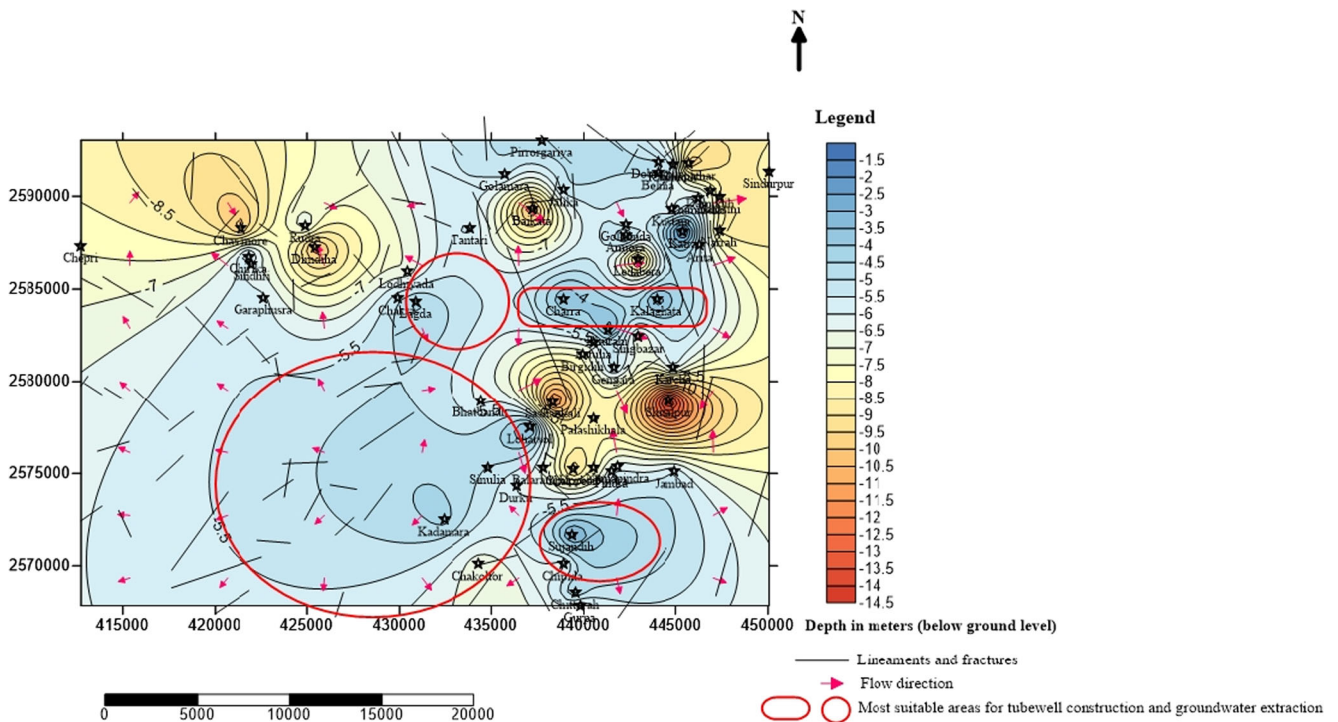


Fig. 12 Groundwater potential zone map showing areas suitable for tubewell construction and groundwater extraction

Sujandih are among areas where groundwater occurs at shallow level, as these places are situated near to some fracture network and water is available in these areas almost throughout the year as gathered from field survey and

interaction with local people. On the other hand, in places where the fractures are sparsely scattered or are absent, water occurs at much greater depth below the ground level. Barasini, Belma, Shitalpur, Karcha, Pirrorgariya, Narrah and

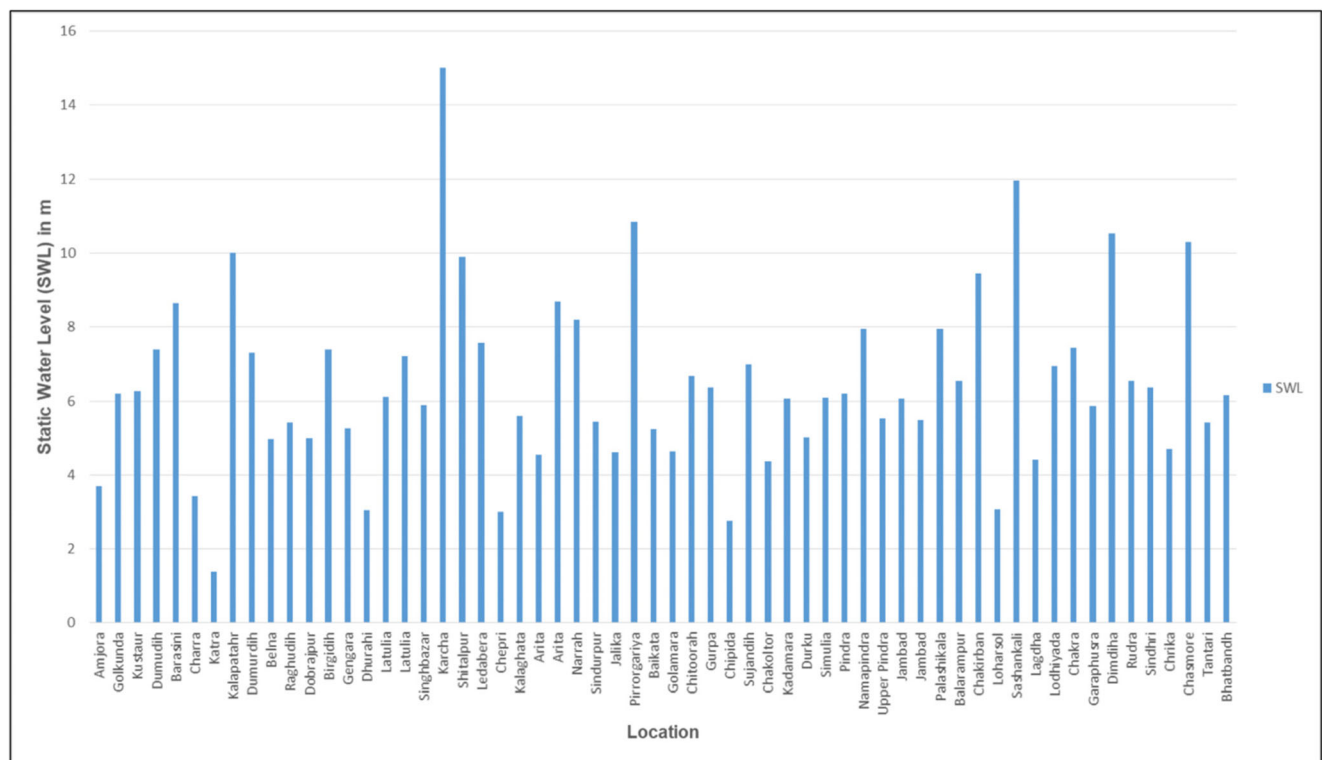


Fig. 13 Bar diagram showing depth to water level variation from observatory wells in the study area

Arita are the places which geologically lie in areas lacking any fractures or joints, and thus, the groundwater occurs at much greater depth in these locations. Extraction of water from tubewells situated in these locations is quite difficult and water is not available for extraction throughout the year. These interpretations were done with reference to the research and findings of Goddard and Evans (1995) and Blenkinsop and Kadzvit (2006). The conductive features which are subparallel to the regional groundwater flow direction help in capturing the groundwater flow. On the other hand, the fractures that intersect the flow at high angles result in impounding of groundwater upstream (Gundmundsson 2000; Babikera and Gundmundsson 2004). The NW-SE trending fractures and joints (Fig. 12) that are along the regional groundwater flow direction are capturing the groundwater flow and thus helping to facilitate the flow along them. The NE-SW trending features that are mostly intersecting the groundwater flow at high angle act like an obstruction for the flow path. The low permeability cores of these fractures as they lie perpendicular to the flow path restrict the flow of groundwater through them and thus direct the flow parallel to the trend of the fractures as can be clearly seen in the map. It impounds the flow in the upstream direction, thus forming a suitable aquifer with abundant water in the upstream direction (Fig. 12). Areas forming dense fracture networks are suitable for holding water and thus forming a shallow aquifer. The findings in this study further suggests that intersection of the two joint sets enhance porosity in the area and create conditions which are favourable for holding groundwater in fractured basement rocks. The areas which are considered most suitable for construction of tubewells after geological consideration are shown in Fig. 12 marked within the map. Most of the interpretations were drawn with reference to the research and findings of Rosenthal et al. (2007) and Al-Taj (2008) which divulge structural control on groundwater flow.

Conclusions

The entire Purulia district is a hard rock terrain which is applicable for both Purulia block I and Purulia block II. The entire area is highly fractured and two major joint sets are identified in the study area having orientation NE-SW and NW-SE and these occur as conjugate pairs. The effect of shearing can also be observed in this area. The fractures act as conduits or networks for the transportation as well as storage of groundwater. The NW-SE fracture set being parallel to the regional groundwater flow direction facilitates groundwater flow while NE-SW fractures being perpendicular to the regional groundwater flow restricts flow and results in impounding of groundwater in the upstream direction. Areas where a network of fractures is intersecting act as good storage

system and water occurs at a shallower depth. Thus, the occurrence of groundwater in this area is structurally controlled. Micro-level works are very few in Purulia. So, the present work was focused on detailed distribution of fractures and joints over a small area, and its control on groundwater occurrence. The results are beneficial for the local population. The maps prepared in support of the findings from this work correlating the depth to water level with lineament density and orientation can be used as a base map by planners and decision makers for selecting suitable areas for the construction of tubewells and dugwells to optimise the extraction of groundwater economically. This pattern of work can also be used as a base by other scientific workers to determine structural control on groundwater in other hard rock terrains. This is a micro-level study, so further work will be done to divulge the impact of structural features on groundwater throughout the district and to use some complex tools, software, and methods to integrate other variables which control groundwater flow in hard rock terrains.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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