Relevance of topographic control on hydrogeological properties of the weathered granite gneiss aquifer in watershed perspective – Usri sub-basin, Giridih, India

Ashok Kumar MSc Tech, PhD

Watershed Hydrogeology Group, Vikramshila Society for Social and Educational Development, New Delhi, India

Correspondence

131, PKT-1, Sector-9, Dwarka, New Delhi, India - 110077

Email: groundwater.modelling@gmail.com

Funding information

Department of Science & Technology, Govt. of India; Grant Number: SP/YO/066/95

HIGHLIGHTS

- Basement surface is replica of ground surface only in regional perspective
- Basement surface is not always exact replica of ground surface at micro watershed scale
- Basin water-divide has better groundwater prospects than lower reaches
- The depth of basement is higher in upper reaches than lower reaches
- No definite trend of water table with respect to ground and basement topography
- Established correlations may be applicable in other area having similar watershed and geological characteristics

Abstract

Usri, a southward sloping fourth order drainage sub-basin of Barakar river, is located in the northern margin of Chhotanagpur plateau, Giridih, India. Gently sloping undulating landforms devoid of hills and outcrops is main characteristics of this sub-basin. Topographic elevation varies between 310 to 390 m MSL. Geographically it is located between lat 24.38° N to 24.54° N long and 86.07° E and 86.28° E longitudes. Thick weathered horizon developed over homogenous Archean granite-gneiss is the principal unconfined aquifer system. Basement topographic (weathering depth) and water table have been correlated with the surface topographic features (landforms). Presence of considerably thick weathered horizons, devoid of rock exposures, regional uniformity in geomorphic characters and its location at fringe of plateau provides favorable condition for correlation of surface topography with basement topography and water table. It has been observed that basement surface is replica of ground surface only in regional or watershed perspective with reference to common datum. The basement surface is not always exact replica of ground surface at micro watershed scale. In many cases, basement surface is reverse of ground surface. The depth basement has remained constant along the basin water-divide situated near the margin of the plateau. The depth of basement (weathered horizon) is higher in upper reaches than lower reaches on the micro water-divides (upland) as well as in the drainage depressions (channels) within the sub-basin. The upper reaches of the sub-basin mainly along the basin water-divide has better groundwater prospects than lower reaches. There is no definite trend of water table with respect to ground and basement topography. Many places water table is shallow on the micro water-divides (upland) and deep in drainage depressions (channels). The established correlations are likely to be applicable in the other geographical area where similar watershed and geological characteristics exits.

KEYWORDS

Hydrogeology, hydro-geophysical, granite-gneiss, unconfined aquifer, watershed, topography, basement depth, water table

1 | INTRODUCTION

Occurrence of groundwater in the Usri sub-basin is restricted to the weathered materials and fractures/ joints within the granite gneiss basement. Aquifer system is unconfined in nature and groundwater occurs under water table condition. Availability of groundwater is very much guided by the annual rainfall. There is seasonal variation in water table. Topography plays important role in seasonal availability of groundwater. The upland witness large fall in water table during summer compare to channel depression. This is fact that even there is no withdrawal; water table continuously declines after the monsoonal recharge due to movement of groundwater towards depression channel or many cases seeps out in topographic depression (drainage channel). This leads to limited availability of groundwater during summer. There is large scale groundwater development in the study area for the both for drinking and irrigation purposes. The non-monsoon crops (*Rabi crops*) are irrigated largely through the shallow open wells (dug-well) with maximum depth of 10-11m BGL. The technical limitation of constructing open wells beyond 11m depth is the limiting factor for groundwater withdrawal. This is one of reason groundwater users has not optimally utilized the available annual replenishable groundwater resources. The non-availability of information about the basement depth and its geometry is another limiting factor for non-development of the aquifer beyond 11m depth. Unlike other parts of Chhotanagpur plateau, rock exposure is very limited within the sub-basin and it is difficult to infer subsurface basement structure.

1.1 | Literature review

Many researchers, Coates (1990), Higgins and Coates (1990), Thompson and Moore (1996), Rempe and Dietrich (2014), Clair et al. (2015), Labedeva and Brantley (2020), Gopinathan et al. (2020) have carried studies to relate the topography with the basement topography / weathering / water table / groundwater prospects in the weathered rock aquifers. Clair et al. (2015) has used geophysical imaging to reveal topographic stress control of bedrock weathering. The study mainly deals with the weathering process at surface of jointed / fractured basement. Rempe et al. (2014) has developed a model that predicts hillslope form and the depth to fresh bedrock. The depth increases upslope and depends strongly on the porosity and permeability of the bedrock and the rate of channel incision at the base of the hillslope. It has limited application in uniformly and moderately weathered pediplain.

Many studies have been carried in the past to establish relation between the topography and the water table. In many cases similarity between topography and water table has been observed (Heath, 1983; Low, 2002; Peck & Payne, 2003; Ophori, 2004) but in many cases significant correlation (Haitjema & Mitchell-Bruker, 2005) has been observed. Coates (1990) and Higgins et al. (1990) has studied the geomorphic controls of groundwater and concluded that landforms, surface-processes and materials play important role in controlling groundwater characteristics. The topographic slope influence depth and position of the water table and the velocity of groundwater flow. Hubbert (1940) and Toth (1963) conceptualized the water table as a subdued version of topography whereas Grayson and Western (2001) caution that topography may not always be the dominant control on water table. Thompson et al. (1996) has studied relations between water table depth in a shallow forest soil and topographic characteristics derived from a raster digital elevation model (DEM). The results are valid only for predictions of water table depths at points and accuracy is grid size dependent. Lebedeva et al. (2020) has demonstrated that erosion of surface layer and infiltration rate can affects the water table position in hilly area.

Freeze and Witherspoon (1967) identified the ratio of basin depth to lateral extent, water table configuration, stratigraphy and variations in permeability as a controlling factor for the steady state regional groundwater flow within a heterogeneous anisotropic basin. Marklund and Worman (2007) have showed that vertical flow of groundwater gets impacted in a situation where there is depth ward decrease in hydraulic conductivity. In such situations the local flow systems increase while regional and total flow decrease. Haitjema and Mitchell−Bruker (2005) has analysed water table ratio (WTRs) for idealized domains and showed that topographically controlled water tables are most likely to occur in low conductivity, high recharge areas with flat terrain.

It is accepted facts that water table is broadly replica of surface topography in regional context. However, local variation in water table do occurs at different scales depending on the permeability, heterogeneity and recharge-discharge processes in the aquifer. The water table topography is controlled by local and regional topography of the basin. In case local relief is negligible, but a regional water table slope exists, only a regional flow system will develop. In area where local hill and valley topography exists, but no regional slope, only local flow systems will develop. In case where both local and regional topography exists in a basin, all three types of flow systems (local, intermediate, and regional) will develop

1.2 | Study area

The Usri sub-basin is located in between 24.38^0 N to 24.54^0 N latitudes and 86.07^0 E and 86.28^0 E longitudes. Its geographical area is approximately 200 sq. km and it administratively comes under the Giridih district of India (Figure 1).

FIGURE 1 Location map of Usri sub-basin, Giridih, Jharkhand

This sub-basin is located on the Chhotanagpur plateau region. Its northern limit is the major water-divide between the Ganga and Barakar river basin. The topographic elevation varies between 310 to 390 m MSL (Figure 2). It aggradational drainage sub-basin and part of Barakar river master basin. It has fifth order drainage network and dendritic to sub dendritic drainage pattern (Figure 3). This drainage patterns have originated largely due to denudational process. Overall surface flow of the sub-basin is towards southward direction as all drainage channels converges to south ward flowing master river. Majority of channels originate from NE and NW side of the sub-basin except one channel which originates from western side and flows in west–east direction. Landform classification (Conrad et al., 2015; Guisan et al., 1999) based on Shuttle Radar Topography Mission (SRTM) elevation data (Figure 2 and Figure 4) indicates that area is dominantly a pediplain with gently to moderate topographic undulations along with narrow ridges (water divides). There are four major drainage channels (Figure 3) which join together to form a Usri river at the exit point of the sub-basin. The Usri River is a tributary of Barakar River. The topography mainly consists of buried pediplain developed over granite gneiss basement rock. Area receives about 1150 mm rainfall per year.

FIGURE 2 Topographic elevation of Usri sub-basin derived from open source SRTM data

FIGURE 3 Drainage and water bodies map of Usri sub-basin

FIGURE 4 Landform classification based on SRTM data

1.3 | Geology

Usri sub-basin is a part of Chhotanagpur granite gneiss complex. Dominant rock type is granite gneiss of Precambrian age. Quartz vein, pegmatite vein, dolerite dike, Meta dolerite etc. are also present within the country rock. But there is such exposure on the surface in the study area. The area has suffered considerable tectonic disturbance since Pre-Cambrian times resulting in upliftment of plateau, subsidence, fracturing and faulting. The area forms a part of the Satpura orogenic belt which has been dated between 972 my and 635 my (Ghosh et al., 1973). However geological map prepared by GSI (1965) has not shown any faults within the area. It appears that sub-basin area developed over the uniform and homogenous lithology i.e., granite gneiss.

The weathered and fractured / jointed granite gneiss basement is principal aquifer system in the area. The weathering profile can broadly into four sub-layers (Table-1).

TABLE 1 Typical weathering profile in granite gneiss

2 | METHODOLOGY

3-D aspect of weathered horizon and basement topography provides better understanding of aquifer system in watershed (Basin) perspective scale. This provides better opportunity to plan sustainable development groundwater in hard rock terrain. Geophysical electrical resistivity method has been used to map the thickness of weathered horizon, depth of basement and identify the fractured basement. Schlumberger vertical electrical sounding (VES) array with maximum electrode separation of 200m. has been used in field survey. Initially VES data were interpreted (Kumar, 1998) using automatic interpretation software (Zohdy, 1989). It has been again revalidated through IPI2Win (2003) software.

Sites has been identified in such a way that it covers all type of landforms. Distribution of locational data is also suitable for mapping 3-D aspect of aquifer's hydro-geophysical parameters on watershed (Basin) scale. Gridded layer of depth of basement (thickness of weathered horizon), iso-resistivity and water table maps have been prepared using System for Automated Geoscientific Analyses (SAGA) v.2.1.4 software (Conrad et al., 2015). The SRTM data has been used to generate digital elevation map and morphometric analysis of sub-basin. Study employs analysis of topographic features, drainage network, rainfall pattern, land use, hydrogeology, hydro-geophysics and lineaments. The hydro-geophysical parameters have been correlated with landforms of the basin / watershed.

3 | RESULTS

3.1 | Water table

The pre-monsoon water table (Figure 5) varies between 3 to 7 m below ground level (BGL) within the sub-basin. It remains in range of 5 to 7 m BGL both in upper and lower reaches of sub-basin. Two deep and four shallow water table zones (Figure 5) of large areal extent have been observed. These anomalous water table zones do not conform with topographic features. Sub-surface heterogeneity or other structural controls are expected in these zones. Water table zone varies between 7 - 8 m BGL in deeper zone whereas it varies between 5 - 6 m BGL in shallow water table zones. The water table varies between 5 -7 m BGL in northern limit of sub-basin which is also a water-divide of two major basins. Water table is shallow in the central and lower reaches of sub-basin.

FIGURE 5 Depth of water table during pre-monsoon period (April-May, 1996) in Usri Sub-basin

The behavior of water table on different landforms have also been analyzed. The minimum water table is 1.5 m BGL and maximum is 8.0 m BGL. Water table data of 12 sites located on lowlands has indicated that it ranges between 4.5 - 6.0 m BGL and 5.8 m BGL dominant depth. Water table data for 18 sites located on midlands has indicated that it ranges between 4.0 - 6.0 m BGL and 4.3 m BGL is dominant depth. Water table data for 35 sites located on upland has indicated that it ranges between 4.0 - 7.0 m BGL and 5.0 m BGL is dominant depth. The slope and aspects of terrain has also been compared with the spatial variation of pre monsoon water table (Figure 5). It appears that spatial variation in water table is not controlled either with slope or aspect of the landforms.

3.2 | Hydro-geophysical characterization

VES data of 99 sites has been used to get the hydro-geophysical parameters & aquifer geometry at sub-basin scale. Sinha et al. (1990) and Kumar and Srivastava (1991), Kumar (1993a, 1993b, 1994, 1996 & 1998a), Kumar and Tomar (1998b) and Kumar el al. (1999) has conducted VES survey in the different parts of hard rock areas of Chhotanagpur plateau and established in deterring depth of basement from VES data. The true resistivity value greater than 200 ohm-m has been considered for semi-weathered to fresh basement rock (Kumar et al. 1998 & 1999). Three to four prominent layers have been identified in each VES (Figure 6).

FIGURE 6 Representative interpreted VES data using computer program

3.2.1 | Depth of basement (Depth of weathering)

Based on VES data, gridded Digital Basement Topography Model (DBTM) has been prepared for entire sub-basin (Figure 7). Depth of weathering decreases from tail to mouth i.e., upper reaches to lower reaches. The depth of weathering is more in southern water-divide (inter channel upland) area compare to the eastern water-divide area. Interpreted The depth of weathering varies between 10 m to 40 m BGL in sub-basin however, it varies between 15 - 20 m BGL in the pediplain area. The upper reaches have highest depth of weathering and it varies between 30 - 40 m BGL.

FIGURE 7 Spatial variation of depth of basement within the sub-basin along with drainage channels and water bodies

3.2.2 | True resistivity of aquifer at depth of 11m BGL

The depth of open wells (dug-wells) is less than 11m BGL in the area. True resistivity value of VES site has been analyzed at 11m BGL to understand the behavior of formation material (Figure 8).

FIGURE 8 Spatial variation of true resistivity at the depth of 11m BGL (at depth of open well) in Usri sub-basin

4 | DISCUSSION

Correlation of hydro-geophysical parameters with geomorphology

Entire over-burden above the basement has been treated as weathered material which may also include some semi-weathered material. Therefore, depth of basement is nothing but thickness of weathered horizon. Surface and basement topography trends have been analyzed together to understand the dependency of basement topography on surface topography. Many researchers (Thompson et al. 1996; Clair et al. 2015; Rempe et al. 2014; Lebedeva et al., 2020) have attempted to establish relation between surface topography and weathering depth. In this paper attempts have also been made to correlated surface topography with basement topography, water table and formation resistivity at 11m BGL at micro as well as sub-basin scale. To understand relation between ground and basement topography, profile lines have been selected in such a way that it represents all types of landform (Table A.3). The profile lines (Figure 9) include major inter sub-basin water-divides and basin water-divides. Apart from water-divides, profile lines along major drainage depressions have also been analyzed.

FIGURE 9 Profile lines with number and section name used for correlation of topography, thickness of weathering (depth of basement), water table and true resistivity

4.1 | Relationship between ground and basement elevation

4.1.1 | Basement depth on water-divides

Total six profile lines (PL-1, 2, 3, 4, 5 and 8) located on the water-divides (uplands) have been analyzed to establish relation between ground and basement elevation (Figure 9 and 10, Table A.2.1). The profile lines (PL-1 and PL-2) runs along basin divide. The ground elevation along profile line is nearly uniform. It has been observed that basement elevation is replica of the ground elevation. The thickness of weathered horizon is uniform (Figure xx) all along the profile. Other four profile lines (PL-3, 4, 5 and 8) are within the sub-basin and it is located on the linear inter-channel upland sloping towards the master drainage channel. Trend wise both ground and basement elevation surface is replica of each other in regional sense however there is difference in depth or thickness of weathering with reference to ground elevation. It has been observed that the higher surface elevation area of the profile lines has higher depth / thickness of weathering.

FIGURE 10 Plot of ground elevation and basement elevation profile lines (PL-1, 2, 3, 4, 5 and 8) along water-divide (upland)

4.1.2 | Basement depth in channel depression

Total four profile lines (PL-6, 7, 9 and 10) have been analyzed to establish relation between ground and basement elevation (Figure 9 and 11, Table A.2.2). It has been observed that ground and basement elevation trend is nearly replica of each other. The depth of basement (thickness of weathered horizon) is uniform all along in the profile line - 6 and 9. Profile – 10 is also same to profile line 6 and 9. The difference is less than 5m in highest and lowest depth of basement. Such difference can be due to interpretational error in VES data. The ground and basement elevation trend of profile line – 7 differs from other three profile lines. There is thinning in thickness of weathered horizon towards the lowest ground elevation point. Basement depth has also decreased towards the lowest ground elevation point. The ground and basement elevation trend of 3 out of 4 profiles matches with the observed trend of the profile line located on the basin water-divide i.e., uniform thickness of weathered horizon. The trend behavior of the profile line -7 is correlated with the trend of ground and basement elevation of the water-divide.

FIGURE 11 Plot of ground elevation and basement elevation profile lines (PL-6, 7, 9 and 10) along channel depression

4.1.3 | Basement depth in anomalous linear resistivity zone

Three linear anomalous zones have been demarcated from Iso resistivity map prepared from the resistivity value derived from VES data (Figure 9 and 12, Table A.2.3). Profile line-11 represents linear high resistivity zone cutting across different types of landforms. Other two namely Profile line-12 and 13 represent low resistivity zone and located in close proximity to depression area. All three profiles have shown basement elevation follows the ground elevation trend along the profile line. However, the depth of basement or thickness of weathering is not uniform along profile line-11. Depth of basement or thickness of weathered horizon is high at margin of sub-basin boundary and lowest in depressional area. Lineaments are also passing through this zone which makes the correlation difficult due presence of fractures at many places. The other two profiles which represent linear low resistivity zone have good correlation between basement and ground elevation. However uniform weathered horizon has been observed along the profile line-12 with some minor deviation in the middle parts of the profile where high thickness of weathered horizon has been observed on highest elevation area which also a sub-basin water-divide area.

FIGURE 12 Plot of ground elevation and basement elevation profile lines (PL-11, 12 and 13) along the linear resistivity anomalous zone

Based on the analysis of different profile sections running along the basin and inter-basin water-divide, it has been observed that majority of basement surface is replica of ground surface in regional sense (Figure 13). The depth of basement is constant all along the basin water-divide area located at margin of Chhotanagpur plateau. At inter-basin water-divide line, higher depth of basement has been observed at high ground elevation (upper reaches of basin) compare to low ground elevation (lower reaches of basin). Analysis of different profile sections running along the major drainage depressions have indicated that the upper reaches of drainage depressions (higher elevation) have higher depth of basement compare to lower reaches (lower elevation). Similarly, the profile along the resistivity low depressions crisscrossing multiple landforms have also indicated that high depth of basement on high ground elevation compare low ground elevation. Based the analysis, depth of basement which is also to be depth weathering has been conceptualized near the plateau margin which is also a major basin boundary. It can be summarized that the basement depth i.e., depth of weathering is high on the high ground elevation of the water-divide particularly near the basin water-divide area which is also plateau margin (Figure 14).

FIGURE 13 Comparison of surface terrain and basement terrain surface through 3D visualization

FIGURE 14 Schematic conceptualizing relation between regional topographic elevation, depth of basement and water table

4.2 | Relationship between water table and ground elevation

The topographic control on groundwater table is based on the facts that groundwater flows from high elevation (high hydraulic head) to low elevation (hydraulic head). Based on this fact, surface topography (landform) controls the water table and aquifer storage in weathered unconfined aquifer. The water table generally follows the topographic and slope. Water table is generally parallel to topographic surface (Karanth, 1994; Earle, 2015). Water table is shallower in topographic depression i.e., lowland. Above mentioned generalized behavior of water table is not likely be valid in the entire situation. Water table is dynamic property of the aquifer and departures from the normal behavior can be observed due to spatial change in aquifer porosity, permeability, recharge and withdrawal from the aquifer. The topographic control on water table has been evaluated at micro watershed and sub-basin scale.

Attempt has been made to compare hydraulic head with ground elevation. But it was difficult to compare due to shallow depth (4 – 7 m BGL) and small difference in highest and lowest value of the water table. Therefore, depth of water table has been compared with the ground elevation to establish relationship between the two.

4.2.1 | Water table at water-divides

Total six profile lines (PL-1, 2, 3, 4, 5 and 8) located on the water-divides (uplands) have been analyzed with gridded data to establish relation between water table and ground elevation (Figure 9 and 15, Table A3.1). Apart from analysis based on gridded data, four profiles (PL-20, 21, 22 and 23) have also been analyzed directly with field measured depth of water table (Figure 9 and 16, Table A.3.1). The PL-1 and 2 are located on the basin divide line in north-west and north-east side of the sub-basin respectively. These areas are supposed to be recharge area of the sub-basin as well as highest ground elevation area. There is variation in ground elevation (minor undulation) at micro level but such micro level ground elevation variation is not visible in water table profile of PL-1 and 2. However water table is deeper in low elevation area of PL-1 whereas deeper in high elevation area of PL-2. Another profile line (PL-20) which connects north-west to north-east side of basin divides in single profile and based on actual field measured value of water table. It indicates that water table is deeper at high elevation points along the water-divide. The PL-3, 4, 5, 8, 21, 22 and 23 runs along the inter-basin water-divide lines. The water table is shallow in the high elevation area (upper reaches) of the PL-3, 5, 9, and 21 whereas PL-23 reflects reverse water table trend. It has been observed that there is no definite trend of water table in PL-22 whereas water table remained nearly constant irrespective ground elevation in the PL- 4.

FIGURE 15 Plot of ground elevation and water table profile lines (PL-1, 2, 3, 4, 5 and 8) along water-divide

FIGURE 16 Profile lines (PL-20, 21, 22 and 23) along water-divide showing variation of ground elevation and water table (based on direct plot of individual stations field data)

Overall mixed type of water table trend has been observed on the profile running along the basin and inter-basin water-divides. However, it can be broadly generalized that water table is deeper at high ground elevation in profile running along the basin water-divide. The water table has been found shallower at higher elevation (upper reaches) in the majority of profile line running along the inter-basin water-divide or remains more or less constant irrespective of ground elevation.

4.2.2 | Water table in channel depression

Total four profile lines (PL-6, 7, 9 and 10) running along the prominent drainage depression have been analyzed to establish relation between water table and ground elevation in depression (Figure 9 and 17, Table A.3.2). It has been observed that water table in the profile line - 6, 7 and 9 are comparatively at shallower depth in the lower reaches (low ground elevation) than the upper reaches (high ground elevation) of the channel depression. It has also been found that depth of water table is nearly uniform over the large parts of profile line (PL-6, 7, 8 and 9).

FIGURE 17 Plot of ground elevation and water table profile lines (PL-6, 7, 9, 4, 5 and 10) along channel depression

The overall the water table is shallow in higher elevation (upper reaches) or nearly constant throughout profile along the drainage depression except one out of four profile lines where water table deeper at higher elevation (upper reaches) and shallow at lower elevation (lower reaches)

4.2.3 | Water table in anomalous linear resistivity zone

Three linear profile lines namely PL-11, 12 and 13 have been analyzed (Figure 9 and 18, Table A.3.3). Profile line - 11 represent linear high resistivity zone cutting across all types of landforms whereas Profile line-12 and 13 represent low resistivity zone and located in close proximity to depression area. The change in water table is more gradual than the surface topography along the profile line. Water table is shallower in profile line-12 in depression area. But it is not always true that depressional area will have lower water table as it is evident from profile line -13. It is also true that it not necessary water table will follow the same trend of topographic elevation. It has remained constant at depth all along the profile line passing through uplands and depressions i.e., mid-point to eastern end of the Profile Line-13. Therefore, uniformity in behavior of water table with topography is limited to uniform geomorphic features.

FIGURE 18 Plot of ground elevation and water table profile lines (PL-11, 12 and 13) along the linear resistivity anomalous zone

Overall water table is shallow at high elevation (water-divide) relative to low elevation (drainage depression) along the profile lines.

4.2.4 | Straight lines profile across multiple landforms

Attempt has also been made to understand the water table behavior across the sub-basin without considering any landforms specific profiles i.e., water-divide, channel depression and resistivity anomalous zone. ach straight N-S and E-W profile line passes through multiple uplands and depressions. Total six profile lines (PL-14, 15, 16, 17, 18 and 19) have been considered (Figure 9 and 19, Table A.3.4). E-W straight line profile dissects the lower, middle and upper reaches of the sub-basin whereas N-S straight line profile dissects eastern, middle and western parts of the sub-basin. The water table is likely to be shallower in the topographic depressional area but many reversals of water table trend have been observed. This may be due to sub-surface ambiguity. Again, water table is supposed to be at deeper level on the water-divide (higher ground elevation), but shallower depth of water table has been observed.

FIGURE 19 Plot of ground elevation and water table in E-W and N-S running profile lines (PL-14, 15, 16, 17, 18 and 19)

5 | CONCLUSION

Study has helped in understanding three-dimensional and regional perspective of weathered layer and water table of unconfined aquifer in granite gneiss terrain. The analysis of vertical profile of ground and basement surface running along the basin and inter-basin water-divide has indicated that majority of basement surface is replica of ground surface only in regional sense. The depth of basement is constant along the basin water-divide located at margin of Chhotanagpur plateau. At water-divide lines within the sub-basin, higher depth of basement has been observed at upper reaches of sub-basin (high ground elevation) compare to the lower reaches of sub-basin (low ground elevation). Analysis of different profile sections running along the major drainage depressions have indicated that the upper reaches of drainage depressions (higher ground elevation) have higher depth of basement compare to lower reaches (low ground elevation). Similarly, the profile along the resistivity low depressions crisscrossing multiple landforms have also indicated that high depth of basement on higher ground elevation.

Analysis of water table in different profile sections has been indicated that there is no definite or conclusive trend in the profile running along the basin and inter-basin water-divides. In general water table is deeper at high ground elevation in profile running along the basin water-divides located at margin of Chhotanagpur plateau. Water table has been found shallower at higher elevation (upper reaches) or water table remains nearly constant irrespective of the ground elevation in the majority of profile lines running along the water-divides within the sub-basin. Water table has been found shallower in higher elevation (upper reaches) or nearly constant throughout profile in the profile lines running along the drainage depressions. Water table has also been found shallow at high elevation (water-divide) relative to low elevation (drainage depression) along the profile lines running along linear resistivity anomaly. In general, shallow water table is expected in the topographic depression area but many reversals of water table trend have been observed in N-S and E-W running profile lines cutting across different types of landform. It has also been found that there no control of morphometry i.e., slope, relative slope and valley depth on variation water table in the sub-basin.

Followings are the broad findings

- Basement topography surface is replica of ground surface with reference to common datum i.e., MSL only in regional or watershed perspective. The spatial variations in basement surface have been obscured due to small range (10 to 40m) of variation in depth of basement in comparison to large range (310 to 390m) of variation in topography. In many cases, basement topography is reverse of surface topography.
- The depth of basement remained constant along the basin water-divide situated near to the plateau scarp zone.
- High depth of basement (weathered horizon) has been observed in upper reaches compare to lower reaches of the sub-basin
- In broader sense, depth of basement (thickness of weathered horizon) is shallow in lower reaches in comparison to upper reaches along the drainage channels.
- No definite trend of water table has been observed with landform and depth of basement.

The established correlations are likely to be applicable in the other geographical area where similar watershed morphometry and geological characteristics exits.

ACKNOWLEDGEMENTS

Author acknowledges NRDMS Division, Department of Science & Technology, Govt. of India, New Delhi for providing research grant for the execution of this research. Author also acknowledges Prof D. P. Singh, then Project Director, Bihar Council on Science & Technology, Govt. of Bihar for his constant encouragements while executing this research work.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

DATA AVAILABILITY STATEMENT

The raw field data is available in research report submitted to Department of Science and Technology, Govt. Of India that does not issue DOIs. The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

https://orcid.org/0000-0002-5872-439X

REFERENCES

Clair, J. St., Moon, S., Holbrook, W. S., Perron, J. T., Riebe, C. S., Martel, S. J., … Richter, D. deB. (2015). Geophysical imaging reveals topographic stress control of bedrock weathering. *Science, 350(6260)*, 534-538. https://doi.org/10.1126/science.aab2210

Coates, D. R. (1990). Geomorphic controls of groundwater hydrology. *Special Paper - Geological Society of America. No.252*, 341-356. https://doi.org/10.1130/SPE252-p341

Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., ... Böhner, J. (2015). System for Automated Geoscientific Analyses (SAGA) v. 2.1.4, *Geoscience Model Development., 8*, 1991-2007. https://doi.org/10.5194/gmd-8-1991-2015. Download.

Dewandel B., Caballero Y., Perrin J. P., Boisson A., Dazin F., Ferrant S., ... Maréchal, Jean-Christophe (2017). A methodology for regionalizing 3-D effective porosity at watershed scale in crystalline aquifers. *Hydrological Processes, 31(12)*, 2277-2295. https://doi.org/10.1002/hyp.11187

Earle, S. (2015). Groundwater. *Physical Geology.* Victoria, B.C.: BCcampus, https://opentextbc.ca/geology/chapter/14-2-groundwater-flow

Freeze, A. R., & Witherspoon, P. A. (1967). Theoretical analysis of regional groundwater flow: 2. Effect of water-table configuration and subsurface permeability variation. *Water Resources Research., 3(2)*, 623-634.

https://doi.org/10.1029/WR003i002p00623.

Ghose, N. C., Shanakin, B. N., & Smirnov, V. N. (1973). Some geochronological observations of the Pre-Cambrian of Chotanagpur, Bihar. *Indian Geological Magazine., 110*, 477-482. https://doi.org/10.1017/S0016756800036268

Gopinathan P., Singh, P.K., Singh, & Ashok K. (2020). A geo-spatial approach to perceive the groundwater regime of hard rock terrain- a case study from Morappur area, Dharmapuri district, South India. *Groundwater for Sustainable Development, 10(100316).* https://doi.org/10.1016/j.gsd.2019.100316

Grayson, R., & Western A., (2001). Terrain and the distribution of soil moisture. *Hydrological Processes, 15*, 2689-2690. https://doi.org/10.1002/hyp.479

Guisan, A., Weiss, S.B., & Weiss, A.D., (1999). GLM versus CCA spatial modeling of plant species distribution. *Plant Ecology 143*, 107–122 (1999). https://doi.org/10.1023/A:1009841519580

Haitjema, H. M., & Mitchell-Bruker S., (2005). Are water tables a subdued replica of the topography? *Ground Water, 43(6)*, 781-786. https://doi.org/10.1111/j.1745-6584.2005.00090.x.

Heath, Ralph. C., (1983). *Basic ground-water hydrology* (Water-Supply Paper 2220). U.S. Geological Survey. https://pubs.usgs.gov/wsp/2220/report.pdf

Higgins, Charles G., & Coates, Donald R., (1990). Groundwater geomorphology; the role of subsurface water. *Earth-Surface Processes and Landforms, Geological Society of America. 252*. https://doi.org/10.1130/SPE252

Hubbert, M. K., (1940). The theory of ground-water motion. *The Journal of Geology, 48(8)*, 785-944. https://doi.org/10.1029/TR021i002p00648-1

Karanth, K. R., 1994. *Ground water assessment, development and management* (pp. 380-386). Tata McGraw-Hill.

Kumar, A., & Srivastava, S.K., (1991). Geomorphological units, their geohydrological characteristics and vertical electrical sounding response near Munger, Bihar. *Journal of Indian Society of Remote Sensing. 19(4)*, 205-215. https://doi.org/10.1007/BF03030772

Kumar, A., (1993a). Ranchi mega lineament & its correlation with geological and geophysical data. *Journal of Indian Society of Remote Sensing, 22 (1)*, 57-64. https://doi.org/10.1007/BF03015120

Kumar, A., (1993b). Groundwater exploration in Kanchi sub-watershed, Ranchi – a study through remote sensing & geophysical techniques. *Proceedings of National Seminar & Convention of Indian Socety of Remote Sensing (ISRS), Gauwahati, India,* 167-174.

Kumar, A., (1994). Aquifer geometry scanning in Chainki Horticulture Farm, Palamu, Bihar - a electrical resistivity survey approach. *Proceedings of National Seminar of Association of Exploration Geophysicist (AEG), Dehradun, India*.

Kumar, A., (1996). Sustainable utilization & management of groundwater in Churchu watershed, Hazaribagh, Bihar - a remote sensing, geophysical & GIS approach. *Proceedings of National Seminar & Convention of Indian Socety of Remote Sensing (ISRS), Pune, India,* 228.

Kumar, A., (1998a). *Aquifer geometry scanning in Usri watershed, Giridih, Bihar - a geophysical analysis* (Report No. BCST/SP/YO/066/95). Department of Science & Technology, New Delhi.

Kumar A., & Tomar, S., (1998b). Groundwater assessment through hydro-geomorphological and geophysical survey - a case study in Godavari sub-watershed, Giridih, Bihar. *Journal of Indian Society of Remote Sensing. 26(177)*. https://doi.org/10.1007/BF02990796

Kumar, A., Tomar, S., & Prasad, L. B., (1999). Analysis of fractures inferred from DBTM and remotely sensed data for groundwater development in Godavari sub-watershed, Giridih, Bihar. *Journal of Indian Society of Remote Sensing. 27*, 105-114. https://doi.org/10.1007/BF02990806

Lebedeva M.I., & Brantley Susan L., (2020). Relating the depth of the water table to depth of weathering. *Earth Surface Processes and Landforms. 45(9)*, 2167-2178, https://doi.org/10.1002/esp.4873

Low, D. J., Hippe, D. J., & Yannacci, D., (2002). *Geohydrology of Southeastern Pennsylvania (Water-Resources Investigations Report 00-4166)*. U. S. Geological Survey. https://pubs.usgs.gov/wri/2000/4166/wri20004166.pdf

Marklund, L., & Worman A., (2007). The impact of hydraulic conductivity on topography driven groundwater flow. *Publication of Institute of Geophysics, Polish Academy of Sciences, E-7(401)*, 159-167. www.agp2.igf.edu.pl/agp/files/E-7/Marklund_Worman.pdf

Ophori, D.U., (2004). A simulation of large-scale groundwater flow and travel time in a fractured rock environment for waste disposal purposes. *Hydrological Processes. 18(9)*, 1579-1593. https://doi.org/10.1002/hyp.1407

Peck, M.F., & Payne, D.F., (2003). Development of estimated water table map for coastal Georgia and adjacent parts of Florida and South Carolina. *Proceedings of the 2003 Georgia water resources conference, University of Georgia, Georgia.* http://www.gwri.gatech.edu/sites/default/files/files/docs/2003/Peck%20and%20Payne.pdf

Rempe, D.M., & Dietrich, W.E., (2014). A bottom-up control on fresh-bedrock topography under landscapes. *PNAS. 111(18)*, 6576-6581. https://doi.org/10.1073/pnas.1404763111

Geological Survey of India (GSI), (1965). [Geological maps of Survey of India toposheet No. 72H/8]. Unpublished map.

Sinha B.K., Kumar, A., Shrivastava, D., & Srivastava S., (1990). Integrated approach for demarcating the fracture zone for well site location - a case study near Gumla & Lohardagga, Bihar. *Journal of Indian Society of Remote Sensing. 18(3)*, 1-8. https://doi.org/10.1007/BF03030727

Taylor G.C. (Jr.), (1981). S*ome general characteristics of ground water in weathered layer of hard rocks, Coimbatore, India* (pp. 25-37). UNESCO publication.

Thompson, J. C. & Moore, R. D., (1996). Relations between topography and water table depth in a shallow forest soil, *Hydrological Processes., 10(11)*, 1513-1525. https://doi.org/10.1002/(SICI)1099-1085(199611)10:11<1513::AID-HYP398>3.0.CO;2-V

Toth, J., (1963). A theoretical analysis of groundwater flow in small drainage basins. *Journal of Geophysical Research, 68(16)*, 4795-4812. https://doi.org/10.1029/JZ068i016p04795.

Zohdy, A.A.R., (1989). A new method for automatic interpretation of Schlumberger and Wenner sounding curves. *Geophysics., 54(3)*, 245-253.