“Remote Sensing and GIS based Geological and Geomorphological attributes of Sindphana river sub-basin Beed district, Maharashtra, India”

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Abstract:
Geological and geomorphological studies were carried out for the evaluation of groundwater potential in the Sindphana river Sub-basin in Beed district of Maharashtra, India using remote sensing and geographic information system (GIS) technique. Satellite IRS-P6 LISS III and SRTM data is considered for the preparation of different thematic maps, such as geological, geomorphological, drainage density, slope and lineament. The groundwater potential map is made using the inputs of these above thematic maps and the weight of each map has been selected. The ranking has been assigned to each features from the thematic map. Based on final weightage and ranking, the groundwater potential zones have been delineated. Thus from the present study it is observed that an integrated approach involving remote sensing and GIS technique can be effectively used in classifying potential groundwater zones in the study area. Groundwater potential zones, have been grouped in to four categories viz. good, moderate to good, poor to moderate and poor. Major part of the study area is having “good” as well as “moderate” prospect zones while a few scattered areas have poor groundwater prospect.

(Key words: Groundwater potential, geomorphic surfaces, remote sensing, GIS)

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Introduction

Groundwater always plays a key role in shaping the economic and social strength of rural and urban areas of the nation. The exploration, assessment and management of the groundwater resource have become very important apprehension as groundwater forms a vital constituent of the total water supply for drinking and irrigation uses. In the present study an attempt is made to describe the groundwater potential zones in Sindphana river sub-basin of Beed district, Maharashtra, India using integrated approach of remote sensing and GIS techniques.

Water is a inadequate resource in Beed district of Maharashtra. The great extent of water required for domestic requirement is from the underground water resources. In almost all villages in district water supply is mainly from dug-wells and from boreholes that are found along major streams and valleys. Selection of well sites for groundwater supply mainly depends on traditional field studies using existing water point sites as guidelines. In general a systematic and judicious utilization of groundwater exploration is not there. The general aim of this study is to contribute in the direction of systematic groundwater studies in conjunction with the remote sensing, field studies, Digital Elevation Models (DEM) and GIS of the Sindphana Basin.

In order to identify the suitable sites for groundwater potential with an integrated approach of geology and geomorphology which are followed by the below mentioned objectives:

(i) To use of remote sensing and GIS technique in groundwater recharge investigations of the basin.
(ii) To prepare the map of groundwater potential zones of the basin.
(iii) Integration of all thematic maps using superimpose analysis tool in ArcGIS 10.1 and demarcating Groundwater Potential Zones.

Study area

The study area is located in Marathwada area of Maharashtra, India and falls within the Deccan Volcanic Province (DVP) of peninsular India. Sindphana river in Beed district drains total area of 3972.70 sq km and spread in DVP of Maharashtra. The course of the Sindphana river is from west to east for its major length and acquired the northern flow for the stretch of 8 km before joining the mighty Godavari river (Fig. 1). The area has a semiarid climate and receives rainfall primarily from southwest monsoon between June and September.

Methodology

The present area is studied from the point of view of quantitative geomorphology using the Survey of India (SOI) topographical maps No. 47M/4, 47M/8, 47M/12, 47M/16, 47N/5, 47N/9, 47N/13, 47N/15, 56A/4 and 56B/1 supplemented with IRS-P6 LISS-III satellite imagery (FCC-geocoded) on the scale 1: 50,000 (Fig. 2). The detailed morphometric analysis of sub-basin is acquired for understanding the drainage pattern, nature of topographic contour, basin outline, slopes and elevations.

Geomorphology map is prepared using visual interpretation technique and interpretation inputs such as tone, texture, size, shape, pattern, shadow and association. The land use/cover categories are visually interpreted into line maps; the mapped categories vary from map sheet to map sheet depending on ground conditions. The analysis of land use/land cover is determined using of IRS P6 LISS III satellite image of 2006. The supervised, unsupervised classification systems and ground truth verification methods are used for the preparation of landuse/land cover map. Various features are recognized and distinguished using interpretation key and visual interpretation techniques. GIS and landuse are natural associates as both of them deal with spatial data.

Result and Discussion

The studies on geological, hydrogeological and geomorphological attributes of the Sindphana sub-basin is carried out with reference to the occurrence, movement and potential of groundwater in Deccan trap terrain. Survey of India (SOI) Topographic maps and IRS P6 satellite images are used to prepare various
thematic layers such as drainage pattern, lineaments, geology, geomorphology and DEM, which influence the occurrence, movement, yield and quality of groundwater. All these themes and their individual features were then assigned weights according to their relative importance in groundwater occurrence. The thematic layers are incorporated using Arc GIS 10.1 software to identifying the overlay analysis and the groundwater potential zone map of the study area.
Geology of the area

The complete study area of Sindphana river in Beed district is occupied by Deccan basalts (Fig. 3) consisting of nearly horizontal lava flows. These flows are considered to be a result of fissure type of lava eruption during late Cretaceous to early Eocene period. The types of basalt flows occurring in the area are compact basalt (aa type), vesicular-amygdaloidal basalt (pahoehoe type) and red bole beds (Tachylitic bands) as observed in the natural exposures and well sections. Quaternary sediments occur as narrow fringe along the river valley. The Sindphana valley sediments in the upper reaches are 2 to 3 m thick and consisting of entirely coarse grained, resting unconformably on the rocky bench of basalt and consisting of angular to sub-angular fragments. In middle and lower reaches of the river the Quaternary deposits (7 to 12 m thick) are made up of rounded to sub-rounded pebbles and cobbles of basalt, zeolites and various varieties of quartz set in a matrix of granular sand and silt showing cross bedding and local inverse grading structures[1].

As the basalts are formed by cooling and solidification of the lava, they contain gas cavities and also joints which are the contraction cracks developed during cooling of the lava. But all the basalt flows do not contain gas cavities and joints and therefore on the basis of presence or absence of gas cavities, basalt flows are grouped into two categories:

i) Vesicular amygdaloidal basalt (Pahoehoe type).

ii) Non-vesicular or compact basalt (aa type).

The two basalt flows have distinct field characters i.e. vesicular amygdaloidal basalt (Fig. 4a) and compact basalt (Fig. 4b) and structural features including lineaments.

Fig. 3. Geological Map of Study Area.

Total numbers of 38 flows of basalt are there out of which 17 are compact (massive) and 21 vesicular-amygdaloidal basalt flows, developed in the study area from the source of the river to the confluence with the mighty Godavari river within the elevation range of 872 to 389 m amsl [1]. At places the flows are separated by the red bole beds (tachylitic basalt). The flows can be demarcated by the presence of ropy lava at the top and the presence of pipe amygdules at the bottom of flow.
Fig. 4(a) Jointed Compact Basalt along Sindphana River at Hingni village.
4(b) Amygdaloidal Basalt along with Quartz veins at Sandas Chincholi village.

Lineaments

Lineaments represent a group of several mega and intermediate lineaments with a NNW to north-westerly trend extending over the Deccan Plateau and include Pranhita-Godavari section with a NNW-SSE trend [2-3]. The lineament (Fig. 5) cuts across the Deccan lava flow Sindphana sub-basin and is characterised by the linear feature with straight stream courses. Lineaments have been picked up on the basis of morphological features, structural alignments, textural contrasts and tonal differences. The lineaments correspond to the three major structural trends like NW-SE, WNW-ESE, N-S and E-W in the present area.

Fig. 5. Lineament map of the Sindphana river sub-basin

Hydrogeology

The hydrogeological conditions in Deccan traps states that the frequency and extent of jointing, fracturing, the flow contacts and weathering of the basalt flows are the most significant parameters imparting permeability and porosity for forming suitable groundwater reservoirs. The vesicular zones occurring in the upper parts of flows, though porous, are not permeable, as the vesicles are not interconnected. Secondly, the
vesicles are generally filled with amygdules, green earth, glassy material etc. The red bole layer, flow breccia with secondary mineral development and the massive parts of the flow, with non-interconnected joints, are generally impervious [4]. The secondary porosity (joints and fractures) generally reduces with depth and hence the near surface (unconfined) aquifer system rarely, extends below 30 m depth [5-6].

The aa type flows can be demarcated into two parts according to their hydrogeological characters. The top portion of this flow is mostly vesicular, un-jointed and watertight in fresh condition, but produces sheet jointing due to weathering [1]. The middle and lower parts of the aa flow are jointed. These joints, can be of fracture origin, are closely spaced linear along preferred orientations and the continuity of these joints is traceable over considerable distances. Such joints, which have a specific distribution in space and orientation, have been reported and explained by various researchers [7-10]. These joints transect several basalt flows and constitute recharge conduits (lateral as well as down ward transmission of water) for deeper Deccan basaltic aquifers [11-12]. However, quantity of percolation of water depends upon joint spacing and pattern of jointing. Water can percolate through closely spaced joints faster as compared to broadly spaced and non-interconnected joints.

In Pahoehoe type flow the original gas cavities are filled up with secondary minerals obliterating original vesicular nature. Due to presence of amygdules, fresh amygdaloidal basalt flow is free from joints and occurs as homogeneous, watertight mass [9, 13]. The vesicular amygdaloidal basalt unit of pahoehoe flow is more susceptible to weathering and exhibits deep weathering profile. It is characterized by the formation of sheet joints. Sheet joints are also developed at the contact between the pahoehoe and aa flows that is within the contact zone. Such weathered zones contain groundwater [14-15]. However, quantity of groundwater depends upon the thickness of weathered zone.

**Geomorphology**

Geomorphological investigations consist of the explanation and mapping of different geomorphological units (landform) and drainage description that could have a direct control on the occurrence and flow of groundwater. In present area geomorphological units serve as synthesis with related components like soil, lithology, structures, and other related hydrological information available in this watershed. Hydro-geomorphological surfaces (Table 1) are interpreted using IRS P6- LISS-III satellite image and SOI Toposheet map and also different process like tectonic and denudational action that have been the dominant factors in development, modification and shaping of the geomorphological units Fig.6. The presence of groundwater in various geomorphological units and its characteristics are listed in Table1 and the groundwater potential map of Sindphana sub-basin is illustrated in Fig. 7.

Geomorphic surfaces of the study area have been classified into nine morpho-units: Alluvial plain, Pediments, Pediplains, Highly Dissected plateau, Moderately Dissected plateau, Denudational Hills, Mesa, Buttes, and Escarpment slopes. These geomorphic surfaces were discussed with reference to geographical area, elevation range, slope, drainage density, stream frequency and groundwater potential of the area:

1. **Alluvial plain**

These are primary sediment storage areas, especially on the valley floors. This geomorphic unit occurs on either side of the major river and its tributaries covering about 425.96 sq. km. (i.e. 10.72%) of the total geographical area of the basin. The alluvial plain features recorded in Present floodplains include the point bar and channel bar deposits [1]. The younger alluvial plain has elevation range from 515 to 600 m above msl, while the older alluvium occurs with an elevation range from 400 to 510 m above msl. The characteristic features of the alluvial plain of study area are of low slope angle (0 to 10°) with almost flat surfaces, low drainage density (< 1 km/km²), low stream frequency (1 to 1.5 streams/km²) and low relative relief (< 5%). The alluvial plain is covered by soils which are very thick dark greyish brown to dark brown coloured, calcareous, moderately well to ill drained alluvium with high moisture retentive capacity.

This geomorphic unit exhibits dark reddish tone and medium mixed texture in the satellite imagery (FCC). The loose alluvial sand exhibit grey tone and smooth texture, while coarse colluvial and pebbly gravel sediments shows the rough texture. The groundwater in these units is brackish on account of leaching of salts
and calcareous material i.e. calcretes developed into the deeper horizons of these zones. The groundwater potential of this zone is good as deciphered through the yield of dug wells (range 80-210 lpm) and bore wells (range 220-390 lpm) (Table 2). The water table fluctuation varies from 1.0 to 2.5 m in dug wells and from 1.3 to 3.3 m in bore wells.

2. Pediments

Pediments are noted as narrow strips adjoining the older alluvial plain at the foot of the moderately dissected plateau in the central and south portion of the basin parallel to the river channel. Pediments occupy about 845.48 sq. km. (i.e. 21.28 %) of the area of the basin. They range in elevation from 580 to 650 m above msl. Morphometric attributes of the pediments are gently sloping surfaces with 20° to 35° gradient, coarse drainage density (~1 km/km²), low stream frequency (1 to 2 streams/km²) and relative relief is about 15 %. Sediments comprising the pediments are not very thick. The soils occurring over this unit are dark greyish brown to black coloured, clayey, calcareous, ill (poor) drained colluvium and scree with low moisture retentive capacity. The gully erosion has dissected the pediments at several places.

Because of the less moisture content, this unit shows brighter tone in the imagery, particularly around the dissected plateau and denudational hills. The groundwater prospective of this zone is moderate to good, which is interpreted based on the yield of dug wells (range 40-85 lpm) and bore wells (range 110-170 lpm) (Table 2). The water table fluctuation varies from 3.3 to 6.5 m in dug wells and from 5.0 to 9.0 m in bore wells.

3. Pediplains

Pediplains range in elevation from 440 to 580 m above msl covering about 1359.13 sq. km. (i.e. 34.22 %) area of the basin. The Pediplains are most dominant geomorphic units found in the basin. These surfaces are having good potentials for crop growing in the area. Geomorphometric characteristics of pediplains areas are: gently sloping to nearly flat terrain with gradient (5° to 30°), moderately coarse drainage density (1 to 1.5 km/km²), moderate stream frequency (1.5 to 2 streams/km²) and moderate relative relief (15%). The materials

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Fig. 6. Geomorphic surfaces of the study area

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comprising these surfaces, consists mainly of weathered products of the surrounding basaltic rocks, mostly comprise moderately thick gravels, pebbles, sand and silt. The soil cover over this unit consists of dark greyish brown to dark brown coloured, silty clay (calcareous), with high moisture retentive capacity. The values of yield of dug wells range from 95 to 170 lpm and in bore wells range from 180-290 lpm (Table 2), while the water table variation is from 1.5 to 2.3 m in dug wells and from 2.8 to 6.0 m in bore wells. This indicates that the groundwater potential of this zone is moderate to good.

### Table 1: Groundwater potential of different themes with reference to their ranks.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Class</th>
<th>Rank</th>
<th>Groundwater potential</th>
<th>Effect on groundwater occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology</td>
<td>Massive Basalt (CB)</td>
<td>1</td>
<td>Poor</td>
<td>The storage capacity of the rock formations depends on the porosity of the rock. In the rock, water moves from areas of recharge to discharge under the influence of hydraulic gradients depending on the hydraulic conductivity or permeability.</td>
</tr>
<tr>
<td></td>
<td>Amygdaloidal Basalt</td>
<td>2</td>
<td>Poor to moderate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jointed Compact Basalt</td>
<td>3</td>
<td>Moderate to good</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Highly weathered AB</td>
<td>4</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geomorphology</td>
<td>Denudational hills/mesa/buttes/</td>
<td>1</td>
<td>Poor</td>
<td>Geomorphological characteristics of an area affect its response to a considerable extent. Linking geomorphological background with hydrological characteristics of an area provides a simple way to understand the groundwater behaviour.</td>
</tr>
<tr>
<td></td>
<td>Escarpment</td>
<td>2</td>
<td>Poor to moderate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dissected plateaus (Highly/moderately)</td>
<td>3</td>
<td>Moderate to good</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pediment/pediplain</td>
<td>4</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alluvial plains</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td>Steep slope</td>
<td>1</td>
<td>Poor</td>
<td>A high sloping region causes more runoff and less infiltration and thus has poor groundwater prospects compared to the low slope region.</td>
</tr>
<tr>
<td></td>
<td>Moderate slope</td>
<td>2</td>
<td>Poor to moderate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flat terrain</td>
<td>3</td>
<td>Moderate to good</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>Drainage density</td>
<td>Dd &gt; 3</td>
<td>1</td>
<td>Poor</td>
<td>Drainage reflects the characteristic of surface and subsurface formation. More the drainage density, higher would be runoff.</td>
</tr>
<tr>
<td></td>
<td>Dd 2 - 3</td>
<td>2</td>
<td>Poor to moderate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dd 1 - 2</td>
<td>3</td>
<td>Moderate to good</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dd 0 - 1</td>
<td>4</td>
<td>Good</td>
<td></td>
</tr>
</tbody>
</table>

4. **Highly dissected plateau**

This landscape unit is dominant in the upper reaches in the hilly terrain of the basin and in the south margin at the basin boundary. It occupies about 417.37 sq km. (i.e. 10.51%) of total area of basin. The lands of this geomorphic surface are dissected by the streams of Sindphana river giving rise to topography comprising of flat peaked ridges and steep scarps. This unit has an elevation range of 620 to 740 m above msl. Morphometric attributes of the highly dissected plateau include steep slopes (> 50°), rapid runoff, high drainage density (> 2km/km²), high stream frequency (2.5 to 3.0 streams/km²) and high relative relief (>60%). The soils over the plateau are dark brown to dark reddish brown in colour, clayey, skeletal, non calcareous in composition, well to excessively drained, low in moisture retentive capacity and underlain by weathered basalt.

In the satellite imagery these geomorphic surfaces appear as light blue colour adjoining the denudational hills. The groundwater potential of this zone is poor to moderate as indicated by the yield of dug wells (range 22-43 lpm) and bore wells (range 42-91 lpm) (Table 2). The water table fluctuation varies from 3.2 to 7.0 m in dug wells and from 6.5 to 18.2 m in bore wells.
5. Moderately dissected plateau

This landscape unit is dominant in the upper reaches of hilly terrain of river and in the south part adjoining the highly dissected plateau at the basin boundary and it occupies about 439.82 sq km. (i.e. 11.08%) of the total geographical extent of the basin. The lands of this landscape are cut across by the streams of Sindphana river producing a terrain consisting of dissected flat topped ridges and plateaus. This unit has elevation range of 620 to 740 m above msl. Morphometric attributes of the moderately dissected plateau include moderate to steep slopes (30° to 50°), rapid runoff, moderate drainage density (2 to 2.5 km/km²), moderate stream frequency (2.0 to 2.5 streams/km²) and moderate relative relief (50 to 60%).

The soils over the plateau are greyish brown to dark brown in colour, clayey, skeletal, non calcareous in composition, well to excessively drained, low in moisture retentive capacity and underlain by weathered basalt. This geomorphic surface also appears as light blue colour in the FCC. The groundwater potential of this zone is poor to moderate. It is observed that the range of yield in dug well of this unit is from 30 to 45 lpm and in bore wells it is from 45 to 90 lpm with an average yield of 38 and 74 respectively (Table 2). The water table fluctuation ranges from 3.0 to 5.4 m in dug wells and from 6.2 to 11.3 m in bore wells.

6. Denudational Hills

The hills in northern and western part of the basin in Beed district are part of hills along margins of Balaghat plateau. The elevation of hills on an average is about 650 m msl. They occupy about 138.49 Sq. km. (i.e. 3.49%) of total geographical area. The hill tops have heights ranging from 720 m above msl to 820 m above msl. Apart from these, there are several isolated barren hills scattered over the plains within elevation range of 640 to 750 m above msl. These hills in the area have steep gradient (>60°), high drainage density (3 to 3.5 km/km²), high stream frequency (4 to 4.5 streams/km²), high relative relief (68%) and are characterized by rapid runoff.

The soil cover this geomorphic unit is very thin. The soils are rocky, clayey, non calcareous and underlain by weathered basalts. The flow characteristics of the basalts can be easily identifiable in the hills. The hills are sometimes barren and at places clothed with tropical arid deciduous jungle. These geomorphic surfaces appear as green colour in the FCC and can be identified with massive size and domal to elliptical
shape. The groundwater potential of this zone is poor as obtained by the yield of dug wells (range 20-30 lpm, average 25 lpm) and bore wells (range 40-70 lpm, average 52 lpm) (Table 2). The water table fluctuation varies from 3.2 to 6.2 m in dug wells and from 6.2 to 13.3 m in bore wells.

7. Escarpment

Escarpment is an area of the Earth where elevation changes suddenly. Escarpment usually refers to the bottom of a cliff or a steep slope (Fig. 5.15a & b). An escarpment is formed by wearing and tearing of rock by water. In an escarpment one side is generally steeper and eroded more than the other. This is resulted because of the unequal erosion from one type of rock to another. This geomorphic unit has less distribution in the basin and occupies about 4.60% of the total area. It has elevation range of 620 to 700 m above msl. The morphometric attributes of the lateritic escarpment include moderate slope (25° to 60°), moderately coarse drainage density (1.5 to 2 km/km²), moderate stream frequency (2 to 2.5 streams/km²) with relative relief of about (25%). The groundwater potential of this zone is not obtained.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Geomorphic Unit</th>
<th>Observation wells</th>
<th>Range of depth to water (m bg1)</th>
<th>Water table fluctuation (m)</th>
<th>Range of yield (lpm)</th>
<th>Av. Yield (lpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alluvial plain</td>
<td>DW 6, BW 5</td>
<td>1.5-5.0</td>
<td>0.5-3.5</td>
<td>1.0-2.5</td>
<td>80-210</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.5-7.4</td>
<td>1.2-4.1</td>
<td>1.3-3.3</td>
<td>220-390</td>
</tr>
<tr>
<td>2</td>
<td>Pediplain</td>
<td>DW 6, BW 6</td>
<td>2.5-5.5</td>
<td>1.0-3.2</td>
<td>1.5-2.3</td>
<td>95-170</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.9-10.3</td>
<td>2.1-4.3</td>
<td>2.8-6.0</td>
<td>180-290</td>
</tr>
<tr>
<td>3</td>
<td>Pediments</td>
<td>DW 5, BW 5</td>
<td>5.6-10.5</td>
<td>2.3-4.0</td>
<td>3.3-6.5</td>
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<td></td>
<td></td>
<td></td>
<td>9.4-15.2</td>
<td>4.4-6.2</td>
<td>5.0-9.0</td>
<td>110-170</td>
</tr>
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<td>4</td>
<td>Highly Dissected Plateau</td>
<td>DW 4, BW 5</td>
<td>6.3-12.2</td>
<td>3.1-5.2</td>
<td>3.2-7.0</td>
<td>22-43</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11.5-28.9</td>
<td>5.0-10.2</td>
<td>6.5-18.2</td>
<td>42-91</td>
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<td>5</td>
<td>Moderately Dissected Plateau</td>
<td>DW 5, BW 5</td>
<td>5.4-10.6</td>
<td>2.4-5.2</td>
<td>3.0-5.4</td>
<td>30-45</td>
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<td></td>
<td></td>
<td></td>
<td>9.4-17.5</td>
<td>3.2-6.2</td>
<td>6.2-11.3</td>
<td>45-90</td>
</tr>
<tr>
<td>6</td>
<td>Denudational Hills</td>
<td>DW 2, BW 3</td>
<td>10.4-15.2</td>
<td>7.2-9.0</td>
<td>3.2-6.2</td>
<td>20-30</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>11.4-22.5</td>
<td>3.2-6.2</td>
<td>6.2-11.3</td>
<td>40-70</td>
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<td>7</td>
<td>Escarpment</td>
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</tr>
<tr>
<td>8</td>
<td>Messa</td>
<td>DW 2, BW 2</td>
<td>12.4-20.3</td>
<td>6.4-11.2</td>
<td>6.0-9.1</td>
<td>20-36</td>
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<td></td>
<td></td>
<td>15.4-22.2</td>
<td>8.2-12.2</td>
<td>7.2-10.0</td>
<td>35-53</td>
</tr>
<tr>
<td>9</td>
<td>Buttes</td>
<td>DW 2, BW 2</td>
<td>11.5-21.6</td>
<td>5.4-10.2</td>
<td>6.1-11.4</td>
<td>18-26</td>
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<td></td>
<td>14.4-24.5</td>
<td>8.0-12.2</td>
<td>6.4-12.3</td>
<td>36-44</td>
</tr>
</tbody>
</table>

DW- Dug well  DBW- Dug-cum bore well  BW – Bore well

8. Mesa

A mesa is a medium size flat-topped hill or mountain (Fig. 15b). Due to continuous erosion of surrounding areas makes it an elevated landmass and the top layer of hard resistant rock due to denudation of underlying rocks, giving it a characteristic shape. This geomorphic unit has less distribution in the basin and occupies about 14.91sq km (i.e.0.38%) of the total area. It has elevation range of 650 to 720 m above msl. The morphometric attributes of the lateritic escarpment include steep slope (> 60°), coarse drainage density (2 to 2.5 km/km²), high stream frequency (2.5 to 3 streams/km²) and relative relief (>25%).

The groundwater potential of this zone is poor, which is deduced on the basis of yield in dug wells ranging from 20 to 36 lpm and in bore wells from 35 to 53 lpm (Table 2). The water table fluctuation varies from 6.0 to 9.1 m in dug wells and from 7.2 to 10.0 m in bore wells.
9. Butte

A butte is a small flat-topped or pointed hill or mountain (Fig. 15a). Continued denudation by water gradually reduces the Mesa into small flat hills called Buttes. This geomorphic unit has less distribution in the basin and occupies about 32.34 sq. km. (i.e. 0.81%) of the total area. It has elevation range of 620 to 700 m above msl. The morphometric attributes of the lateritic escarpment include steep slope (> 60°), coarse drainage density (2 to 2.5 km/km²), high stream frequency (2.5 to 3 streams/km²) and relative relief (>25%).

The values of yield in dug wells obtained varies from 18 to 26 lpm with average of 22 lpm and in bore wells it ranged from 36 to 44 lpm with average 40 lpm (Table 2), while the water table fluctuation varies from 6.1 to 11.4 m in dug wells and from 6.4 to 12.3 m in bore wells. This indicates that the groundwater potential of this zone is poor.

On the basis of different geomorphic units, four categories of groundwater potential zones were delineated as (i) Good (ii) Moderate to good (iii) Poor to moderate and (iv) poor. In the year 2015 and in summer 2016 because of less rainfall in earlier 3 years (below average rainfall) the groundwater level depleted much more and areas needed tankers of water supply.

Conclusion

The occurrence of groundwater in the sub-basin is dependent on rock type (geology), landforms (geomorphology) and slope as revealed from GIS analyses and field investigations. Remote Sensing and GIS are helpful tools for the preparation of groundwater potential areas mapping and management plan on a scientific basis. The overall results of the study reveal that the use of remote sensing and GIS proved to be dominant tools to study groundwater resources of the area and plan appropriate exploration plan. This gives additional reasonable groundwater potential map of an area which may be used for any groundwater development and management programme.

Acknowledgement

The authors take the opportunity to thanks University Grants Commission, New Delhi for financial assistant in the form of Major Research Project scheme (F.No. 41-1026/2012 (SR) Dated 23rd July 2012). Author also officially acknowledged to Dnyanopasak Shikshan Mandal Parbhani for every support and help.

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