International Conference "Water, Environment, Energy and Society" (WEES–2009)
New Delhi, 12–16 January 2009

Water Resource Management of Chandrabhaga River Basin, Chikaldhara Region, Amravati District, Maharashtra, India

S.F.R. Khadri
Department of Geology, Sant Gadge Baba Amravati University
Amravati, Maharashtra - 444 602, INDIA
E-mail: khadrisfr@yahoo.com

ABSTRACT: Detailed hydrogeological and hydro-geochemical investigations have been carried out for a part of Chandrabhaga river basin exposed around the Chikaldhara region, Amravati District, Maharashtra. with an aim to understand the hydro-geochemical, geophysical, geological, geomorphological and environmental control on the groundwater regime of the region. The study area is characterized by the presence of 825 m thick horizontal sequence of lava flows which can be divided in simple and compound units based on their field characters, textual parameters and geomorphic expression.

Detailed study of geomorphic features and the analysis of the remotely sensed data through visual interpretation of the Chandrabhaga River basin around Chikhaldara region, Amravati District was carried out to elucidate the role of various morphometric features, geomorphic processes and structural trends in the evolution of the landscape. The results indicate the presence of seven distinctly different geomorphic units which include alluvial plain, bajada zone, moderately dissected plateau, highly dissected plateau, plateau top, structural ridge and denudational hill. Hill slopes exhibit stepped appearance with parallel retreat during pediplanation due to differential erosion of various litho units exposed in the region. The structural, denudational and alluvial landforms, on the basis of land use and land cover have been sub-divided into agriculture land, built up land, wasteland and water bodies. In addition, remote sensing techniques have been effectively utilized in identifying the potential aquifers so as to enable groundwater exploration in the region. The present investigation based on numerous topographical profiles has shown the presence of marked flat terraces at different levels indicating the present state of the cycle of erosion and landform development. The results confirm the hydrogeological and morpho-tectonic conditions, which have also helped in locating suitable aquifers for the water resource development of the region.

Major element chemistry of groundwater samples from dug wells and bore wells from 100 selected sites from the Chikaldhara region has been analyzed during pre-monsoon and post-monsoon periods to understand the groundwater quality and its impact on the environment. Various thematic maps showing the distribution of various elements and their ration along with iso-contour maps of physico-chemical parameters have been utilized to understand the water quality management of the region. Pumping test results have highlighted the safe yield and other related parameters which have helped in improving the groundwater resource of the region.

Hydro-geological and geochemical studies have thrown light on the water level fluctuations in the region with emphasis on water resource and environmental management of water quality. The results of the chemical analysis indicate that both the surface and groundwater are suitable for drinking and irrigation purposes. The results of geophysical resistivity studies have thrown light on the nature of sub surface geology of the region along with groundwater potential zones. The highly fractured, amygdaloidal and weathered basaltic horizons have yielded sufficient amount of water whereas, the compact and massive portions show poor yield in the region. In this study, an attempt has been made to suggest various suitable measures for improving the groundwater potential of the area with due emphasis on water resource management. Detailed environmental analysis was carried out to understand the water level fluctuations and quality of water. In addition, suitable remedial measures were suggested for water resource development and management of the region.

Keywords: Environmental Management, Groundwater, Deccan Traps, Watershed Development.

INTRODUCTION

Water is one of the main resources essential for the overall socio-economic development of any region and it requires careful planning and appropriate exploration. The study area is characterized by the presence of 800 m thick pile of horizontal lava flows of Deccan Traps. The topography is characterized by the presence of flat terraces of lava plateau, lava hill, mesa, butte, escarpment and linear ridges, which have been resulted from lateral erosion. The heterogeneous nature of the basaltic lava flows exposed in the study area is clearly evident from the wide variation in the hydro-geological parameters of these basalts, mainly their permeability and porosity resulted from the nature and degree of weathering, fracture pattern and jointing. The variation in permeability of lava flows

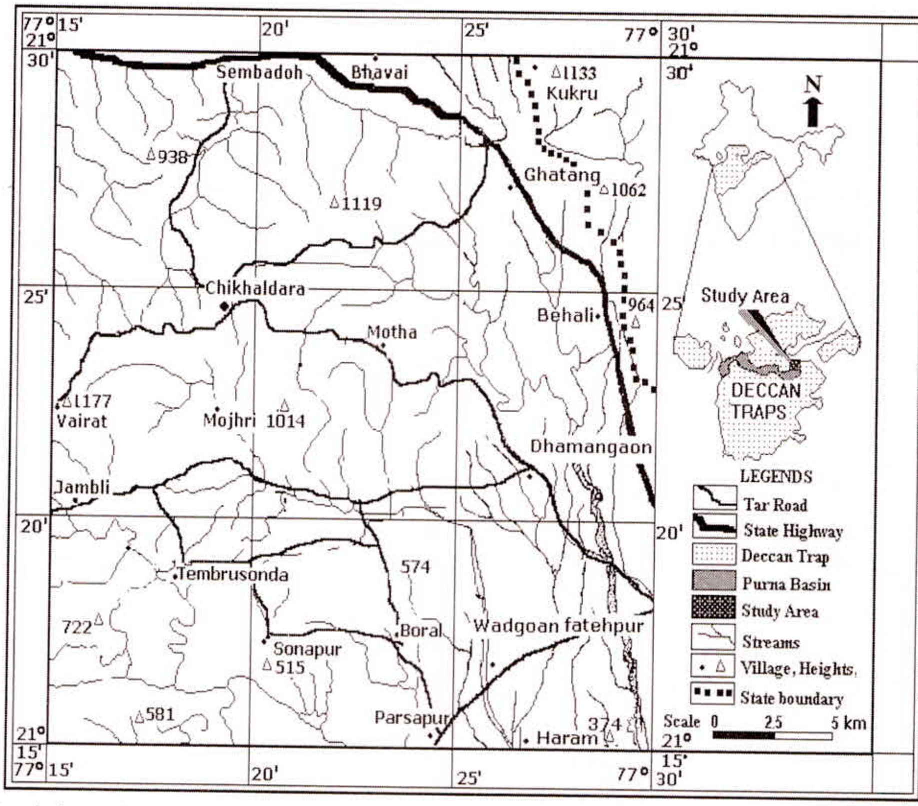

Fig. 1: Location map of the Chandrabhaga River Basin exposed at Chikaldhara region

exposed in the area is reflected by geometry of drainage network, which provides a reliable index for measuring the permeability of rocks from the drainage basin (Wisler and Brater, 1959). The Geomorphological and hydro-geological details aid in base flow estimation (Raju and Jha, 1990).

The work done so far in understanding the hydrological conditions of the study area is very limited except some basic data report of exploratory boreholes by Central Ground Water Board. Tiwari *et al.* (1996) have given primary data on the geomorphology and geology of Purna valley. The basic objective of the present investigation is to delineate various hydrogeomorphic units through remote sensing techniques, understanding the hydrogeological conditions of the Chandrabhaga River basin and also to gather information on the occurrence, movement and development of groundwater by examining the open dug wells and tube wells. The study area is located at about 95 km from Amravati, between. 21° 15' and to 21° 30' N latitudes and between 77° 15' and 77° 25' E longitudes (Figure 1).

METHODS OF STUDY

Field traverses and numerous spot checks have been carried out to trace the individual flows and flow sequences at detached out crops. Drainage morphometric analysis was carried out to understand the drainage characteristics and their role in the formation of present day landscape. Topographic features have been studied and various parameters related to drainage network and basin geometry were computed and various measurements including height and intensity of dissection have been made. In addition, remote sensing techniques have been utilized with the help of Indian Remote Sensing Satellite (IRS) imagery to delineate the geomorphological and structural features, which help in understanding the tectonic fabric and related landform unit distribution. Further, various erosional surfaces have been identified by utilizing certain parameters like flatness, consistency in the height of the ridges and slope characters of topographical profiles.

PHYSIOGRAPHY

The study area can be broadly divided into low lying plain towards the banks of the Chandrabhaga River in the southeast and horizontal Deccan Trap flows with multiple scarps and abrupt cliffs towards the northern parts. The geomorphic analysis indicates the predominance of erosional landforms over the depositional landforms. The study area can be interpreted as moderate morphogenetic region consisting of various erosional surfaces in step-like terraces. The horizontal dispositions of the lava flows with a fair degree of uniformity in lithology have considerably simplified the changes brought by the secondary processes like weathering and denudation. Differential weathering forces has resulted in wiping out of about 800 m thick lava pile in SE part of the region, which is evidenced by the absence of upper flows at Haram village.

As per the physiographic classification of India, the study area falls in the central high land region underlain by thick pile of lava flows, deeply dissected by Chandrabhaga River. Hill slope analysis indicates the presence of flat crest, and interim slope with a fairly consistent angle off from the plain. The average annual precipitation of the study area is 1548 mm out of which 85% occurs from July to October. The temperature ranges from a maximum of 40° C during summer to a minimum of 5°C during the winter. The soil profile consist of well defined A, B and C horizons with pH of the soil suspension varying from 6 to 7.8 and moisture content from 8.97% to 21.32%. Amphitheatrical valley heads with narrow intersected and fairly steep-sided walls are common along the edges of the plateau and ridges.

DRAINAGE MORPHOMETRIC ANALYSIS

The area of investigation is represented by erosional landforms like lava plateau, lava plain, linear ridges, conical hills, mesa, butte and escarpments. The Chandrabhaga River, a fifth order stream rises from the Chikhaldara hills and flows towards south. In this study, stream ordering was done following the method given by Horton (1945), modified by Strahler (1952). The morphometry of the study area reveals the predominance of dendritic drainage pattern indicating the uniform lithology with negligible structural disturbances (Figure 2, Table 1). The average drainage frequency and drainage density computed for the study area are 5.49 and 4.10 respectively, with high values in the plateau and plains and lower in the hilly terrain with steep slopes and scarps and undulating features. The bifurcation ratio varies from 1.20 to 4.05 for various streams. The lower bifurcation ratio values are characteristic of the watersheds which have suffered less structural disturbances (Strahler, 1964) and the drainage pattern has not been distorted. The elongated portion of the basin has shown high values of bifurcation ratio indicating that the watershed has suffered major structural disturbances such as Gawilgarh fault and other minor faults and the drainage pattern has been distorted because of structural disturbances. Circular portion has shown low values of the bifurcation ratio indicating that the basin has suffered less structural disturbances. The length of over land flow (2.06) indicates that water cover a small distance on the surface before reaching into a definite stream channel. The basin relief value (803 m) when correlated with the relief ratio indicates the nature of erosion in the study area where as the form factors

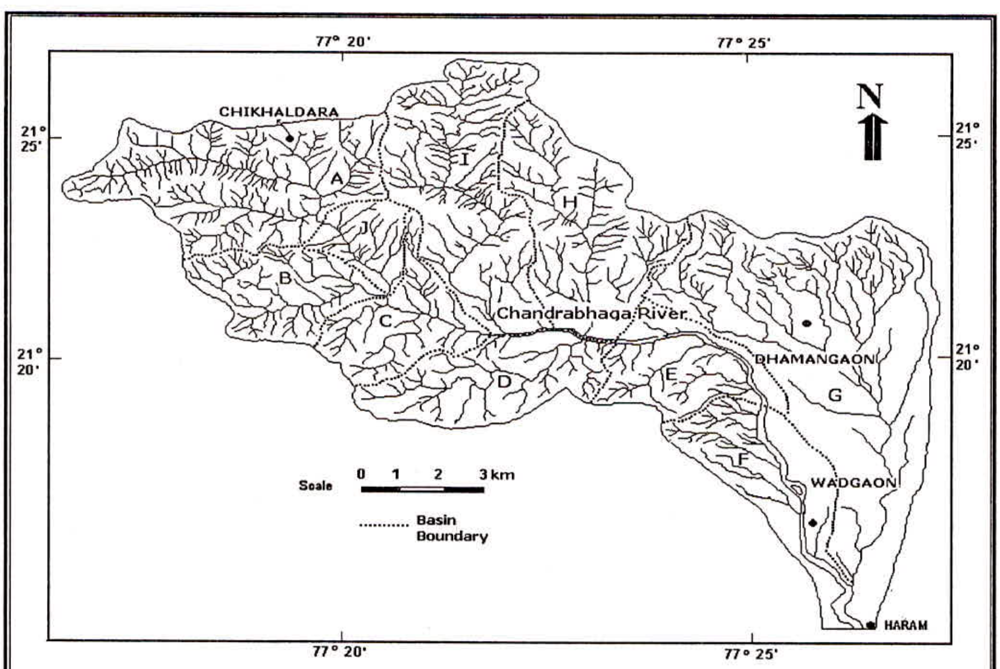

Fig. 2: Drainage network of the Chandrabhaga River basin

Table 1: Morphometric Parameters of Chandrabhaga River Basin near the Chikhaldara Region

Drainage Network											
Sub Basin	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*Total*
Total No. of streams, N	197	81	52	66	35	32	111	107	150	14	845
Bifurcation ratio, Bf = N/N + 1	3.95	3.17	2.96	3.02	1.45	1.20	2. 52	3. 57	4.05	1.51	2.84
Total Stream length L (km)	95.75	48.45	41.92	46.45	31.55	32.75	61.700	78.00	98.50	21.02	610.5
Drainage density, Dd = L/A	3.76	4.94	7.07	3.70	4.17	3.00	1.18	2.69	4.09	6.11	4.10
Drainage frequency Sf = N/A	7.75	8.26	8.85	5.25	4.63	2.93	2.13	4.07	6.24	4.79	5.49
Form Factor Rf = A/lm^2	0.39	0.80	0.64	1.18	0.30	0.13	0.33	2.14	0.28	0.16	0.64
Basin Geometry											
Area of Basin A (Sq. km)	25.40	9.80	8.89	12.55	7.55	10.89	51.87	26.28	24.02	1.65	178.9
Area of Basin percentage (%)	24.32	5.49	4.98	7.03	4.23	6.10	29.06	14.72	13.46	0.65	100.0
Length of basin along river course (km)	8	3.50	4.50	3.25	5.00	9.25	12.50	3.50	9.30	4.00	28.40
Max length of basin (km)	6.87	5.12	6.75	6.50	4.00	8.25	14.50	8.50	9.00	3.25	20.36
Max. width of basin (km)	6.75	4.37	4.12	2.75	3.25	2.50	6.50	4.00	4.00	2.00	10.50
Basin perimeter (km)	24.12	18.75	17.62	17.50	12.50	27	38.75	24.37	24.37	5.62	67.50
Circularity ratio Rc = A/Ac	0.54	0.35	0.81	0.51	0.30	0.59	1.51	0.55	0.50	0.12	0.59
Elongation ratio, Re = Dc/Lm	1.11	1.16	1.25	0.85	0.99	1.04	0.80	0.81	0.86	0.40	0.93
Length of overland flow, Lo = 1/2Dd	1.88	2.47	3.85	1.85	2.08	1.46	0.59	1.34	2.04	3.06	2.06
Measures Involving Height											
Height of the basin mouth (m)	600	580	500	490	420	380	374	455	485	520	374
Highest point on watershed (m)	1177	1045	1030	656	552	574	831	1085	819	1044	1177
Total basin relief, H (m)	577	465	530	166	132	194	457	630	334	524	803
Relief ratio Rh = lm/H (km)	72.12	138.57	78.00	48.00	26.40	20.97	44.32	158.57	188.69	78.80	86.44
Relative relief, Rr (km)	23.91	25.86	23.23	8.91	10.56	7.18	15.07	24.21	17.80	37.82	19.45
Ruggedness number, Hd = Rr/Dd (km)	6.35	5.23	3.28	2.40	2.53	2.39	12.77	9.00	4.35	6.19	5.45

demonstrate that nature and shape of the drainage basin. The higher values for the circulatory ratio (1.51) confirm the uniform lithology of the study area. The form factor value varies from 0.13 to 2.14 for the basin. The higher values of form factor indicate the circular shape of the basin showing uniform lithology and the lower values denotes elongated shape of the basin, which has suffered structural disturbances. In the study area, elongated basin with low form factor (F basin) indicates that the basin had a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basins.

Drainage density is a measure of the length of the stream segment per unit area. The calculated values of drainage densities of sub-basins area given in the Table 1. The drainage density is affected by the factors that control characteristic length of the stream. The factors controlling stream length are resistance to weathering and permeability of rock formations a part from the climatic and other factors like vegetation. In general low drainage density is observed in regions of highly resistant and/or permeable soil material under vegetative cover in the regions of weak and impermeable mountainous relief. In the present case, the low value of drainage density (1.18) in 'G' basin indicates the presence of highly permeable alluvium exhibited by low run off with the presence of shallow and deeply buried foot slopes associated with low drainage frequency (2.13) because of highly permeable sub soil material and low relief, which are in turn favourable for high infiltration indicating very good groundwater occurrence in the area. The inverse of the drainage density gives the constant of channel maintenance (Schumm, 1956). Generally, it varies directly with the size of the drainage basin.

GEOMORPHOLOGY AND GROUNDWATER POTENTIAL

The groundwater potential map based on visual interpretation has been prepared using satellite imagery of IRS 1C (LISS-III) and LANDSAT imagery on a scale of 1:50,000. Regarding groundwater potential, the sites containing intensive fracture/joints (Figure 3), moderately weathered pediplain and valley fills are the most preferred zones. Groundwater is poor in all other sites (Figures 4 and 6, Table 2).

The different image elements that were taken into consideration are tone, texture, pattern etc. The multispectral imagery of the study area displays a more or less monotonous dendritic drainage pattern, at places controlled by local structures. Some of the linear features, which have been recorded with remarkable consistency on multidate and multispectral image, is clear-cut evidence and strongly suggest the presence of subsurface fault/fracture in this area (Figure 3).

Table 2: Hydro-Geomorphologic Units of the Study Area

Origin	*Geomorphic Unit/Landform*	*Description*	*Groundwater Potential*
Fluvial	Alluvial plain (A.P.)	Thick unconsolidated alluvial material consisting of sand, silt and clay	Very Good
Fluvial	Bajada zone (B.Z.)	Unconsolidated alluvial material consisting of rock boulders, cobbles, pebbles, sand and silt	Good
Structural	Moderately dissected plateau – A	Basaltic plateau, moderately dissected, with high drainage density with thin soil cover	Poor
Structural	Moderately dissected plateau – B	Basaltic plateau, moderately dissected, with high drainage density and thick soil cover	Moderate
Structural	Highly dissected plateau – A	Moderate to steeply sloping basaltic plateau margins with high drainage density and negligible soil cover	Poor
Structural	Highly dissected plateau – B	Moderately slopping basaltic plateau margins with high drainage density and thin weathered mantle and soil cover	Poor
Structural	Plateau top	Isolated basaltic plateau with steep side slopes with moderate soil cover	Poor
Structural	Structural ridge	Narrow aligned ridges	Poor
Denudation	Denudation hillock	Basaltic hills with steep sided slopes	Poor

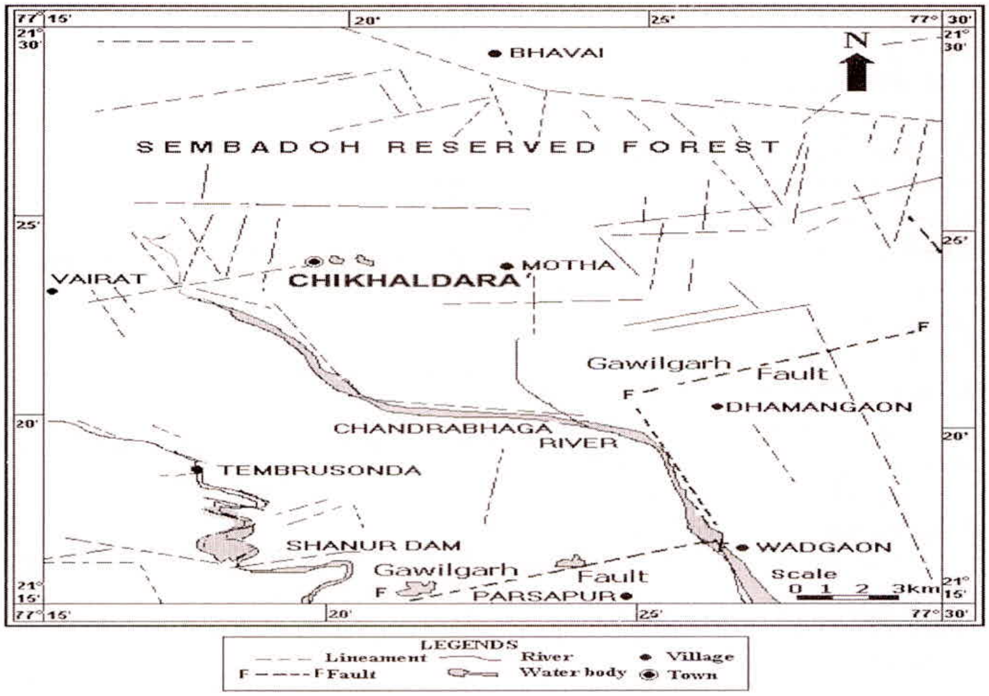

Fig. 3: Lineament map of the study area based on Remote Sensing data

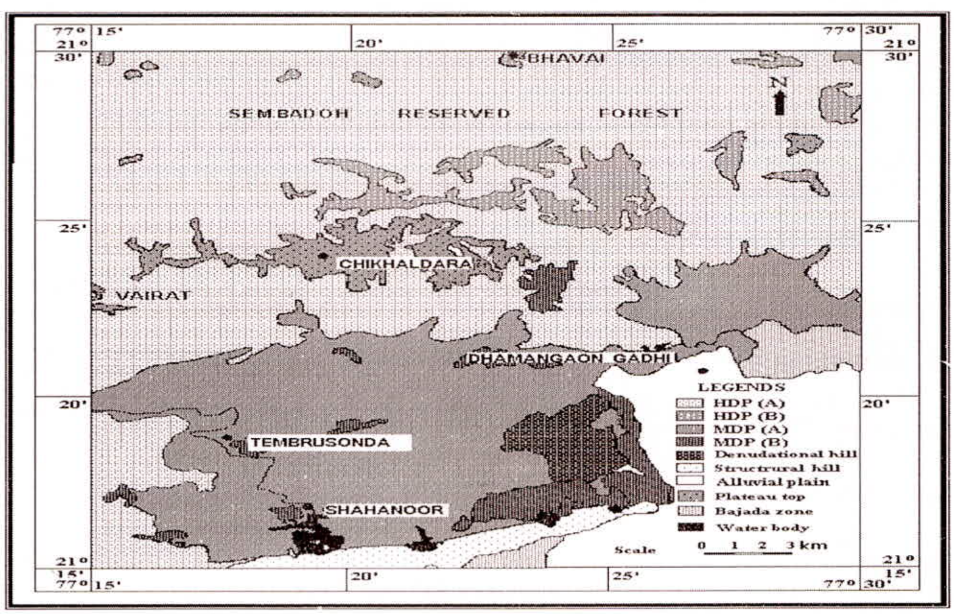

Fig. 4: Geomorphologic map of study area based on Remote Sensing data

Following the general procedures for the preparation of groundwater potential map, delineation based on visual interpretation of satellite data, groundwater potential zone maps have been prepared for Chandrabhaga river basin at 1:50,000 scale (Figure 6). The groundwater in this area occurs primarily in the hard rocks, within the weathered mantle and fracture zones of the underlying rocks. Good groundwater potential exists in narrow zones of unconsolidated deposits along valley fills. Geomorphologically, the entire area is classified into: (a) Alluvial plain, (b) Bajada zone, (c) Moderately dissected plateau (A, B), (d) Highly dissected plateau (A, B), (e) Plateau top, (f) Structural ridge and (g) Denudational hillock. Very shallow weathered pediments have very poor groundwater prospects due to very thin (0–1 m) weathered zone, and at some places country rock is exposed leaving the place almost barren. Moderately weathered pediments are potentially good areas having 5 to 15 m weathered mantle and most of the villages are situated on the zone; due to its fairly good groundwater and soil conditions, it has been put to paddy or other types of cultivation. A structural hill consists of resistant and bold landforms, which are either exposing structures or showing structural trends. They are prominent because they form bold escarpments.

The groundwater in structural hills is absolutely rare. The rainwater mostly goes as surface runoff. Bajada zone represents isolated upland suddenly ejecting out from the plains and the outcrops are mostly bare and eroded. The loose material at the base of such hills form good recharge zone because of high porosity and permeability. Alluvial plain and surrounding zones are relatively the best, from groundwater point of view, due to the high porosity and permeability except at few places where these are of very shallow in nature. In general, they contain appreciable amount of unconsolidated deposits (i.e., upto 20 m) and are put into extensive cultivation because of their high moisture bearing capacity.

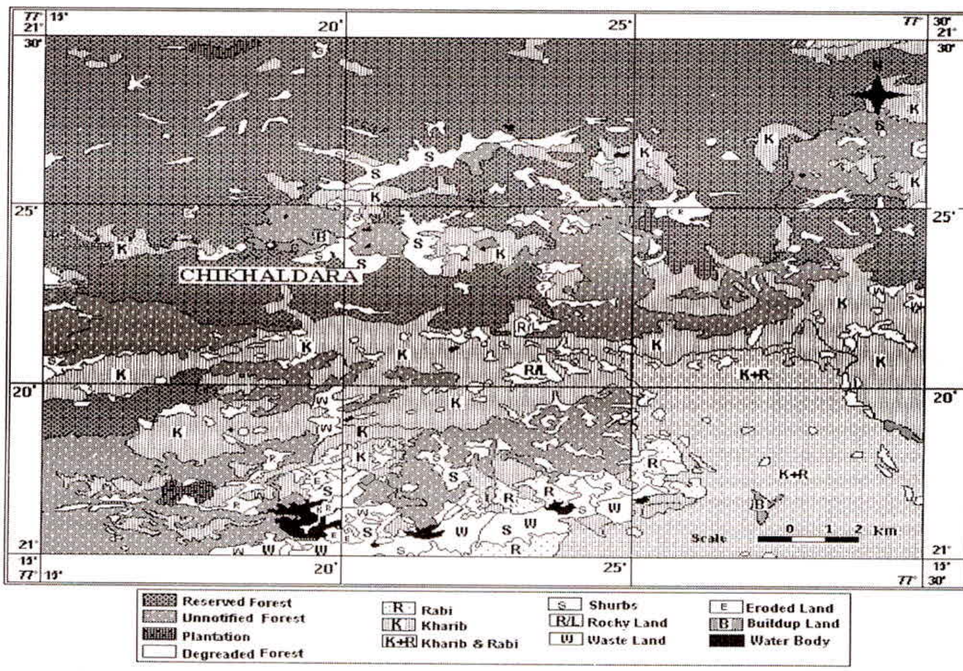

Fig. 5: Land use/land cover map of study area based on Remote Sensing data

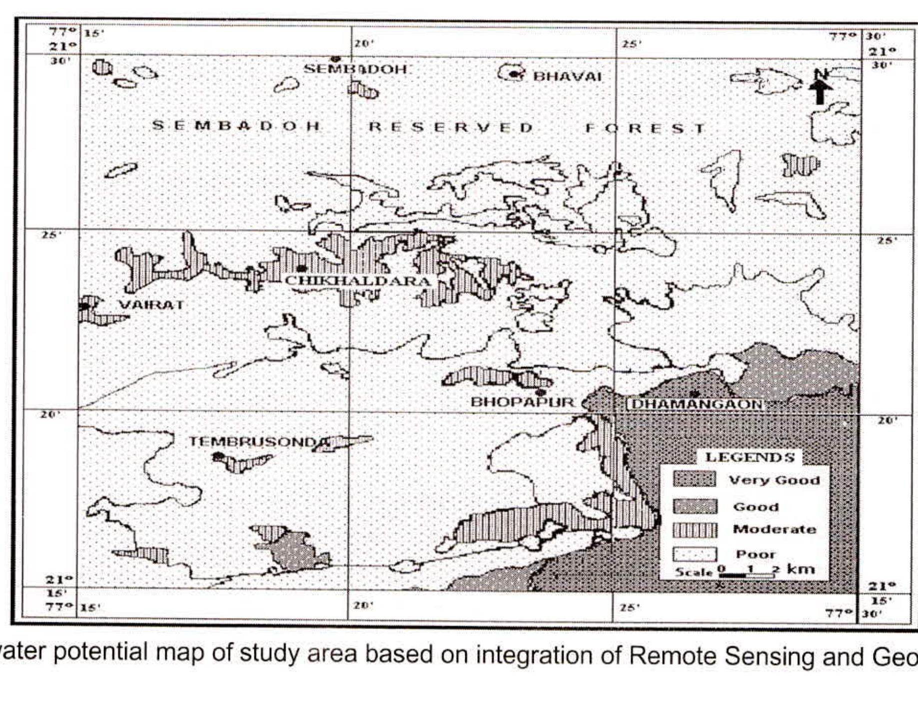

Fig. 6: Groundwater potential map of study area based on integration of Remote Sensing and Geomorphologic Data

In alluvial plain areas, post-monsoon water level is found to be 1 m (bgl) where as it is 1to 10 m in the case of moderately weathered pediment and still deeper in very shallow weathered pediment respectively.

REMOTE SENSING DATA ANALYSIS

Analysis of the remotely sensed data through visual interpretation of IRS LISS III imagery indicates the predominance of basaltic lava flows in the study area with two distinct geomorphic expressions viz. vast plateau surface on monotonous lava flows and dissected plateau (Figures 3 and 4, Table 2). The light toned areas in the imagery indicate the low level flood plains scattered along various drainage channels and indicate the changes in the stream courses during the past. The dark toned areas suggest presence of hills with steep scarps. In general, the study area is dominated by undulating topography, which has undergone considerable erosion as evidenced by the presence of plateau surfaces, linear ridges, mesa, butte and escarpment. The area is dominated by the presence of dendritic drainage pattern over the lava flows which are characterized by homogeneity in texture and resistance to erosion. However, at certain places where the tectonic and structural controls dominate over the lithology, sub-parallel and trellis drainage patterns have been observed (Figure 2). Along the steep slopes and escarpments, pinnate drainage pattern has developed due to the pronounced regional slope and also due to the dominant control of slope over the parallel topographic features. In the study area, the linear ridges indicate the presence of lineaments. A close observation of the lineaments interpreted from IRS imagery revealed the presence of two generations of lineaments. For instance, the satellite data interpretation supports the view that Gawilgarh fault indicates as an older age and the remaining lineaments represent a younger age. Low relief linear landforms demonstrate the dominant control of structures such as faults when they are sufficiently large, whereas, smaller lineaments are controlled by small-scale features like fracture joints, shears and at places basic dykes. The results of visual interpretation of remote sensing data demonstrate the presence of various types of landforms such as structural landforms, denudational landforms, bajada zone, Moderately Dissected Plateau (MDP), Highly Dissected Plateau (HDP), plateau top, pediment and alluvial plain (Figure 4, Table 2). The highly dissected plateau is characterized by the presence of intricate network of dissection on the lava flows. The availability of groundwater is negligibie except where there is a weathered mantle or the presence of some vesicular horizon. The yield from open dug wells varies from 40 m^3 to 70 m^3/d. Land use/land cover map of the study area has been prepared by utilizing remotely sensed data interpretation which demarcated various units such as forest cover, irrigated lands, barren lands, hilly terrain etc (Figure 5). The identified land use/land cover features are agriculture, plantation, deciduous forest, degraded forest, scrubland, gullied land, forest plantation, shifting cultivation, lakes/reservoirs and road network. The irrigated crop areas are identified in the LISS III imagery as features with light to medium red tone, fine/medium texture exhibiting scattered/ contiguous pattern, varying in size, often rectangular in shape and mostly associated with water bodies. The red tone with white patches and fine to medium texture with irregular shape and varying size, associated with forest plantation, serve to demarcate deciduous species, shedding their leaves in February to April. The false colour composite shows the degraded forest in light grey to greenish white tone, fine to medium texture, irregular in shape and varying in size, showing degradation characteristics. A number of water bodies are observed on rolling plains and demarcated in the imagery due to their light blue colour to blue colour.

The rocky land identified in the land use/land cover map represents hilly region with high relief (374 m to 1177 m) with steep slopes and forms the denudational hills above pediplain with poor groundwater potential. The eroded land represents badland topography of this region, which is due to the erosion of fine material from the bottom of the denudational hill leaving the rock exposed. This zone has recharge potential for groundwater because of the occurrence of fractured rocks through which rainwater percolates. But the groundwater flows away towards the adjacent plain, and therefore, groundwater prospecting is less feasible than in the surrounding plains. Thus groundwater occurs under semi-confined conditions and groundwater potential is moderate to poor. The area covered by plantation and agriculture is nothing but the alluvial plain, which is identified in the imagery as a feature with light pinkish tone and with gentle gradient along the river course and has excellent groundwater potential.

HYDROGEOLOGY AND WATER RESOURCE MANAGEMENT

Groundwater potential map showing the groundwater prospect zones (good moderate and poor horizons) has been prepared to depict the groundwater resource position of region (Figure 6). The area is characterised by the presence of heterogeneity within the rock formations, which in turn affect groundwater, recharge. Based on the geomorphic processes and agents involved, the landforms are grouped into structural, denudational and fluvial in origin. The highly altered, fractured and jointed horizons serve as potential interflow zones for the accumulation of groundwater whereas, in vesicular units, groundwater occurs in interconnecting vesicles both under water table and confined conditions. The denudational landforms are characterized by the presence of thick weathered mantle ranging from 4 to 7 m with less dissection and associated with intersection of lineaments indicate potential storage zones. The depth of wells in this region varies from 5 to 11 m bgl and depth of water level from 4 to 8 m bgl and safe yield of open dug well varies from 44 m^3 to 80 m^3/d with sustained discharge of over 3 hours indicating phreatic and confined to the semi-confined aquifer conditions. The moderately dissected plateau occurs along the fringes of steep scarps indicating moderate thickness (2–4 m) of the weathered horizons. The bedrock is shallow and depth to groundwater level varies from 6 to 8 m bgl with moderate water bearing horizons depending upon the placement of interflow zone suggesting the storage potential zone of groundwater.

The recharge of groundwater in the study area is controlled by topography, thickness of weathered zone, and vegetation and infiltration capacity of soil and sub-soil strata within the zone of aeration. The water bearing capacity of various lava flows depends on the flow nature and geomorphic expression. The massive portions show low porosity due to the lack of openings and hence unproductive for groundwater, whereas, the vesicular and amygdaloidal horizons of lava show interconnected and uniformly distributed vesicles contributing to their groundwater potential due to high degree of porosity and permeability which further increase with weathering. Occasionally, the closely spaced inter-connecting joints if present in between the massive horizons may contribute towards formational porosity and forms productive zones. The size and number of vesicles, degree of weathering and joint pattern controls the water productivity and yielding capacity of aquifers in the study area. Hence, highly weathered zones of vesicular and amygdaloidal basalts are potential zones of groundwater. The red/green bole horizons in the area are less productive due to the their clayey nature which tend to stop the vertical movement of groundwater as they act as confining aquicludes. The study area is characterised by the presence of multiple aquifer system showing both productive and unproductive zones due to the presence of alternating massive and vesicular units with lateral variations. The weathered and jointed zones in the massive units and vesicular and amygdaloidal units forming water table aquifers of basalts are presently tapped in the region. The depth of water table indicates four distinct horizons, which include shallow water level (1.5–5 m), moderately deep water level (5 –8 m) and very deep water level (>15 m). The shallow water level in the study area is mainly influenced by the surface irrigation showing artificial recharge of water table.

The water level fluctuation in the area of investigation depends on the differences of water levels in the pre-monsoon and post-monsoon periods, which is related directly to the recharge and discharge of groundwater. It is generally grouped into three distinct classes namely low water level fluctuations (1–2 m), moderate fluctuations (2–3 m) and high water level fluctuations (>3 m). The study area is dominated by low water levels fluctuations, which is controlled by the recharge of groundwater, surface irrigation and low frequency dug wells causing a less groundwater withdrawal. High water levels fluctuations are caused by the mining of groundwater during non-monsoon season for irrigation purposes (Khadri and Deshmukh, 1998).

CONCLUSIONS

The geomorphic and morpho-tectonic evolution of landscape in the study area has been controlled by various parameters like hydro-geomorphological, lithological, structural, climatic and environmental factors. The landforms have been resulted from various geomorphic processes like erosion, deposition, faulting, upliftment, tilting and pediplanation. The topographical profiles reveal the presence of marked flat terraces at 350 m, 600 m and 1050 m, indicating the sequence of events, which have resulted during the geomorphic and morpho-tectonic evolution of the landscape (Figure 7). The lithological variations have caused undulations in the topography. The results indicate various topographic forms developed by intrusive phase of the igneous activity offer more resistance to weathering and erosion, which are represented by the presence of linear ridges breaking the monotony of the plains. The result of the drainage analysis indicates hydro-geological conditions of the study area, which is more suitable for groundwater exploration with high drainage frequency.

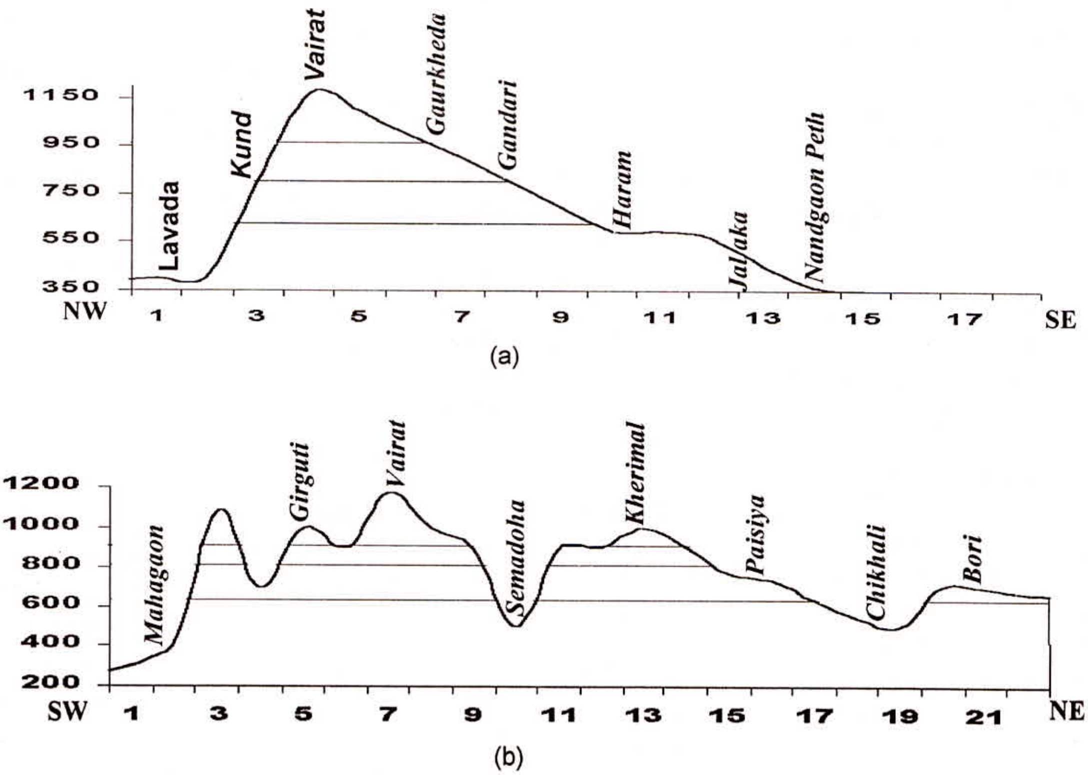

Fig. 7: (a) NW-SE, (b) SW-NE and (b) W-E topographical profiles through the Lava pile showing marked flat terraces

ACKNOWLEDGEMENTS

The authors are thankful to Late Dr R.S. Ayyangar, Mr. Y.D. Khare and Mr. Vivek. Kale from the Maharashtra Remote Sensing Application Center, Nagpur for providing the necessary remote sensing facilities. The assistance provided by Amravati University, Department of Science and Technology, University Grant Commission and Indian Council of Agricultural Research are thankfully acknowledged. We also thank the anonymous reviewers for their valuable suggestions and constructive comments that have certainly helped in improving the quality of the manuscript.

REFERENCES

Applied Hydrology (Ed. Ven Te Chow). Mcgraw Hill Book Company, New York.

Horton, R.F. (1945). Erosional development of streams and their drainage basins, hydrological approach to quantitative morphology, Geol. Soc. mer. Bull. 56: 275–370.

Khadri, S.F.R. and Deshmukh, M.S. (1998). Geomorphological characteristics of Pohara region, Amravati Dist. (M.S.) with emphasis on water resource management, workshop on G.W recharge and management in Wardha River basin, Organized by water irrigation commission, Govt. of Maha. 25–26 June, Amravati, 31–38.

Raju, T.S. and Jha, B.M. (1990). Relationship of Base Flow and geohydrological properties of Bina River Basin; Hydrology Jour. IAH. XIII(2), 55–72.

Sankar, K., Jegatheisan, M.S. and Balasubramanian, A. (1996). Geoelectrical Resistivity studies in the Kanyakumari District, Tamil Nadu. Jour. of Applied Hydrology. IX(1&2), 83–90.

Schumm, S.A. (1975). Evolution of drainage systems of geomorphology; Bull. Geol.Soc. America, 67: 597–646.

Strahler, A.N. (1952). Dynamic basis of geomorphology; Bull. Geol. Soc. America; 63, 923–938.

Strahler, S.A. (1964). Quantitative geomorphology of basin and channel networks. Handbook of

Tiwari, M.P., Bhai, H.Y. and Padhi, R.N. (1996). Geomorphology and geology of Purna.

Valley. Symposium Vol. Vishweshvarayyah Regional College of Engineering, Nagpur, 11–20.

Wisler, C.O. and Brater, B.F. (1959). Hydrology, John Willey and Sons, New York. 408.