

Temporal geoelectric behaviour of dyke aquifers in northern Deccan Volcanic Province, India

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Vertical electrical resistivity soundings (VES) were carried out over four major dykes of Nandurbar district in the northern Deccan Volcanic Province (DVP) of Maharashtra to investigate the subsurface geological conditions, with an aim of identifying zones with groundwater resource potential. Dykes can act as pathways or barrier to the groundwater flow depending upon the intensity of fracturing in the dyke rock. Whether the dykes act as water conduits or as barriers depends on their structure, location and orientation with respect to the groundwater flow. The Nandurbar district is known for occurrence of dykes and dyke swarms. A total of 33 dykes were demarcated in the study region and four major dykes (D4, D5, D6, and D7) from these were chosen for detailed VES studies. Data were acquired over these four dykes during pre-monsoon and post-monsoon periods to observe the seasonal variation in groundwater movement. These studies revealed changes in field characters, their attitudes, thickness and structure of the dykes. Longitudinal geoelectrical sections along these dykes demonstrated carrier as well as barrier stretches which identified potential aquifers up to depths of 25–30 m below which hard and compact rock exists. These studies also indicated that dykes with sufficient width, length and favourable hydrogeological structure form potential aquifers for the occurrence and movement of groundwater in the study area.

1. Introduction

Dykes are important features commonly occurring in the Deccan Volcanic Province (DVP). Importance of dyke features in hydrogeological set-up of the hard rock terrain like DVP is not clearly known. The dykes from DVP (figure 1) have been studied largely from the point of view of mineralogy, geochemistry (Sethna *et al* 1996; Melluso *et al* 1999), their mode of emplacement, their phases of intrusion (Auden 1949; Beane *et al* 1986) and palaeomagnetism (Subbarao *et al* 1994; Prasad *et al* 1996; Patil and Rao 2002). Therefore, the role of dykes in the occurrence and movement of

groundwater is a topic of challenge to hydrogeologists. However, information on the relationship of dykes in the occurrence and movement of groundwater is very limited (Singh and Jamal 2002; Babiker and Gudmundsson 2004; Duraiswami 2005). In areas with acute shortage of water, the need for locating additional sources of groundwater for exploitation is felt and it is felt almost all over the Deccan Plateau. The purpose of the present work is to study the aquifer conditions such as depth and nature of the dykes, boundaries and location of the potential aquifers for groundwater using electrical resistivity technique.

Keywords. Resistivity; deccan dykes; aquifers; Nandurbar.

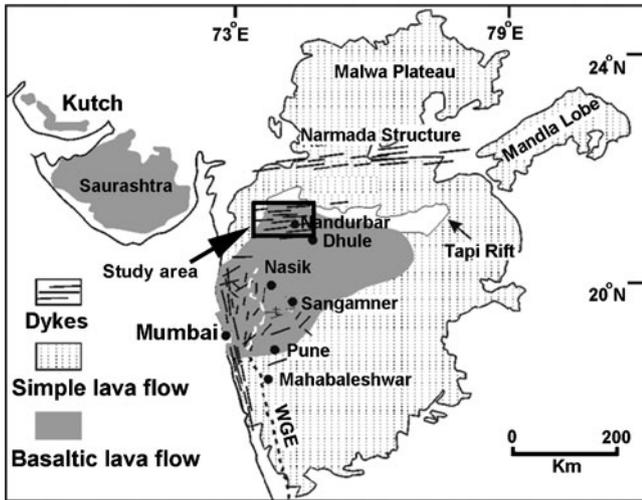


Figure 1. Geological map of the Deccan Volcanic Province showing the dykes. Also shown here is the study area.

2. Geology of the region

Numerous doleritic dykes intrude the basaltic lava flows in the study area (figure 2a). Dykes can act as pathways or barrier to the groundwater flow depending upon intensity of fracturing in the

dyke rock (Babiker and Gudmundsson 2004). Whether the dykes act as water conduits or as barriers depends on their structure, location and orientation with respect to the groundwater flow (Singh and Jamal 2002; Nilsen *et al* 2003; Babiker and Gudmundsson 2004). The Dhule and Nandurbar districts of Maharashtra, of which study area is a part, is known for occurrence of dykes and dyke swarms (GSI 2001; CGWB 2009). Field observations in the area show that parallel to unparallel bodies of dykes are intruding basaltic flows and forming linear ridges of moderate relief. Majority of dykes is partially exposed and partially concealed, while some are exposed only in stream, well and road cuts. Topography of the study region is partly controlled by dykes. In order to indicate the influence of dykes on occurrence and movement of groundwater, systematic geophysical studies by vertical electrical resistivity soundings (VES) was undertaken. A total of 33 dykes were mapped by taking traverses in the field besides using toposheets and satellite images. Detailed geophysical investigation was carried out over four major dykes, D4, D5, D6 and D7 (figure 2b). Geological mapping revealed field characters of dykes, their attitude, thickness and structure besides emphasis

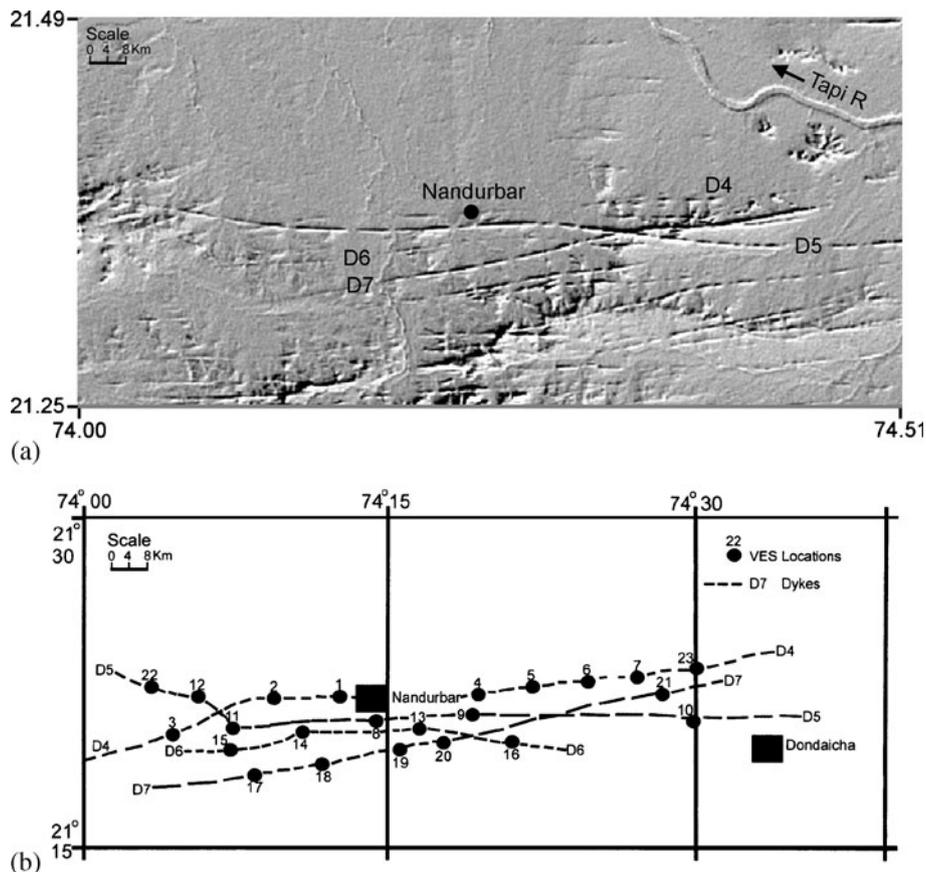


Figure 2. (a) DEM of the area based on SRTM data (after Jarvis *et al* 2006) showing regional dykes from the area. (b) Location map of the study area showing the VES sounding points.

on hydrogeological, geophysical and structural aspects that are important for groundwater occurrence and flow.

3. Hydrogeological characteristics of the study region

The major part of the Nandurbar district is covered by basaltic flows commonly known as Deccan Traps and dykes of Upper Cretaceous–Lower Eocene age (Duncan and Pyle 1988). Tapi alluvial deposits are observed in Tapi River valley occupying parts of Taloda, Shahada and Nandurbar regions. Along the north-western corner of the district, pre-trappean Bagh beds of Middle to Upper Cretaceous age are exposed over a small area along

the valley. A map depicting the hydrogeological features is shown in figure 3(a, b).

As mentioned earlier, Deccan Trap includes several flows of basalt which are supposed to have extruded from fissure volcanoes. The flows are mainly of two types, i.e., ‘Pahoehoe’ and ‘aa’ types, the former being very common. The flows have been intruded by large number of doleritic dykes. The dykes are aligned in an E–W to ENE–WSW direction and a few have N–S or WNW–ESE trends (Deshpande 1998).

Alluvial deposits of Tapi River valley occurs in long narrow basin, which are probably caused by faulting. It consists of clays, silt, sand, gravels and boulders. These deposits are encountered down to 100 m depth. In this region, the groundwater occurs under unconfined conditions in the near surface

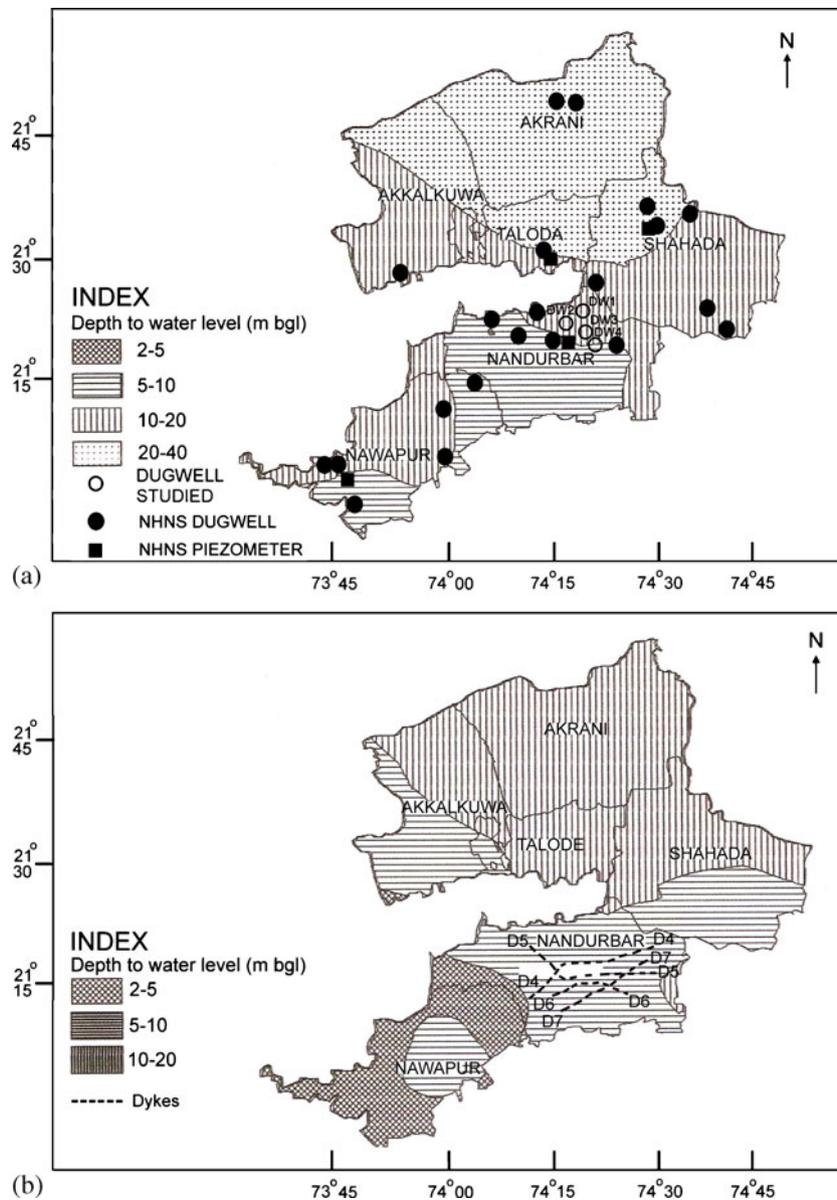


Figure 3. Hydrogeological map of Nandurbar and surrounding regions during (a) pre- and (b) post-monsoon periods. Also shown in the figure are the location of dug wells and dykes under study.

strata down to the depth of 20 m in the weathered zone of the vesicular/amygdaloidal basalt, jointed and fractured units of massive basalt. Groundwater occurs under semi-confined to confined conditions generally below 40 m depth beneath the red bole and dense massive basalt in the fractured or jointed massive/vesicular/amygdaloidal basalt. On the elevated plateau tops having good areal extent, local water table develops in topmost layers and the wells in such areas show rapid decline of water levels in post-monsoon season and go dry during peak summer. In the foothills zone, the water table is relatively shallow near the water courses and deep away from it and near the water divides. In the valleys and plains of river basin, the water table aquifer occurs at shallow depth and the wells in such areas do not go dry and sustain perennial yield except in extreme summer or drought conditions. The yield of the dug wells in this region varies from 60 to 200 m³/day, whereas that of bore wells varies from 2 to more than 20 m³/hr, however in most of the bore wells it ranges between 2 and 10 m³/hr. The yield of the tube wells ranges from 20 to 250 m³/hr. The yield of exploratory wells ranges from 34 to 940 m³/hr (CGWB 2009).

Periodic monitoring of National Hydrograph Network Stations (NHNS) in Nandurbar district has been carried out during pre-monsoon and post-monsoon periods (CGWB 2009). These studies reported depth to water level between 5 and 10 m bgl during pre-monsoon of 2007 in parts of Nandurbar area. The water levels are thus mostly confined within the alluvials. During post-monsoon of November 2007, the depth to water levels is observed to be between 3 and 20 m bgl.

There are mainly two types of groundwater abstraction structures in Nandurbar district, i.e., dug wells and bore wells/tube wells, however, the yield of wells vary according to nature of formation tapped and its saturated thickness. Dug and bore wells are the primary source of water supply and groundwater withdrawal is confined to vesicular, weathered, jointed and fractured upper basaltic crust. Dug well sections were studied at four locations in the near vicinity of Nandurbar division from 2005–2010 for both pre- and post-monsoon periods (figure 3a). The dug wells are DW1 (Akrale, depth 9 m), DW2 (Vavad, depth 11.5 m), DW3 (Dhandhane, depth 8 m) and DW4 (Shani Mandal, depth 14 m). It is observed that the static water levels in all the wells vary from 6–12 m bgl during pre-monsoon, whereas the water levels vary from 3–14 m bgl during the post-monsoon season. Therefore, the dug wells located in the topographic lows, morphological depressions and on or near the lineaments yield comparatively more water than that located elsewhere, which is

particularly true in basaltic terrain. The yield of dug well also varies depending on the season (Pawar et al 2008).

4. Aim of the study and data acquisition

The electrical resistivity survey is based on measuring the potentials between one electrode pair while transmitting direct current (DC) between another electrode pair. The depth of penetration is proportional to the separation between the electrodes, in homogeneous ground, and varying the electrode separation provides information about the stratification of the ground (Dahlin 2000). As mentioned earlier, four major dykes (D4, D5, D6 and D7) were selected for detailed resistivity sounding. A total of 43 vertical electrical resistivity soundings were conducted over these dykes in the study area during the pre-monsoon and post-monsoon phases (figure 2b) using the Schlumberger configuration with an electrode half space of 100 m. The IGIS signal stacking based Signal Enhancement Resistivity Meter (Model: SSR-MP-AT-S) data acquisition system was used to acquire the data. The main aim of conducting the resistivity survey was to identify nature of dykes as to whether they are carrier or barrier type, delineate the conduit and barrier type stretches of dykes, estimate the depth to which dykes has potential to store and transmit water and to develop a conceptual model of groundwater flow and study the effects of dykes. By adopting VES technique, detailed information on the vertical changes in the lithological succession of dykes and various conducting zones within them were deciphered on the basis of their apparent and true resistivities.

5. Methodology

The dyke length, width, its orientation and its structure has direct bearing on groundwater storage and transmission. However, their petrochemistry affects the groundwater quality characteristics. Thus, in the present study, dyke lengths were measured from satellite images and toposheets and verified in the field. The width, attitude and structural parameters were studied at different segments and averages were taken. Geological mapping of the 33 dykes revealed field distinctiveness of dykes, their attitude, thickness and structure above and beyond hydrogeological and structural facets that are important for groundwater occurrence and flow. After visual observations of dykes at road cuttings and excavations, four of them were chosen for detailed geophysical investigations.

In all, 43 electrical resistivity soundings were conducted during the pre-monsoon and post-monsoon periods. The resulting geoelectrical layer succession obtained was used for predicting different conducting zones on the basis of true resistivities. The apparent resistivity was calculated using the Schlumberger configuration (Kearey and Brooks 1988) as:

$$\rho_a = \pi [(L/2)^2 - (b/2)^2] / b * V/I$$

where, L and b are the current and potential electrode spacing respectively. The data obtained from the field was processed and modelled using IPI2WIN software, version 3.0.1.a7.01.03 (Bobachev 2003) for interactive semi-automated interpretation. The geo-electrical cross-sections were generated to understand 2-D geometry of the aquifer developed along the regional dykes D4, D5, D6 and D7 for the pre- and post-monsoon periods as shown in figures 4–7.

6. Results and discussions

The apparent resistivity data was used for preparing the longitudinal geoelectrical sections along the dykes (D4, D5, D6 and D7) from the study area. The objective of making these subsurface sections was to create comprehensive subsurface hydrogeological picture of these four dykes which may be helpful in groundwater exploration, exploitation and management programs.

East-west trending dykes are more dominant than the others trending NW–SE. Nearly all dykes follow straight course with pinching and swelling. Regional dykes D4 and D5 are intersecting at the western end of the region whereas the dykes D5, D6 and D7 intersect each other at several places towards the eastern flank (figure 2b). Length of all the four dykes varies from 23–36 km and widths measuring between 40 and 200 m.

The apparent resistivity (ρ_a) *vs.* half of the current electrode separation ($AB/2$) on log-log graph suggests much variation in curve types, reflecting

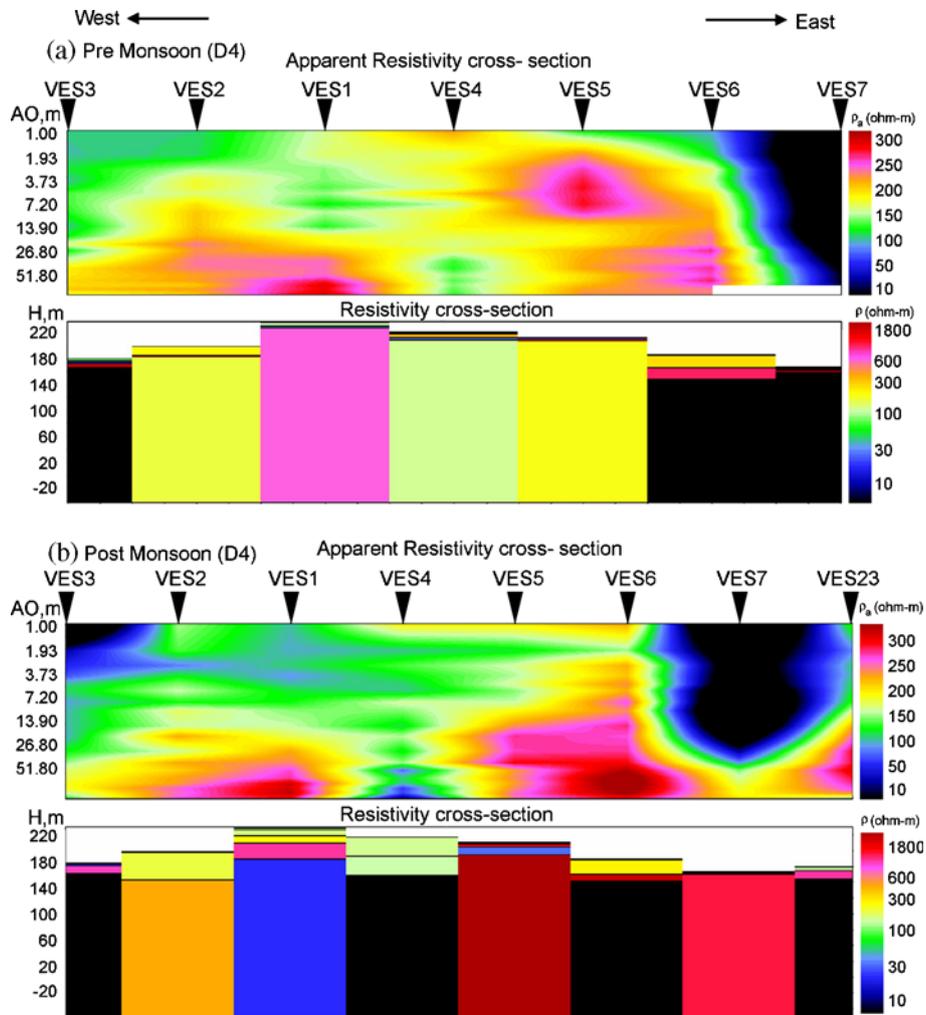


Figure 4. Geoelectric cross section along Dyke D4 during (a) pre- and (b) post-monsoon periods.

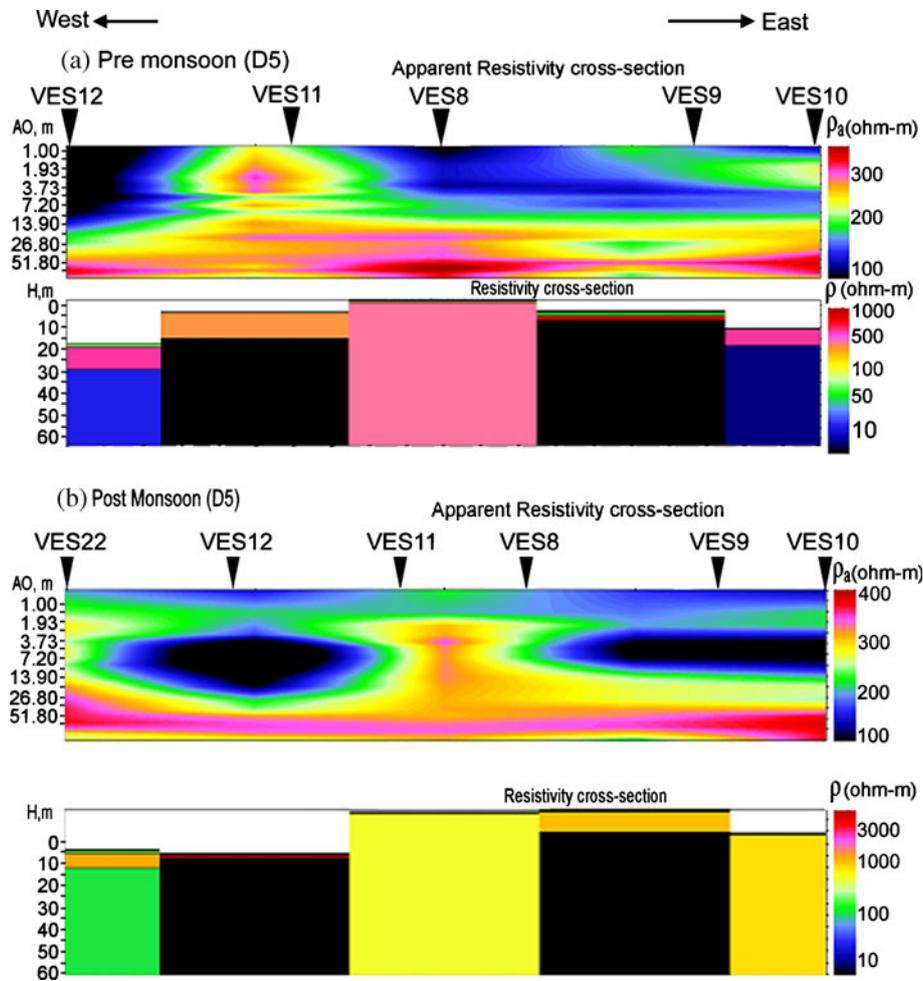


Figure 5. Geoelectric cross section along Dyke D5 during (a) pre- and (b) post-monsoon periods.

4–5 layered sub-surface medium (table 1). As these dykes are discrete and distinctive bodies cutting across fairly homogeneous basaltic host rocks, the VES data points were collected along their strike. Apparent resistivity data were used for preparing longitudinal geoelectrical sections along D4, D5, D6 and D7 (figures 4, 5, 6 and 7). Longitudinal geoelectrical section along the dykes (figures 4, 5, 6 and 7) exhibits 2-D geometry of shallow aquifers (up to 25–30 m) epitomized by intermittent presence of bowl-shaped low conductivity depressions (aquifer bodies). The aquifers were identified based on true resistivities of the conducting zones (table 1).

Longitudinal geoelectrical section along D4 (figure 4a and b) shows that the stretch of dyke passing through VES 6 and 7 is of carrier type having resistivities of the order of 10–50 Ωm and VES 3, 2, 1, 4 and 5 is of barrier type in the pre-monsoon campaign. It was noticed that the potential aquifer observed below VES 6 and 7 at depth ranging from 1 to 30 m was not completely seen. In order to establish the entire potentiality of the aquifer zone, an additional VES sounding (No. 23) was carried out at the eastern part during the post-monsoon

campaign. It is seen in the post-monsoon period that the complete carrier stretch exists between VES 6, 7 and 23 up to depths of about 30 m. It can further be inferred from the figure that VES 3 (post-monsoon) is favourable for the development of a shallow aquifer (15 m). Moreover this low-lying (180 m amsl) site is augmented by lateral flow from adjacent higher site (199 m amsl) VES 2. It is pertinent to mention here that besides lateral and vertical recharge, presence of favourable hydro-geological structure (fairly thick conductive layer above an impervious layer) is indispensable for the development of an aquifer. Absence of such a litho-environment could be the reason for not forming an aquifer at VES 5. Nevertheless, this site seems to have augmented the adjacent VES 4 at deeper levels below 60 m (figure 4b).

Similarly, the geoelectrical section along D5 (figure 5a and b) in the pre-monsoon phase indicates an incomplete carrier stretch at VES 12 and barrier at VES 11. Below VES 8, 9 and 10, a noticeable flow of groundwater is observed. During the post-monsoon period, an additional VES (No. 22) was sounded to the west of VES 12. This helped

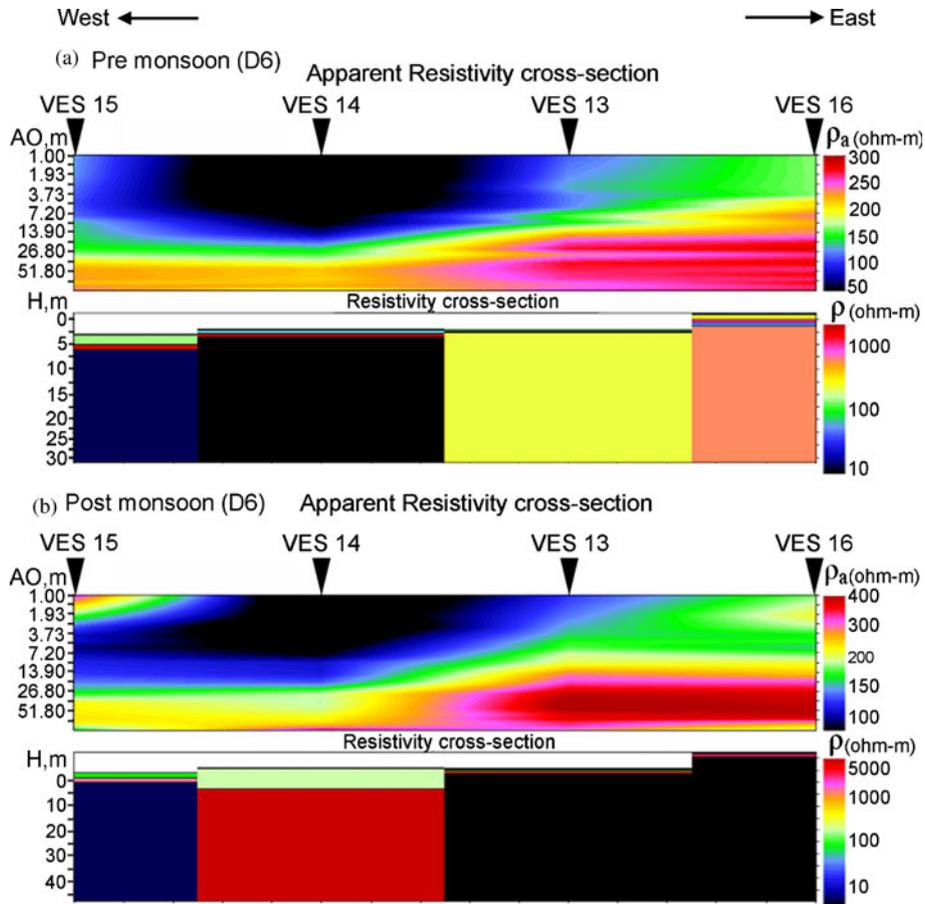


Figure 6. Goelectric cross section along Dyke D6 during (a) pre- and (b) post-monsoon periods.

in getting the complete carrier stretch below VES 12 with resistivities of about 100 Ωm at depth of 5–25 m. Another localized carrier stretch is also observed below VES 9 and 10 at depths of 5–7 m. It was observed that there was movement of groundwater from VES 8 towards VES 10 during pre-monsoon. During post-monsoon, the stretch below VES 9 and 10 got recharged due to lateral and vertical transmission of water. It should also be noted that large lateral distance between VES 9 and 10 (figure 2b) because of field constraints and thus no controlling points in between have any bearing on data consistency.

During the pre-monsoon period over the dyke D6 (figure 6a), a clear carrier stretch is observed below VES 15, 14 and 13, at depths of 1–10 m having resistivities of about 10–50 Ωm . Whereas during the post-monsoon period (figure 6b), the same stretch is observed with a movement of groundwater towards east. For both pre- and post-monsoon, a barrier stretch is observed below VES 16. Here VES 15 is recharged due to vertical flow of water. Also VES 15 is receiving additional water through lateral recharge from adjacent higher site VES 14. Also from figure 6, it seems that there is neither lateral nor vertical recharge of water at VES 13 and

VES 16, resulting in wet zones (VES 13) or poor development of aquifer (VES 16).

The goelectric sections over dyke D7 for both pre- and post-monsoon phases (figure 7a and b) show carrier stretches below VES 17, 18, 19 and 20 with high potential zone below VES 17 and 18 with thickness ranging from 1 to 10 m. There is also an indication of groundwater flow in both east and west direction of this dyke. VES 17 is recharged due to vertical transmission of water and receiving additional water through lateral recharge from VES 18 which is at a higher position. Only lateral recharge is evident at VES 19. There was not enough controlling VES points between VES 20 and 21 due to lack of availability of sounding sites.

As mentioned earlier, an intrusive body like dykes may act as conduit or barrier for groundwater movement and occurrence (Singh and Jamal 2002; Tam *et al* 2004; Babiker and Gudmundsson 2004). A single dyke may also act as carrier or barrier with respect to occurrence and movement of groundwater (Bondre *et al* 2004; Duraiswami 2005). Thus to identify a dyke as carrier or barrier type, the intensity of jointing and fracturing becomes a key factor (Singh and Jamal 2002; Bondre *et al* 2004). The barrier dykes cannot store

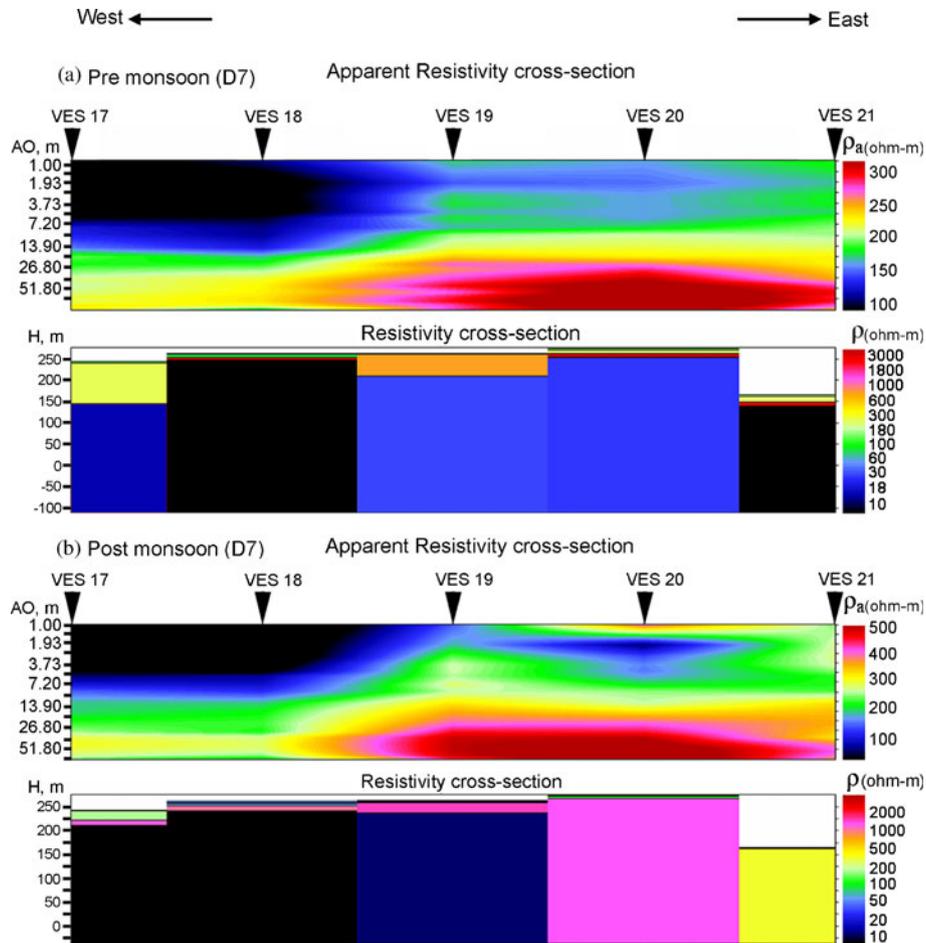


Figure 7. Geoelectric cross section along Dyke D7 during (a) pre- and (b) post-monsoon periods.

and transmit the water, but they act as underground dams wherein area in the upslope of the dyke shows presence of groundwater. Therefore these dykes are good locales for construction of Minor Irrigation Tanks (Duraiswami 2005). Under such conditions the water table in the upslope of dykes become very shallow (<12 m) and in down slope areas it is as deep as 80 m (Duraiswami 2005). The width of dykes varies as also the length, both affecting the storage characteristics.

Doleritic and gabbroic dykes have been encountered and mapped from the study area in Nandurbar region. However, the doleritic dykes are more suitable for groundwater occurrence because of its deeper depth of weathering, close spaced jointing and moderate hardness. In the Nandurbar region both types of dykes have control over the occurrence and movement of groundwater as these are tapped by high yielding wells (CGWB 2009). Here the major dykes have a length of 23–36 km in the study area. Most of the dykes in this region are in EW direction and show variable width ranging from 40 to 200 m due to pinching and swelling character. This makes them potential aquifer zones for groundwater. Hence, they can be recognized as

separate aquifers in this area because they possess sufficient width, length and favourable hydrogeological structure to yield enough quantity of water. The two season resistivity data provide a comprehensive picture of the groundwater occurrence, movement and seasonal recharge. The information is imperative as it has sound implications on groundwater management. Based on true resistivities and thicknesses of the layers, along with their seasonal behaviour, suitable sites for groundwater exploitation could be VES 3 (post-monsoon), VES 4 (deeper aquifer, 60 m, post-monsoon), VES 9 (post-monsoon), VES 12 (pre- and post-monsoon), VES 15 (pre- and post-monsoon), VES 17, 18 and 19 (pre- and post-monsoon) and VES 23 (post-monsoon). Thus almost 50% of the VES sites investigated comprise prospective aquifers either during post-monsoon or during both the seasons. Considering the groundwater flow paths during post-monsoon, artificial recharge wells may be built to tap the surface runoff at sites VES 10, 14 and 18. Furthermore, recharge structures at VES 2, 3, 10, 12, 15 and 17 would either augment the aquifers beneath or at adjacent sites. This, to a certain extent, would ensure the sustainability of potable

Table 1. *VES data for dykes in Nandurbar area.*

Long.	Lat.	VES	E	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h1	h2	h3	h4	h5	Curve
Pre-monsoon VES data														
74.21	21.37	1	235	82	562	108	39	650	0.29	0.15	5.41	2.27	–	KQH
74.15	21.36	2	199	293	20	212	1357	162	0.30	0.23	13.1	2.9	–	HAK
74.07	21.33	3	180	85	418	21	2072	2	2.74	1.10	3.53	7.41	–	KHA
74.32	21.37	4	221	686	49	331	71	345	0.35	0.31	0.91	1.75	5.55	HKH
74.37	21.38	5	213	37	3616	26	1998	192	0.27	0.57	2.68	2.64	–	KHK
74.41	21.38	6	186	70	253	1033	2	–	1.01	19.7	17.3	–	–	AK
74.45	21.39	7	167	27	4	62	3	3341	0.57	0.60	1.09	3.34	2.06	HKH
74.24	21.35	8	259	41	286	25	171	438	0.26	0.55	0.33	3.48	–	KHA
74.32	21.35	9	236	187	40	1341	59	1577	1.68	1.24	1.95	6.16	10.9	HKH
74.50	21.36	10	197	42	1303	20	665	8	0.25	0.40	0.98	36.6	–	KHK
74.12	21.34	11	233	190	1219	26	341	3	0.77	0.64	0.51	56.0	–	KHK
74.09	21.36	12	163	17	72	651	15	–	0.10	6.96	50.5	–	–	AK
74.27	21.34	13	229	108	38	4674	213	–	2.96	1.12	1.67	–	–	HK
74.18	21.34	14	230	85	33	54	2295	4	0.23	1.51	6.42	7.94	–	HAK
74.12	21.32	15	220	117	24	126	2180	11	1.84	0.27	18.2	10.8	–	HAK
74.35	21.33	16	261	145	289	1052	44	594	2.44	9.16	6.53	7.41	–	AKH
74.14	21.30	17	244	96	13	119	227	7554	0.59	0.37	3.19	95.9	–	HAA
74.19	21.31	18	262	157	56	74	2047	2	0.36	1.75	6.03	7.38	–	HAK
74.26	21.33	19	263	396	31	441	31	645	0.36	0.28	0.84	1.09	50.2	HKH
74.29	21.33	20	264	367	125	215	11324	27	0.16	3.73	8.00	8.47	–	HAK
74.47	21.37	21	165	155	214	2760	6	–	3.54	13.6	9.50	–	–	AK
Post-monsoon VES data														
74.21	21.37	1	235	117	150	258	1132	19	2.63	8.84	12.5	26.1	–	AAK
74.15	21.36	2	199	177	27	195	474	–	1.06	0.31	44.4	–	–	HA
74.07	21.33	3	180	11	2025	21	1054	6	0.26	0.39	2.95	11.6	–	KHK
74.32	21.37	4	221	574	41	144	133	4	0.35	0.19	29.3	30.5	–	HKQ
74.37	21.38	5	213	661	44	455	43	1654	0.33	0.36	0.75	1.48	4.67	HKH
74.41	21.38	6	186	1666	36	262	2396	4	0.27	0.20	23.0	10.8	–	HAK
74.45	21.39	7	167	10	487	6	295	1379	0.27	0.31	1.89	1.75	–	KHA
74.32	21.35	9	236	147	647	23	591	4	0.68	0.50	0.97	34.7	–	KHK
74.50	21.36	10	197	60	1109	25	10386	465	0.27	0.39	1.34	0.27	–	KHK
74.12	21.34	11	233	1077	39	1393	71	328	0.29	0.26	1.03	0.74	–	HKH
74.09	21.36	12	163	67	946	14	5317	6	0.28	0.48	1.51	5.43	–	KHK
74.27	21.34	13	229	115	198	109	4977	2	1.17	2.38	2.04	5.95	–	KHK
74.18	21.34	14	230	23	146	17	208	65384	0.25	0.39	0.83	42.4	–	KHA
74.12	21.32	15	220	2760	358	89	1852	5	0.21	0.71	10.5	8.58	–	QHK
74.35	21.33	16	261	82	880	32	4032	2	0.27	0.43	1.14	5.89	–	KHK
74.14	21.30	17	244	49	193	1349	4	–	2.33	19.8	10.2	–	–	AK
74.19	21.31	18	262	45	1550	61	1122	2	3.02	1.32	5.10	11.1	–	KHK
74.26	21.33	19	263	109	856	47	1771	11	1.23	0.87	2.08	22.3	–	KHK
74.29	21.33	20	264	2649	33	2411	125	1443	0.31	0.65	0.16	5.74	–	HKH
74.47	21.37	21	165	174	618	46	5551	324	0.92	0.58	1.60	0.44	–	KHK
74.05	21.37	22	–	185	730	143	735	94	1.08	0.86	4.74	24.2	–	KHK
74.50	21.39	23	–	440	44	120	1165	2	0.30	0.15	6.54	13.2	–	HAK

E: elevation amsl.

water resources in scarcity affected villages. Thus from the present study, it is inferred that the dykes D4, D5, D6 and D7 are partly acting as conductors and partly as barriers. Scaling up of similar efforts in other regional dykes will go a long way towards the sustainability of valuable drinking water resources.

7. Conclusions

Resistivity studies conducted over four major dykes (D4, D5, D6 and D7) quantifies the occurrence and movement of groundwater in Nandurbar region during the pre- and post-monsoon phases. These studies have indicated that dykes form

potential aquifers, as they possess adequate width, length and favourable hydrogeological configuration. These studies also suggest that dykes have formed separate potential aquifers in the region. Also the regional dykes in this region show significant effect on the groundwater occurrence and flow depending upon their trends in relation to the local hydraulic gradient and steepness of the slope. It can also be surmised that smaller dykes have little influence on the groundwater flow, at least in the hilly parts of the study area. A single dyke can behave as carrier or barrier along its length, a finding, which differs from previous studies which report them either completely carrier or barrier type.

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