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VERTICAL ELECTRICAL SOUNDING FOR ARTIFICIAL RECHARGE TO GROUNDWATER: A CASE STUDY IN DECCAN VOLCANIC PROVINCE, MAHARASHTRA, INDIA

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Abstract:
The study area is a small part of territory of Alate Village in Deccan Volcanic Province, Maharashtra, India. Vertical Electrical Sounding (VES) studies were carried out for assisting selection of sites for bore wells and dug wells in farmlands of local farmers. Certain deeper strata that were interpreted as confined aquifers were found to be unproductive on drilling. Many such bore wells are left unused in this area. It was contemplated that these strata were aquifers receiving insufficient natural recharge. Attempt was made to check the possibility of 'bore well flooding' to augment the natural groundwater recharge to such unproductive aquifers. Nine unused bore wells in the area were identified as possible injection wells. Six open wells were recognized as source of water for injection and storage space in the sub-surface was identified by correlating the VES data. On this basis suggestions are made to tackle the problem of water scarcity in this area.
Keywords: Deccan Volcanic Province, Aquifer, Artificial Recharge, VES, Bore well flooding, Injection well.

Introduction:

An attempt was made in this work to find out whether unused boreholes could be used as injection wells for artificially recharging the dry aquifers and suggest some plan for the same. This exercise was aimed at solving the problem of water scarcity in the area.

The Area

The village Alate appears in the 'Survey of India Toposheet' no. 47 L/5 at co-ordinates $16^{o}46^{'}20^{"}$ N and $74^{o}24^{'}17^{"}$ E **(Figs. 1 and 2).** The area of this village forms part of the mini watershed 1/5 of 'Kabnoor Odha' within the Watershed No. 55 of the Groundwater Surveys and Development Agency (GSDA) of Maharashtra.

Topographically the area is located in the hilly terrain of eastern extension of the Sahyadri Mountains. The hills of moderate size show flat tops that are typical of the plateau basalts of the Deccan Traps. The smaller hills show rounded tops. The height of hills in the area ranges from 700 to 800 m. The village Alate is situated at about 600 m from MSL.

Water resources scenario in the area

All the streams in this area are seasonal. There is no perennial source of surface water in the area. Agriculture is the main activity in the area. It depends solely on groundwater after monsoon. The water table in the area lowers rapidly after monsoon due to pumping out from the unconfined as well as confined aquifers. In summer season, supply of water from wells is not assured.

Methodology:

Geological field work including well inventory and Vertical Electrical Soundings at selected locations were carried out for assisting farmers in selection of sites for bore wells.

Geology

Geologically the area falls in the southern part of the Deccan Volcanic Province (DVP) of Peninsular India. The area under study forms a part of the Mahabaleshwar Formation of Wai Sub-group of Deccan Trap Group. 'Aa' type simple flows are exposed in outcrops and sections. The basalts can be further classified as compact and vesicular.

The compact basalt is dark grey to black in colour, fine grained dense, hard and tough. Well jointed compact basalt serves as a good aquifer. The vesicular / amygdaloidal basalt is reddish or violet in colour. This rock if weathered serves as a good aquifer. The exposed vesicular / amygdaloidal basalt is more prone to weathering than the compact jointed basalt. The depth of weathering varies from 0.25m to about 7 m.

The Red Bole occurs as thin layers of clayey material between lava flows. The thickness and lateral extent of red bole is generally small. In this area this rock is found to serve as good aquifer. The joints and fracture pattern in compact basalt, depth and thickness of vesicular basalt and extent of weathering are the important factors that play major role in the occurrence and movement of groundwater in these rocks. The thickness and physical characters of lava flows in the area is given in Table 1.

Hydrogeology

The aquifers are generally thin and discontinuous having limited storage capacity. At shallow depth, groundwater occurs in unconfined aquifers and in perched bodies. At greater depths, buried zones of weathering (disconformities), red bole layers, weathered flows of vesicular / amygdaloidal basalt, and fracture zones in compact basalt constitute confined /semi-confined aquifers. They are tapped by bore wells.

Vertical Electrical Sounding (VES)

VES were carried out with a D. C. Resistivity meter – Model DDR-3 - developed by Integrated Geo Instruments and Services (IGIS), Hyderabad. Wenner array was used for electrode spacing. Interpretations were made using 'Inverse Slope Method' (Sankar Narayan and Ramanujachary, 1967). The VES data obtained at selected locations is given in Table 2.

The standardised values of resistivity used for interpretation in this area are given in Table 3. There has been reasonable conformity between these interpretations and the litho-logs reported by farmers after drilling their bore wells.

RESULTS AND Discussion:

For convenience of study the area is divided into five parts (Fig. 3) as listed below.

Part I: Vipashyana Kendra- Kunthugiri-Sankana Farm.

Part II: Kaundade-Badgujar-Satpute farm.

Part III: Bhimnagar.

Part IV: Kothawale farm.

Part V: Majalekar- Jangonda-Nagave farm.

The observations on geology of the area are described below with reference to these parts.

Part – I: Vipashyana Kendra- Kunthugiri-Sankana Farm

There are few open wells in this part. The water table in them is raised to near surface in monsoon. Their yield is satisfactory till the month of March. Water table is lowered below the well bottom in April-May .Generalised interpreted section based on VES in Part I is given in Table 4.

Part - II: Kaundade-Badgujar-Satpute farms

The open wells in this area are productive only seasonally. The water table in these wells fluctuates from near surface in monsoon to below the well bottom in April-May. Generalised interpreted section based on VES in Part II is given in Table 5.

Part - III: Bhimnagar

The number of dug wells in this part is more than that in other parts. The unconfined aquifer is relatively thick. The water table rises to near surface in monsoon. The wells are good yielding in post-monsoon season too. In the late summer / pre-monsoon season the water table falls below the well bottom.

Part - IV: Kothawale farm

There are only two open wells in this part. These two well are only seasonally productive. In summer months the water table lowers down to the well bottom and the well yield supports only the domestic needs of the farm-hut. Generalised interpreted section based on VES in Part IV is given in Table 6.

Part – V: Majalekar – Jangonda - Nagave farms

This part is relatively rich in groundwater as the depth of weathering and the thickness of unconfined aquifer is considerably greater as compared to other parts. There are many dug wells along the stream banks. The yield is good and continues for long time after the monsoon. Generalized interpreted section based on VES in Part Vis given in Table 7.

Proper recognition of subsurface storage space, availability of surface water for injection and planning of injection wells are the important factors in exercising this technique. Observations indicate that all these factors are favourable in the study area.

Aspects of artificial recharge

1. Availability of injection wells and
2. Availability of water for injection.
3. Availability of suitable storage zones in the subsurface

Availability of injection wells:

The following dry or poor-yielding nine bore wells that are not in use can be used as injection wells without incurring additional expenditure (Figs. 3 and 4).

1. Vipashyana Kendra area: Four bore wells south of locations 22 and 23
2. Sankana farm VES -1: One bore well at location 12,
3. Kaundade farm- VES – 3: One bore well at location 9,
4. Annasaheb Patil farm - VES- 4: One bore well at location 11,
5. Badgujar farm- VES – 5: One bore well at location 10, and
6. Kothawale farm- VES – 7: One bore well at location 16.

Availability of water for injection

a) Dug wells

During monsoon the water table in open wells is raised to near surface in all the above parts of the study area. Water from these wells is not required for crops of the 'Kharip season' during monsoon. It remains unused. With the passage of time, the water table lowers naturally, mainly due to groundwater movement in downstream direction. Thus the water from unconfined aquifer is lost to stream flow, without any use. This surplus water from the wells can be used for injecting into the dry or seasonally productive bore wells before it is lost to the stream flow. During late monsoon period the surplus water in following six dug wells can be used for injection.

Part I – Wells at Locations 21 and 38.

Part II – Wells at Locations 8, 10, and 11.

Part IV - Well at Location 16.

b) Surface water conservation structures

The streams in the area are small and seasonal. Monsoon run-off can be stored by construction of surface water conservation structures on these streams. The topography of Part I (Fig.3) is favourable for the construction of percolation tanks. Topography in Part II and III is suitable for construction of structures like nala (stream) bunds and gully plugs. Construction of traditional bunds on the stream in Part IV is also possible.

Availability of suitable storage space in the subsurface

The depth zones identified as possible productive aquifer by VES but found to be unproductive in spite of favourable rock type after drilling can provide subsurface storage space recharged water. Such dry aquifers occur at different depths. Some of them are correlated and inferred to be extensive, while others seem to be local in extent or isolated.

Experience in Part I and Part II of the study area shows that pumping from one bore well affects the other bore well seriously. This is indicative of lateral linkage of aquifers in the area. In Part IV the confining layer between the inferred aquifers is likely to be semi-confining and can serve as storages space / warehouse for water.

In Part V the inferred confined aquifers appear to merge with each other from west to east in the downstream direction. Correlation of aquifers in this part with those in Part IV reveals lateral continuity of aquifers. Thus, bore well flooding in Part IV will be useful in recharging the confined aquifers in that part as well as the unconfined and confined aquifers in Part V (Figs. 3 and 4.)

Table 1: Thickness and physical characters of lava flows observed in the area

Type No.	Elevation / Thickness	Physical Characters	Locations (Shown in Fig. 6)
1	Above 644 m MSL – Youngest in the area	Jointed compact Basalt	In the hills in west of Bhimnagar (Part III) and south of Satpute's well (Location 8)
2	Between 644 m and 628 m MSL = 16 m	Jointed compact grey- black basalt underlain by reddish brown vesicular / partially amygdaloidal red basalt of 2 to 3m.followed by greenish weathered portion of about 1 m thickness the top of lower compact basalt flow.	In the hills in west of Bhimnagar (Part III) and south of Satpute's well (Location 8)
3*	Between 628 m and 623 m MSL = 5 m	Weathered red basalt	In Satpute's well (Location 8)
4	Between 623 m and 602 m MSL = 21 m	Compact jointed basalt	In the area between Satpute's well (Location 8) and Kothawale's well (Location 16)
5	Between 602 m and 589 m MSL = 13 m	Massive unjointed basalt	In the well section of Kothawale (Location 16)
6	Below 589 m MSL – Oldest in the area	Vesicular red basalt with weathered flow top breccia	In the well sections of Kothawale (Location 16) and Jangonda (Location 27)

3*: Lateral Extension of this weathered red basalt seems to be limited in the area. Therefore, whether to call this a separate flow is uncertain.

Table 2: Electrical Resistivity data for selected locations in Alate area

Reading No	Depth in m	ρ values in Ω-m										
		VES-1	VES-2	VES-3	VES-4	VES-5	VES-6	VES7	VES-8	VES-9	VES10	VES11
1	0 to 1	5	16	12	14	25	41	15	8	9	13	5
2	1 to 2	vh	86	13	18	16	27	12	5	14	45	11
3	2 to 3	93	75	12	23	21	25	13	vh	5	31	13
4	3 to 4	331	vh	19	40	24	52	41	14	17	19	14
5	4to 5	vh	vh	21	62	42	60	41	14	16	16	17
6	5 to 6	vh	60	46	483	225	66	65	28	49	19	9
7	6 to 7	262	60	65	165	22	66	65	10	107	23	12
8	7 to 8	44	63	32	251	30	76	175	34	18	20	35
9	8 to 9	46	63	51	51	48	76	175	68	119	23	11
10	9 to 10	34	62	43	84	30	59	vh	77	68	21	20
11	12 to 14	34	62	75	78	56	72	vh	vh	262	27	31
12	14 to 16	52	31	69	63	55	79	vh	418	44	21	25
13	16 to 18	36	131	61	54	37	60	89	x	50	25	26
14	18 to 20	71	166	80	48	45	46	75	x	30	22	24
15	20 to 23	27	166	78	41	vh	43	61	x	331	29	44
16	23 to26	54	266	66	42	88	67	68	203	193	42	28
17	26 to 29	vh	63	vh	62	59	56	41	164	36	45	175
18	29 to 32	vh	78	111	34	133	49	44	145	vh	60	35
19	32 to 35	vh	78	103	36	84	34	41	75	106	45	44
20	35 to 39	120	49	105	43	103	33	31	54	46	57	58
21	39 to 43	99	46	104	vh	69	45	27	54	38	51	41
22	43to 47	95	36	141	94	89	35	33	78	vh	90	49
23	47 to 51	74	36	76	72	73	38	46	62	61	69	51
24	51 to 55	66	36	69	57	82	45	56	50	139	107	91
25	55 to 60	96	37	191	122	60	56	54	64	159	103	54
26	60 to 65	101	56	38	60	98	48	60	53	71	70	78
27	65 to 70	75	46	125	94	82	51	62	52	69	53	177
28	70 to 75	50	72	69	81	44	35	63	61	104	96	190
29	75 to 80	30	65	64	47	87	50	35	90	244	67	186
30	80 to 85	70	58	81	69	105	40	99	41	73	73	361
31	85 to 90	31	49	63	133	105	46	55	78	48	220	83
32	90 to 95	144	89	88	93	64	105	55	38	310	66	111
33	95 to 100	95	178	92	87	109	x	140	83	70	105	107

VES -6 and 7: Data modified by averaging, to suit with other data in this table.
VES-1: Location-12: Suresh Bapu Sankana VES-2: Location-39:Prakash Chavan
VES-3: Location-9:Kaundade Sir VES-4: Location-11:Annasaheb Patil- near Sankana mala VES-5: Location-10:Badgujar VES-6: Location-16:Kothawale West 2008
VES-7: Location-16:Kothawale East VES-8: Vijay A. Majalekar*
VES-9: B.S. Majalekar* VES-10: Annasaheb Patil NW corner- Nagave farm*
VES-11: Annasaheb Patil E boundary- Nagave farm*
**Location numbers are not assigned to VES 8, 9, 10 and 11; they are shown in Fig. 5*

Table 3: Ranges of Electrical resistivity values (used as standards) for interpretation of VES data

Resistivity Range	**Interpretation**
Up to 20 Ω-m	Moist soil cover, soil with salinity, particularly in consistently highly irrigated areas
20 to 50 Ω-m	Good to moderately good aquifer in weathered vesicular / amygdaloidal basalt and red bole
50 to 100 Ω-m	Good to moderately good aquifer in compact jointed basalt or non-productive / poorly productive unweathered vesicular / amygdaloidal or less jointed compact basalt. The distinction between productive and non-productive zones is uncertain; therefore correlation with existing nearby boreholes can be of help.
Above 100 Ω-m	Non-productive compact jointed or massive basalt, sometimes with reddish brown concentrations of iron-rich minerals in the form of sinuous bands or patches and unweathered vesicular / amygdaloidal basalt

Table 4: Generalized interpreted section based on VES in Part I

Sr. No.	**Altitude**	**Resistivity Range**	**Interpretation prior to drilling**	**Observation and interpretation on drilling**
1	627 m to 616 m	27 to 52 Ωm	Probable aquifers	Not found to be productive in spite of favourable rock viz. soft, red bole or weathered vesicular basalt
2	613 m to 593 m	95 Ωm to very high	Confining bed	Probable a barrier blocking the recharge to lower aquifer, partially or wholly.
3	593m to 585 m	66 and 74 Ωm	Partially weathered vesicular / amygdaloidal basalt or less jointed compact basalt	Soft and dry red bole or vesicular basalt layer was encountered. These rock types are favourable as aquifers. But as they are dry, they could be augmented by artificial recharge.

Table 5: Generalised interpreted section based on VES in Part II

Sr. No.	**Altitude**	**Resistivity Range**	**Interpretation prior to drilling**	**Observation and interpretation on drilling**
1	572 m to 577 m.	38 Ωm	confined or semi-confined aquifer	Red soft rock cuttings were obtained in these zones. However, they could yield only little water for a short time or did not yield water at all. These low resistivity layers can be favourable sites for artificial recharge.
2	560 m to 565 m	44 Ωm		

Table 6: Generalised interpreted section based on VES in Part IV

Part – IV Generalised interpreted section based on VES				
Sr. No.	**Altitude**	**Resistivity Range**	**Interpretation prior to drilling**	**Observation and interpretation on drilling**
1	586 m to 563 m	27 to 51 Ωm	Probable aquifer	At the time of drilling at this site, water was struck at about 563 m MSL, and 533 m MSL, but the bore well remained poor yielding for some years and then became unproductive. This is probably because these aquifers are not naturally recharged enough to be productive.
2	563 m to 533 m	48 to 63 Ωm	-	
3	538 m to 533 m	35 to 40 Ωm	Probable aquifer	

Table 7: Generalised interpreted section based on VES in Part V

Sr. No.	Altitude	Resistivity Range	Interpretation prior to drilling	Observation and interpretation on drilling
1	572 m to 569 m	36 Ωm	Confined or semi-confined aquifers	The low resistivity zones in this part have remained richly productive for some months after monsoon. However, in recent years, the yield of some bore wells in this part has shown gradual decline with approaching summer each year.
2	563 m to 556 m	38 to 46 Ωm		
3	515 m to 510 m	48 Ωm		

Fig. 1: Location map of the area

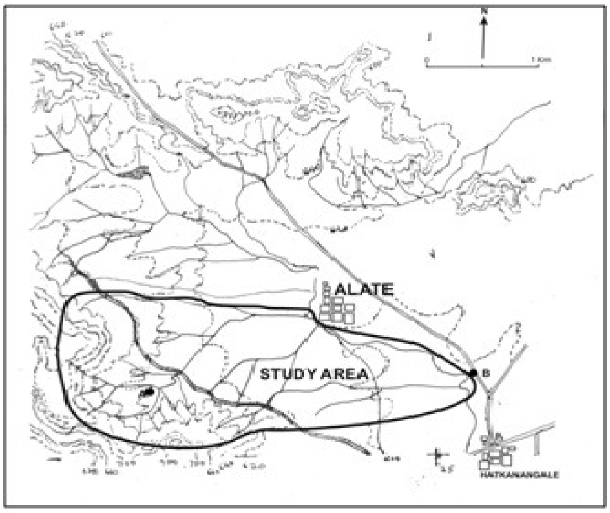

Fig.2: Map showing topography and drainage of the area around Alate village

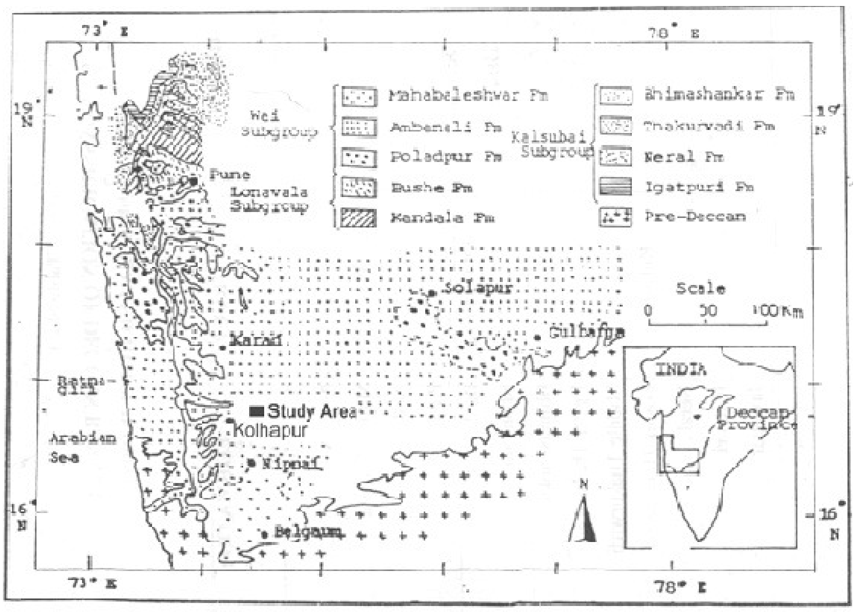

Fig. 3: Regional Geological Map of part of Maharashtra (After Mitchell and M. Widdowson, 1991)

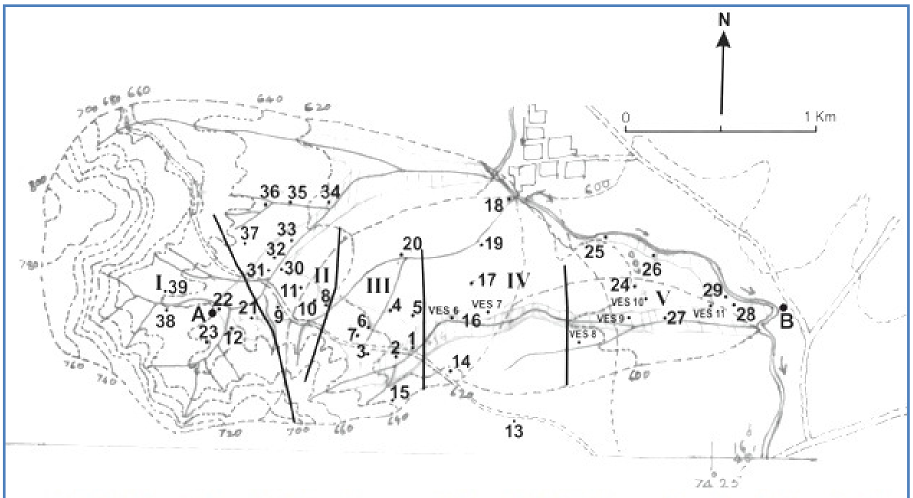

Fig. 4 Map showing location numbers (1,2,3 ---) and parts (I,II ----) of the study area. Points A and B indicate Section line for Fig. 4

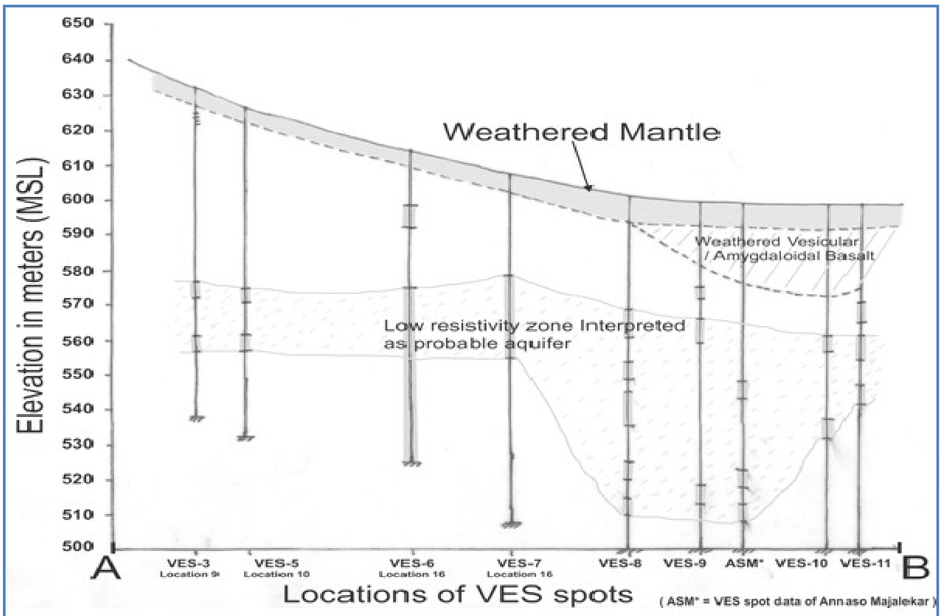

Fig. 5: Section showing thickness of weathered zone and aquifer (schematic). (Section-line shown in Fig. 5)

Conclusions:

1. Flooding of the bore wells in Parts I and II during late monsoon season will be helpful in recharging the confined and semi-confined aquifers in these parts.
2. The confined aquifers inferred in Part IV could be correlated with the unconfined as well as confined aquifers Part V. Together; they appear to be part of a groundwater basin. Thus, bore well flooding in Part IV will be useful in recharging the confined aquifers in that part so also the unconfined and confined aquifers in Part V.

Suggestions

1. The planning for bore well flooding can be made on the basis of rainfall pattern of each year..
2. Monitoring studies can be taken up to estimate the quantity of water accepted in each injection bore well selected for flooding and its effect on productivity of the other bore wells in the area.
3. In absence of nearby open wells the water from unconfined aquifer can be made available to bore wells if their casing is perforated to appropriate depths. In some bore wells it can be a major source of water.

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