DUEL AMONG DUALS? POPULAR SCIENCE OF BASALTIC HYDROGEOLOGY IN A VILLAGE OF SAURASHTRA

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Abstract

Just as scientific data collection forms the backbone for national-level policy making on groundwater, there is a parallel stream of popular science that is used in decision making by farmers. These two 'dual' streams of knowledge exist together, sometimes complement, and at others times at conflict with each other in a 'duel'. People's knowledge on hydrology is not 'dying', but thriving and growing well, being refreshed continually by interfaces with science. It may be crude and unpolished, but it is localized, pervasive and relevant to needs of people. Especially in case of hard rock areas, the high hydrogeologic variability makes observation as important as theory. Such observation over decades leads to a developing science such as found in hard rock Saurashtra. It is this innate knowledge in society that has energised the action on conservation of water over the past two decades. Pockets of knowledge sources in villages are repositories of this science. Tapping such pockets, example that of well drillers, and harnessing them towards the state-organized data collection can potentially open up a new direction for localized groundwater management. The Jasdan area of Rajkot district has stirred in terms of groundwater recharge and conservation. In this area, the main actors of groundwater, apart from farmers are well drillers and related professionals of different vocations. Each professional has their own role, but as the main risk-taker, the farmer is the final decision-maker. Decisions on well drilling, location of ponds or recharge structures are made within these multiple points of knowledge sources. Innate terminology such as Kanh, Aadwan and Pad are used for describing hydrogeology, but these words have their roots in the local language. The main structures such as dykes and pore interspaces are easily located by knowledge generated through years of both, vertical and extensive horizontal drilling. Further, using these basic concepts, other applied subjects such as, well hydraulics, can be explained in these same terms. Comparison of this village hydrogeology with regional-level databases shows that there is rich information stored within these knowledge sources. The large level picture of surface lineaments available through geophysical and remote sensing studies, imparts a global picture to this localized knowledge and a potential fusing of these two can be highly potent.

Perhaps, this apparent duality between formal science and people's science is just an illusion, a product of our point of observation, and both of these possibly belong to the same process of societies' program of knowledge generation. Thus, as this case study shows, instead of launching new data collection programs at village-level or persisting with the nation-wide monitoring networks for groundwater as is the current practice, it might be better to listen to the people and tap the right knowledge sources. There might be a large treasure hidden beneath just by scratching the surface.

1. INTRODUCTION

Groundwater, especially in the hard rock regions is best managed locally. 65% of India is covered by basaltic and crystalline hard rock terrain spanning mainly the peninsular part of the country. Many parts of this region are drought-prone and are heavily dependant on groundwater for irrigation and domestic purposes. The management of scarce and highly variable groundwater resource is very important over time. However, the question has been, who takes responsibility for managing groundwater? What incentive do farmers have in community management of groundwater? Do farmers have enough information to make decision on groundwater?

Some recent experiments and research answers some of these questions. Firstly, it is evident that centrally managed government programs of data collection and policy are effective only to an extent. The high

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costs involved and management structure necessary for implementing schemes over the entire country is daunting. On the other hand, experiments are pointing towards community management of groundwater externally stimulated and enabled by civil society organizations or government agencies. Experiences from Andhra Pradesh are inspiring. For any such local management, the strengthening of local people's institutions in terms of knowledge building is essential. The Andhra Pradesh programs have a local knowledge generation process in place that is producing results in terms of local water budgeting and water planning.

Local knowledge on groundwater, therefore, is highly valuable and can be channeled in positive directions towards management of critical local resources. Such local knowledge can be tapped in different ways from different sources: for example by involving farmers in monitoring of well water levels. The point put forward in this paper is that non-formal local knowledge on groundwater already exists in abundance in many parts of India and plays a crucial role in decision making on local groundwater resources. Such knowledge also has an interface and is fed continually by the mainstream science and engineering based knowledge through technologies and surveys. However, the different sources of such knowledge and their relevance to management and policy have not been brought out completely yet.

Several research studies have tried to document local knowledge in hydrology. Rosin's study of a village in Rajasthan talks about groundwater irrigation and water management practices in this arid region based upon a rich knowledge of local water resources (Rosin, 1993). His study, spanning 25 years of observation, looks at how local water harvesting structures are built with knowledge of siltation, runoff, groundwater recharge, salinity processes and groundwater flow. Dying Wisdom (CSE, 2001), documents examples of traditional water management practices from across India. Traditional water harvesting structures show sound understanding of local hydrological processes and intuitive knowledge of essential geology. Shah in his study of a coastal village of Junagadh district of Gujarat describes how farmers built their own picture of local groundwater hydrology through observation of water level dynamics during pumping (Shah, 1993). Sengupta (1993) documents cases of proper planning for local water resources development and the aggregate effects of many small water harvesting and extraction structures at the regional level. He suggests that there must have been some sort of regional level planning at basin level in the past and ancient cultures may have survived because of such integrated planning of water resources. Shaw and Sutcliffe (2003), in their documentation of ancient small dams in the Betwa basin of central India links the size of these structures to the runoff from their catchments. This leads us to believe that the builders of these structures followed some variant of rainfall-runoff curve during design and sound understanding of local hydrology.

Krishnan et al., (2008) carried out a research project in the Alluvial plains of the Ganges river in north Bihar in 2006-07 and found that well drillers are an efficient knowledge source about local groundwater. In Vaishali district of Bihar, a new methodological approach was used to identify and sensitize well drillers towards creating a local groundwater database. A localized lithology of current practices in a single village was created using the experience and knowledge of these drillers. The compiled knowledge was verifiable and cost effective though it had subjective and tangible sources of uncertainty. There is potential for upscaling this approach and creating accurate regional groundwater databases at low cost. However the idea needs to be tested in different terrains and areas with different practices of well drillers. The current study is a step forward in this direction.

2. AIM AND OBJECTIVES OF THIS STUDY

The aim of this study is to document the role of local non-formal knowledge of well drillers, farmers and other local resource persons in decision making around groundwater and to explore how such knowledge can be used for better implementation on policies related to groundwater.

2.1 They Specific Objectives of this Study are

1. To document local knowledge on groundwater hydrology and practices in hard rock area of Saurashtra and build a local database using this local knowledge. Compare this with science-based information available currently for the same area

2. To chalk the relevance of this local knowledge in current decision making on groundwater related practices

3. TO UTILIZE THIS KNOWLEDGE IN IMPLEMENTING FUTURE POLICIES RELATED TO GROUNDWATER

Table 1 shows a framework for differentiating between scientific and local knowledge. If scientific knowledge is conceptual, focused, sparse, potentially unbiased, repeatable and communicable; local knowledge is specific to the observation, unfocused, dense, possibly biased, generally non-repeatable and relatively difficult to communicate. As can be seen from the characteristics, each of these approaches at information-collection has their own advantages when seen with respect to a particular objective. If the objective is to build a national picture of groundwater across India, then the approach of local knowledge would hardly make any sense because of the time and effort needed; what makes sense in that case is the approaches used for example, by CGWB (CGWB, 2004). But if the objective is to bring about better management of groundwater in small aquifers and micro-watersheds, then one needs to pay more attention to local knowledge, but within a larger scientific context and concept.

Table 1: Comparing science-based knowledge and local knowledge about groundwater

Characteristic	Science	Local knowledge
Scale	Large scale, general, conceptual *Aquifers*	Smaller scale, specific, practical *Can describe nature of local flow*
Tool	Designed instruments, limited, focused recorded *Rain gauge, Water level recorder, drill logs*	Many undefined instruments, unfocussed observation, mostly unrecorded *Different sensors, word of mouth, passing of information through generations*
Spatial coverage	Time and space sparse, interrupted time-series *Depends on monitoring network*	Dense in space and time, long term observations *Every individual is an observer*
Precision	More precise, errors more objective and amendable *Results from repeated measurements*	Perceptive, individual, errors difficult to evaluate *Every individual has different perception, possible bias*
Repeatability	Repeatable measurements *Can use same monitoring equipment at different places*	Possibly poor repetition *Cannot expect similar perception and experiences for same observation*
Communication	Easy to translate and communicate *Somewhat standardized terms, such as porosity*	In local language and need to be interpreted Terms such as *Kanka, Pathar, Khara Nadi*
Purpose	Observations useful for scientific interpretation and modeling *Measurements such as hydraulic conductivity*	Observations of importance to daily life and water use *How fast does water fill into a well?*

Note: *Kankar:* gravel*; Pathar:* stones*; Khara:* saline*; Nadi* river

A right mix of these different knowledge sources can bring about an improved knowledge-based management of groundwater.

4. METHODOLOGY OF STUDY

The approach followed here is to first explore all the knowledge sources (KS) present within the study area with regards to hydrogeology and extract the appropriate information from each of them. The following step-wise process was followed:

Step 1 : Identify all knowledge sources who can inform about hydrogeology of the study area

Step 2 : Based on initial conversations with each KS, develop tools and methods for obtaining information from each of them

Step 3 : Apply tools to each of the KSs

Step 4 : Identify the terminology and concepts used in local science. Compare these with scientific terms. Cross-verify collected information with linguists and with organizations which have worked in this area.

Step 5 : Merge all the acquired information towards developing the local science picture of hydrogeology of the study area

Step 6 : Compare developed hydrogeology picture of study area with any available scientific study of the area

All these steps in this study were performed with the help of an NGO named Saurashtra Voluntary Action in Rajkot (SAVARAJ), which has been working in the study area for the past 20 years. Within the course of this study, a total of 7 KSs were identified in this area, right from a regional district level to that of the farm. These are enlisted in the next sub-section. Apart from these KSs, the guidance of a linguistics professor was utilized in understanding terminologies. Further, officers of Centre of Environmental Education (CEE) in Ahmedabad and Jasdan were useful in confirmation of the summarized results and wider expansion of these.

4.1 Knowledge Sources

4.1.1 Rajasthan Well Drillers (RWD)

Description: Bulk of the well construction in Saurashtra, especially those of open wells is performed by laborers from Rajasthan. They migrate to Saurashtra during the drilling season which starts from November and proceeds till May every year. These laborers are mainly from the southern and western Rajasthan districts such as Bhilwara, Barmer and Kota.

Area of influence: Each such group of laborers, generally numbering 4-5, construct 5-10 wells in a season. Their area of influence circles around 3-4 villages at most. In most cases, the leader of the group keeps visiting the same area every year and hence, keeps developing his knowledge about the area's hydrogeology. Even though they follow instructions from the farmer and do not make decisions regarding well location or depth, the RWDs due to the nature of their work of spending days literally inside a well, have a very close observation of local hydrogeology. Some of them, after years of experience, graduate to become well construction contractors and manage several teams of laborers.

Nature of method and tool used: With regard to RWDs and also several other KSs, the mode of knowledge gathering has been to approach them when they are involved in their work. After this, a specific interview schedule was administered to the KS, here, RWD. The different sections of this were:

a) Personal information
b) Professional information
c) On process of drilling
d) On knowledge about hydrogeology
e) Linking their knowledge to groundwater management

As an example, the specific interview schedule for RWD has been provided in the Appendix. The schedules for other KS are different, but follow a similar structure of sections.

4.1.2 Horizontal Well Drillers

Description: These drillers are mainly concerned with horizontal boring within open wells. These borings exist from 1-2 to upto as many as 20 in a single well at different depths and towards different directions. Such drilling is performed using hand-held drilling tools by these drillers who are locally based, generally farmers.

Area of influence: These drillers operate within a radius of maximum, 2-3 villages at most.

Nature of method and tool used: The nature of method is the same as for RWD except that in Section 5, there are more questions, which are provided in the Appendix. These mainly concern with the impact of horizontal bores on the local groundwater hydrology.

4.1.3 Well Owners

Description: The nature of Saurashtra's groundwater is that there is tendency to have a well in almost every farm. There is very less trade in water, so the density of wells is very high compared to others parts of Gujarat. Most of these are open wells from 50-80 ft deep.

Area of influence: Each well owner is aware of the groundwater hydrology within surrounding area of the well i.e. interactions with neighboring well, or for farther away wells what are the hydraulic connections.

Nature of method and tool used: For this KS, one needed to move through the village and use tool similar to that of RWD.

4.1.4 Small Drill Rig owner

Description: The mode of well drilling for open wells is such that mostly, the RWDs rent the drilling equipment i.e. the compressor and drill from a drill rig owner. Such drill rig owners are located 1 in every few villages and have much control on the drilling procedures.

Area of influence: Generally, such small drill rigs are operated over a radius of 4-5 villages.

Nature of method and tool used: A tool similar to that of RWD was employed with some variations and the KS located in the field of action.

4.1.5 Experienced Former Drillers (EFD)

Description: Formerly, most drilling in Saurashtra was done locally. Villages have several drillers who have been in operation for several decades.

Area of influence: The EFDs contacted in this study have had an area of influence of almost a taluka since there were fewer drillers when they used to operate.

Nature of method and tool used: In this study, the EFD came out as the principal source of local knowledge. Therefore, the mode of interaction required extensive interviewing, recording of information and cross-verification with other sources. The tool used with EFD was similar to that with the RWD.

4.1.6. Water Diviners

Description: Most of the previous water-prospecting in this area was performed by persons using traditional techniques knows as 'Water Diviners' and locally as '*Pani Joa-wale*' or 'those who can see water'. Such persons use many methods which are now considered as experiential or location-specific for water-prospecting. Many of these techniques are now debunked by scientists, but are still used in villages example of those of using the avantika branch or using a coconut. In this study, the approach has been to view the diviners with a perception of 'respectful skepticism'.

Area of influence: Since most villages possess atleast one diviner, the area of influence of each is within a few villages at most.

Nature of method and tool used: The mode of approaching the diviner in this study has been to observe if the diviner also uses any experiential or observation-based knowledge in their practice. Similar tools such as for EFD has been used for the diviner and then their practice been recorded.

4.1.7 Blasters

Description: The blasters or the providers of dynamite are located in small towns from where they provide material for the surrounding areas.

Area of influence: Generally, each blaster would provide dynamite material for 15-20 villages, depending on the towns in that area with such shops.

Nature of method and tool used: A simple tool was administered to the blaster to gain information on the occupation and magnitude of drilling.

4.1.8 Regional Well Driller

Description: Located in the larger towns and cities, there are deep bore drillers who drill up to 500-100 ft and more. These drillers have large rigs and operate over a wider area. In this study, 2 such regional drillers, RegWD were identified in Rajkot and Aatkot.

Area of influence: Some of these RegWD operate over a district or even larger area. They therefore know of drilling practices and hydrogeology over vast areas.

Nature of method and tool used: The nature of tool was similar to that of RWD with some changes to account for scale.

4.2 Sampling procedure

Since, a wide variety of knowledge sources have been identified in this study and that too over different scales, a judicious selection was required. Keeping in mind the focus on 1 village unit for the study, but obtaining a regional picture as well, the sampling procedure showed in Table 2 was followed.

Table 2: Sampling of Knowledge Sources

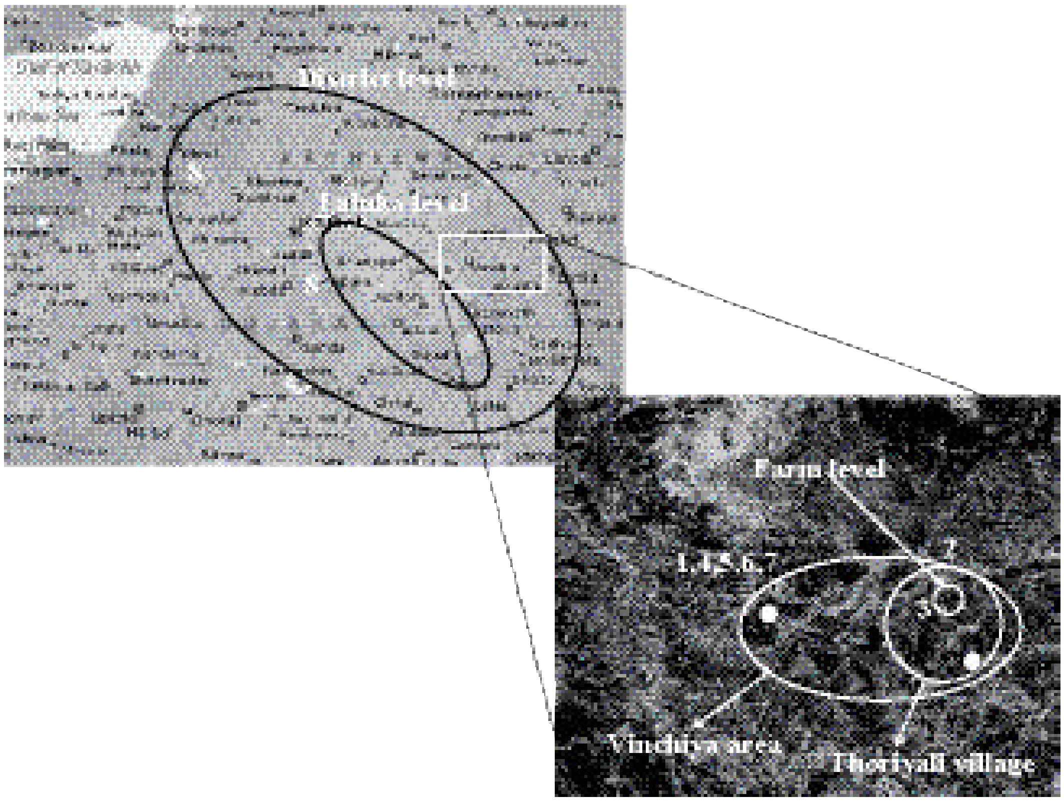
Sl. No	Knowledge Source	Number of Samples	Locations
1.	Rajasthan Well Driller	3	Thoriyali (Rajkot D), Vangedhra (Bhavnagar D)
2.	Horizontal Well Drillers	2	Thoriyali
3.	Well Owners	17	Thoriyali
4.	Small Rig Owner	1	Vangedhra
5.	Experienced Former Driller	1	Thoriyali
6.	Water Diviner	1	Thoriyali
7.	Blaster	1	Vinchia
8.	Regional Well Driller	1	Aatkot

4.3 Traditional Knowledge vis-à-vis People's Current Science

It is important to distinguish between the 2 concepts. As mentioned earlier, there have been several documents on the traditional knowledge of hydrology in the Indian subcontinent and other places (CSE, 2001; Shaw and Sutcliffe, 2001; Rosin, 1993). That kind of knowledge has developed over the ages and has been mentioned in scriptures (NIH, 1999). Here we do not refer to that type of traditional knowledge. Here we refer to a living science that is continuously being developed because of drilling and groundwater use. For example in our KSs above, the KS no. 6, i.e. a Water Diviner follows that traditional knowledge using the stick of an avantika branch in searching for water. All other KSs have their knowledge built out of their current experience and observations, therefore, they can be trusted more. Here we are dealing with current science as opposed to traditional knowledge.

5. STUDY AREA

Figure 1: Location Map and Area of Influence of Different Knowledge Sources



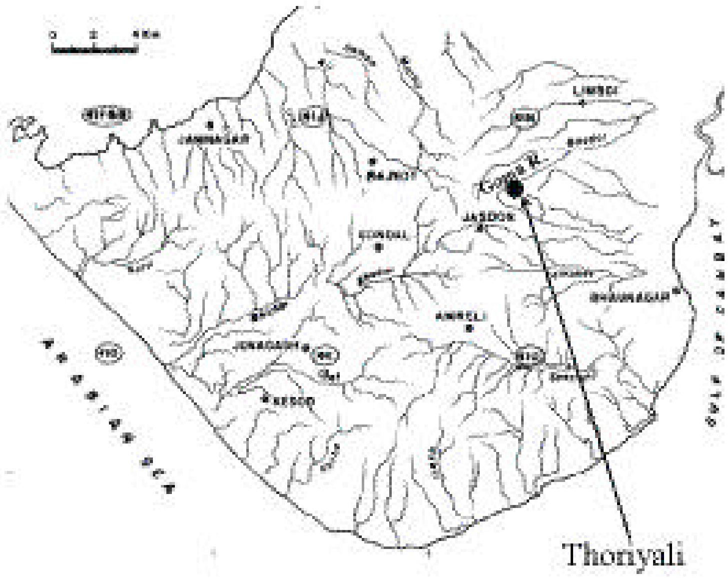
The following criteria were used for selecting the village for this study:

a) Primarily basaltic hydrogeology
b) Neither too flat terrain nor highly undulating so that there is some dynamics of groundwater hydrology which can be captured.
c) Some level of water conservation activity such as check dams, but not to saturation level
d) Presence of a known NGO whose help can be sought in implementation of this study

With these criteria in mind, many different areas were considered and finally Thoriyali village of Jasdan Taluka in Rajkot district of Saurashtra was chosen. The nearest town is Vinchiya, which is around 5 kms away from village Thoriyali, shown in Figure 1. The region of influence of each knowledge source is marked approximately in this map. With our approach, we try to pan out into a larger area such as a district and also zoom into the level of a farm by identifying these multiple scales of KS.

Figure 2 shows the study village within the stream network map of Saurashtra. The Goma river which is a tributary of the Bhadar river, passes through Thoriyali. Note that Goma river, like most rivers of Saurashtra, originates from the central upland region of Chotila-Jasdan. The Goma river originates from the Jasdan uplands that lie within the Hingolgad forest reserve. The total length of the main river bed is approximately 42 kms until it merges with the Bhadar river. It is an ephemeral river characterized by intense storm flow for few days of the year typical of arid and semi-arid regions. The study area being a highly wet monsoon, there was base flow and seepage from check dams even in February.

Figure 2: Location of Thoriyali within Stream Network Map of Saurashtra



The village has a population of around 1500 and total area of around 10 km^2. The total relief of the village is 70 ft and maximum NS and EW transects are 4 km and 3 kms respectively. The Jasdan-Botad highway passes through the village. Just 10 kms west to the village lie the Hingolgad forest reserve which is the source of many rivers such as Goma and Gehlo. Right from the catchment area down to the plains and beyond, the vestiges of the Saurashtra water conservation movement can be seen. Dotted along the landscape, one finds several check dams which were constructed mainly from 2000-05. Within Thoriyali village, there are 2 main check dams and 2 smaller ones. There are currently around 250-260 wells in Thoriyali, almost all of which are open dug wells in the range of 50-70 ft in depth. There are no deep bore wells in the village, except for 1 drilled for drinking water and failed soon after construction.

6. PEOPLE'S VIEW OF HARD ROCK GROUNDWATER HYDROLOGY

Before going further into the study of Thoriyali, it is necessary to understand the language of the 'people's science'. The understanding of terminology used by people was captured by this non-native language speaking author with the help of an interpreter. Further, these concepts have been verified by conversation with a linguist Professor and officers of CEE. These concepts have been formed from conversations during the period of field work i.e. from July 2007 – February 2008. The main source of these terminologies has been an 'Experienced Former Driller' (EFD) of the Thoriyali. They have been verified by cross-verifications with the other KSs used in this study.

6.1 Terminology

The concept of hydrogeology is hierarchical and adapted to a Basaltic terrain that is dominated by surface lineaments and dykes. It is to be noted that these concepts would not hold true for 'groundwater hydrology' in general and also, to this specific terrain when going into details. The 3 main concepts identified are:

6.1.1 *Kahn*

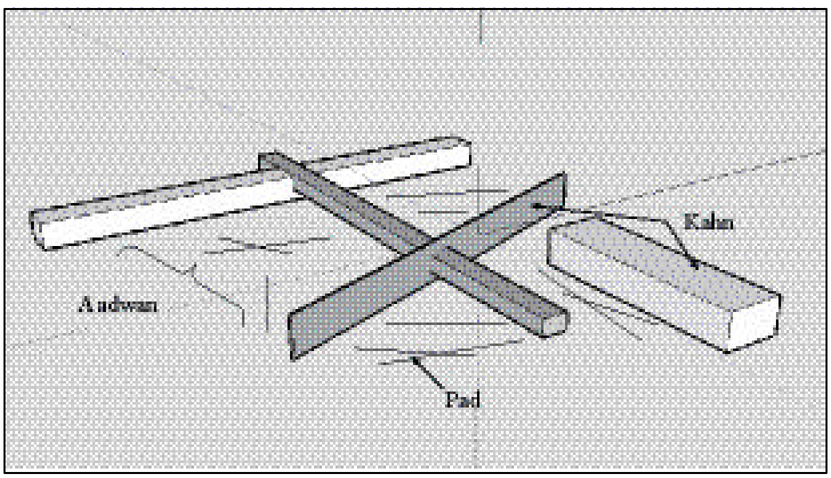
The largest and most important structures in this terrain are referred to as *Kahn* (pronounced with a half-emphasis on the '*hn*'). *Kahn* is used to refer to surface lineaments and dykes which are most critical as transmitters of groundwater. In regular language of Saurashtra, the word *Kahn* refers to the *essence* or *substance* of any entity. Perhaps it is this meaning which has gotten transmitted over to groundwater. *Kahns* can be as short as few metres in length, and can run to many kilometers. The important dykes of Saurashtra have been identified using Remote Sensing and gravity measurements (Mishra et al., 2000). The *Kahns* identified in villages can be much smaller than these large scale structures.

In most cases, *Kahns* cuts up the base basalt rock vertically and forms flow barriers on either side. If there are pore spaces connecting them to the surrounding rock, then there can be some transmission, otherwise, the flow is mostly longitudinal along the *Kahns.* The tilt can be vertical to as much as 15-20^0 from the vertical. The width can vary from 2-3 ft to as much as 20-30 ft. Hydraulically, *Kahns* are excellent transmitters of water, depending on the fractures within it and orientation. However, they are difficult to drill into and do not support wide-diameter open wells. Also, they are not stable to horizontal drilling.

6.1.2 *Aadwan*

The second level within the local hierarchy of hydrogeology conception is the *Aadwan*. The spaces of rock enclosed *between* the *Kahns* are referred to as *Aadwan.* This word perhaps springs from other similar words such as *Aada* etc., i.e. on the side. The *Aadwans* are all that space which consists of the upper soft *Murrum*, and base basaltic rock. Within a village with 5-6 *Kahns* cutting across there could be 15-20 such *Aadwans* and there is identity of farmers lying within an *Aadwan* of being on the same patch of aquifer. So, in some ways, the *Aadwans* enclosed by *Kahns* can be said to comprise of 1 aquifer unit with flows to and from the *Kahn* and from surface recharge/discharge units such as ponds, river, wells, etc.

Figure 3: Local concepts on Hydrogeology
(Scale can be assumed as 1 km x 1km in plan and 20 m in depth)



6.1.3 Pad

The third and final level of concept in this hierarchy is the *Pad*. A word used to refer to as *layer* in the local language, *Pad* is the *pore spaces* within the *Aadwan* which can store and transmit water. They can be a few cm to a few ft thick. In a single well of 50 ft depth, one can encounter not a single *Pad* or can hit 4-5 *Pads.* The practice now, however, in face of high uncertainty, is not to be bothered about striking a *Pad* during drilling. Horizontal bores are dispatched from different depths and directions of the well to try and encounter *Pads*. What matters are *Pads* that are recharged by either rain water or some surface recharge body and also those that are not connected to or shared by other users. The search is always for that elusive undiscovered *Pad.* However, looking at the current density of wells and network of horizontal bores, it is surprising how new and yielding *Pads* would exist at all.

6.2 Storage and Transmission

The key concepts of hydrogeology science are those of storage and transmission (Todd, 2004). They are measured by parameters such as specific yield, storativity and storage coefficient (for storage) and hydraulic conductivity and permeability (for transmission). In the local equivalent, similar ideas are prevalent. The *Kahn* and *Pads* are the key receptacles. However, transmission needs connectivity between these storage structures. If such connectivity is not present, it is artificially made by horizontal boring. Both storage and transmission reflect together in well yield. Well yield is measured mainly in terms of time for which water can be pumped from a well, which can vary from 30 minutes to as much time as electricity or diesel is available. For example, a well far away from any *Kahn* or *Pad* bearing water can have a low yield of just 30 minutes. Whereas another well that is connected to a pond through a *Pad* or *Kahn* or horizontal bore will yield as long as the source is available.

6.3 Well Hydraulics

Hydraulic head fluctuations, flow directions and interference are key concepts , which are understood in terms of local concepts. Sharing a single *Kahn* causes interference for wells within the *Kahn* and less to none for wells across it even close by. On the other hand, wells sharing the same *Pad* are also affected mutually by interference. Deeper wells are at an advantage since *Pad* water flows to the lowers *Pads.* Each well owner has acute picture of interference with all surrounding wells and other wells which are hydraulically connected. This concept of interference is mainly through drop in hydraulic head and in reduction in the duration of availability of water for pumping.

7. INNATE PICTURE OF A VILLAGE HYDROGEOLOGY

After an understanding of the basic terminologies and their observation on the field, we proceed to utilize these concepts for the study village.

7.1 Knowledge sources and their contribution

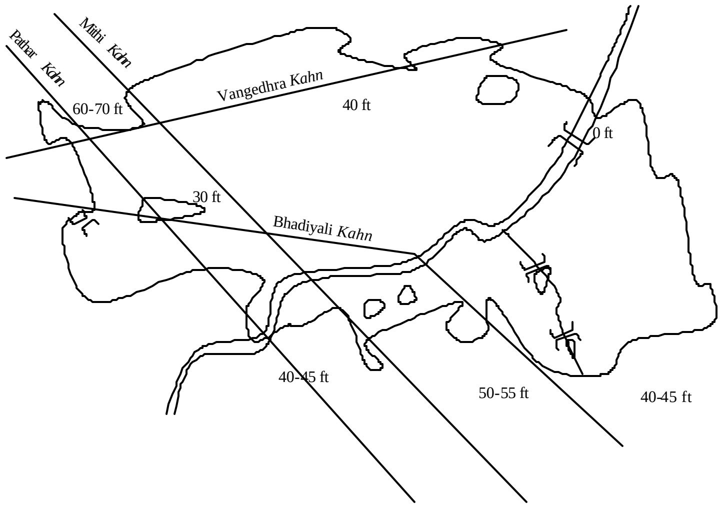
In this particular study, out of all KSs mentioned in Table 2, the most important was the experienced former driller. The understanding of terminology and overall picture of the village hydrogeology was made possible through this EFD who was also a horizontal well driller once. This particular EFD had 5 years of experience in drilling and 15 years in horizontal drilling. In all he has drilled around 50 wells and drilled horizontal bores in around 300 wells. Further, the KS no. 3 i.e. well owner added some local complexities and corrections to the larger picture. The KS no. 6, i.e. the water diviner through years of prospecting for water, also possesses good local knowledge, which was used for verification. The other KSs were mainly used for insights into the drilling process and their roles into that process.

7.2 Village Hydrogeology and Current Well Arrangements

As shown in Figure 4, the main pond of the village is located in the western part of the village. There is a much smaller pond in the north-eastern part and 2 small ones, with almost no catchment and hence dry, in the south part. The large check dam is built right on the Goma river in the north-eastern part. Apart from these, there is 1 check dam in the north-west side of the village which has an inundation zone of around 2-3 ha and 2 small cascading check dams in the south-east which have (< 1 ha) small indundation areas.

The relief of the village is saucer-shaped with dip towards the river that passes through the middle. The river flows from west to east, so there is a general slope downwards along that direction too. The map shows the relative elevation of different points in the village as compared to the bottom-most point i.e. the river bed at the north-east edge. The central wasteland of the village, very recently cultivated, lies on the north-central part.

Figure 4: Constructed map of village with water bodies and geologic features



The village has 4 main *Kahns* that cut across the village boundaries. These have been named during the course of this study for convenience as the Badiyali *Kanh*, Vangedhra *Kanh*, Pathar *Kanh* and Mithi *Kanh* as shown in Figure 4. These *Kahns* form a total of 8 *Aadwan* regions. Apart from these major 4 *Kahns*, farmers are also able to locate a multitude of smaller *Kahns*, that are 10-15 ft or so in length. All these *Kahns* are doleritic and some gabbroitic.

7.2.1 Badiyali Kanh

The oldest well of the village, perhaps a few 100 years old lies on this *Kanh* which is 5-20 ft in thickness. It is a well of very large diameter of around 20 ft, having expanded along the *Kanh* over the years (a common problem for all wells situated on *Kanhs*). Since this well used to be very high yielding, all further wells started being constructed along this *Kanh*. Most of the old wells, 30-40 years or more old, are located along this *Kanh*.

7.2.2 Vangedhra Kanh

This is a 10^o from the vertical tilted *Kanh* that is 10-40 ft in thickness. It cuts across from east to west and possibly forms one of the large dykes cutting across the Saurashtra region. This *Kanh* also forms the northern boundary of the village and passes into Vangedhra village, hence the name. Since in Thoriyali, this *Kanh* mainly is adjacent to the erstwhile wasteland, there are not many wells along it as compared to the Badiyali *Kanh.* In contrast on the northern side of this *Kanh,* i.e. in Samadiyala village, there are more wells located along it.

7.2.3 Pathar Kanh

This Kanh runs roughly north-south and is composed of entirely brittle material with large crevices. It has less sand material within these crevices, hence the name.

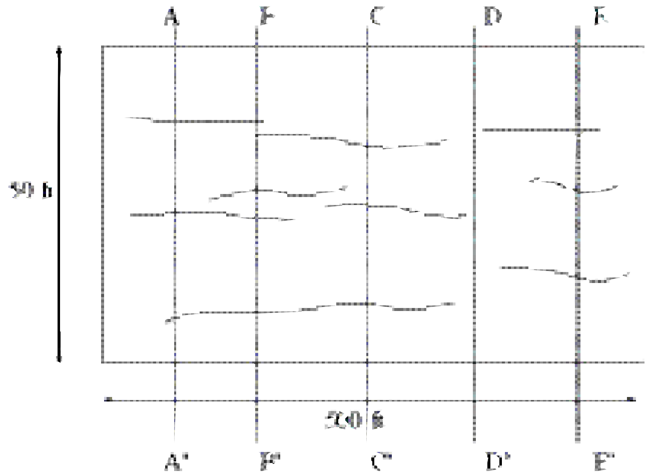
7.2.4 Mithi Kanh

Running almost parallel to the Pathar *Kanh*, this *Kanh* has more of sand material within the crevices. It has relatively poorer transmission properties than the Pathar *Kanh.*

The *Pads* of the village mainly start occurring from 20 ft onwards and below, but the depth at which these *Pads* start becoming useful and bear water are between 35-40ft. The thickness of the *Pad* is very small here, from 1-5 inches. There could be a minimum of 0 to maximum of 5 *Pads* in a vertical cross-section of up to 50 ft. The mode of distribution of *Pads* is around 3 in number for any vertical cross-section.

As shown in Figure 5, which is a conceptual 2-D distribution of *Pads*, we have 5 equi-spaced cross-sections, A-A' through E-E' with number of *Pads* equal to 3, 5, 3, 0 and 3, i.e. minimum of 0, maximum of 5, mode of 3 and average of 2.8.

Figure 5: Conceptual picture of *Pads* distribution within the *Aadwan*



7.3 A Case of Well Interference

Most of the wells in the village lie in the range of depth 40-60 ft. The water bearing layer, *Pad*, is struck within such depth and the next *Pad* cannot be struck till 100 ft or so. In such a situation, any single well being drilled to a deeper level causes much interference and capture from the neighboring wells.

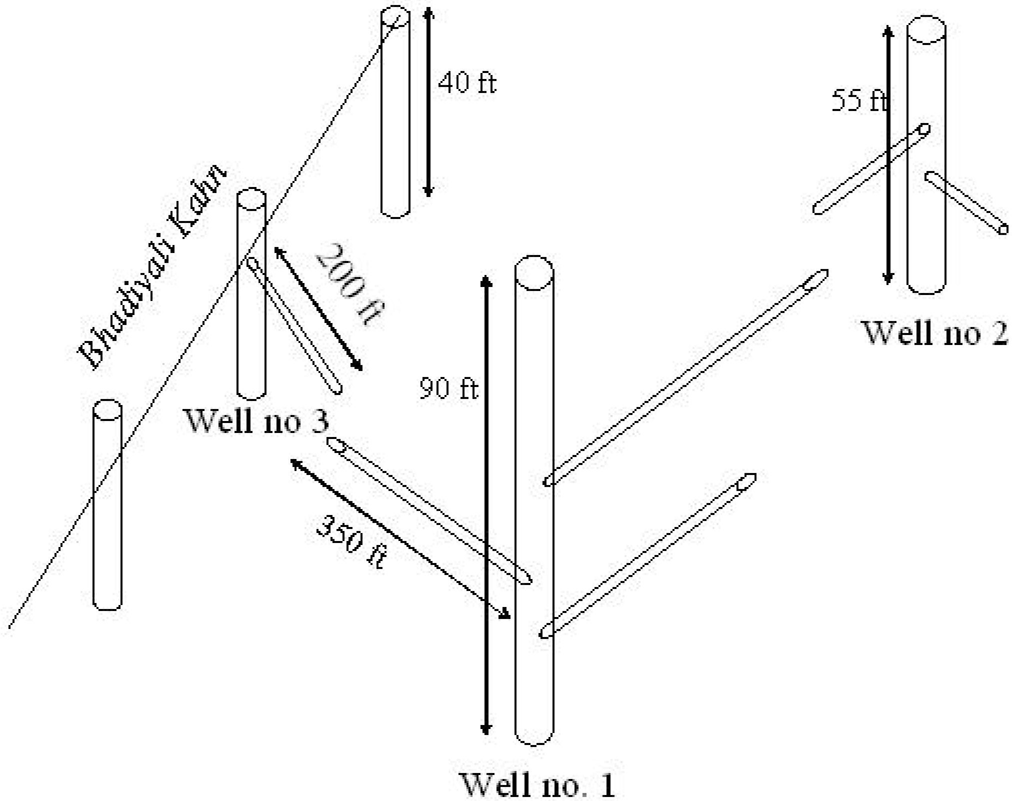
This example is from the eastern part of the village close to the check dam near *Badiyali Kahn*. There lies a series of wells along this *Kahn* at a separation of around 50 ft. There are also other wells in the *Aadwan* region to the west of the Kahn, but lying more than 500 ft distance away. But, one farmer's break of implicit rule led to a serious altercation in this region arising from well interference. Figure 6 illustrates the situation currently. Well no. 1 was drilled up to a depth of 50 ft and did not strike a single water bearing *Pad*. The well owner here is the village's water diviner. He decided to go deeper and reached up to 90 ft, which was much deeper than all neighboring wells. He struck a *Pad* at that depth which abstracted water from all neighboring wells. Due to the downward gradient, he benefited immensely at the cost of neighboring wells such as well no.2. Further, the well owner started drilling horizontally as shown in the Figure. Well no. 3 used to obtain continuous supply of water by being on the *Kahn* fed. This led to abstraction of water from one of the *Kahn* wells, leading that well owner to drill towards well no. 1, but to no avail.

Here, the levels of interference reported at each step go as follows:

- Before the well no. 1 was constructed, the well no 2 used to obtain water in his well for 2 hr during post-monsoon period in January for a normal rainfall year. But, after well no. 1 was drilled, this well went dry until well no. 1 stopped pumping.
- Similarly, well no. 3 used to obtain continuous supply of water by being on the *Kahn* fed by the check dam. But, this went down to 3 hr of water supply only after well no. 1 was constructed.

All these reductions in water availability to well no. 2 and 3 directly benefited well no. 1 because of the depth of 90 ft and several horizontal bores arising from it.

Figure 6: Example of Well Interference triggered by Well no 1 drilling deep



7.4 Level of development and knowledge

An observation of Figure 4 will show that the biggest *Aadwan* of the village lies south of the Vangedhra *Kahn*. It is interesting to note that this region also consists of the erstwhile wasteland of the village therefore an area of poor density of old wells. A relationship exists between the level of development of groundwater in an area and the amount of knowledge generated. Here, there are certainly small sized *Kahns* in this *Aadwan* region, but they are not known properly since there has not been much observation of hydrogeology here. Over the years, as there is more observation, there would be better knowledge of the hydrogeology in this part too.

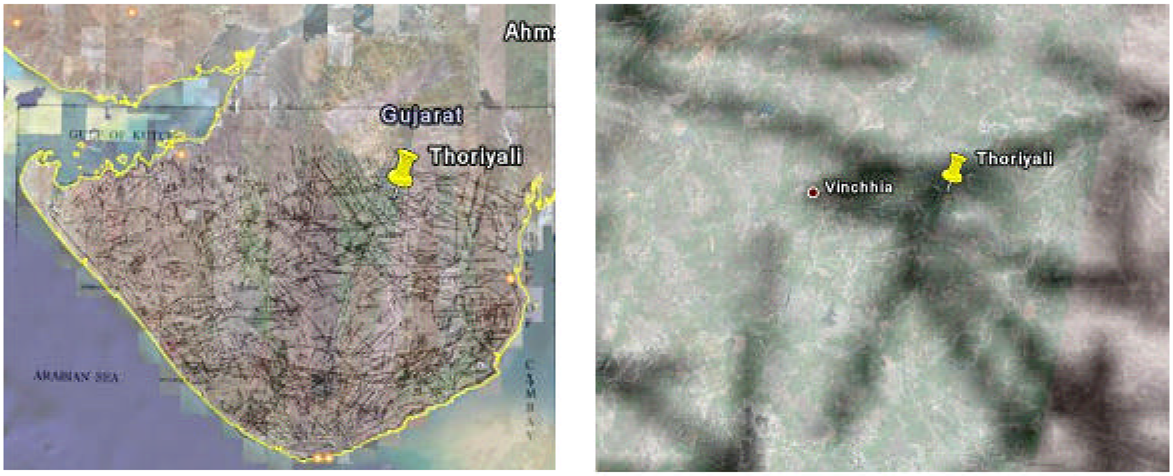
Extending this observation, if one compares an intensively explored groundwater area such as Saurashtra with some other area with similar basaltic hydrogeology, such as upland western Madhya Pradesh, one would not find as much observation and innate knowledge as in Saurashtra since knowledge matures with experience, in this case groundwater development. As stated before, this knowledge is slowly expanding and developing as more and more areas develops groundwater intensively.

7.5 Comparisons with Available Surface Lineaments Map of Saurashtra

The surface lineament map of Saurashtra has been mapped using gravity and magnetic measurements by an NGRI team using false colour thematic maps provided by NRSA on 1:250,000 scale (Mishra et al., 2000). This map was overlaid using the public available Google Earth software that uses satellite imagery from DigitalGlobe's Quickbird satellite. Note that this overlay has several potential source of errors:

a) Scale errors: Both these images are at different scales of resolution
b) Overlaying errors: The location and orientation of these images can produce an error of maybe range of a km.

Figure 7: Overlay of Saurashtra Surface Lineament map over the satellite map of village



But in spite of these errors it is surprising to find the similarities in Figure 4 and Figure 7. Figure 8 shows the comparison of these 2 pictures of Thoriyali village, one generated by interpreting the people's knowledge and the other by processing of 2 satellite measurements. The major *Kahns* of the village appear distinctly on Figure 8b. Such a comparison has to be seen with some degree of doubt until this process of overlaying of maps is performed rigorously using ground observation points for anchoring.

If this overlaying is indeed true, then it is heartening to note how much more of information the people's knowledge can add since the inherent knowledge is that of much smaller *Kahns* of few ft in length. On other hand, maybe, using a satellite image of resolution finer than 1:2,50,000 scale used by the NGRI study could also result in such similar features. In any case, it is interesting to note the same degree of resolution obtained by both approaches, which are completely different from each other.

Figure 8: Comparing Information from the (a) People's Knowledge of *Kahns* and (b) Scientific Studies on Surface Lineaments in Thoriyali Village

(a) (b)

8. DECISION MAKING AND KNOWLEDGE

One of the key decision making process regarding groundwater is well drilling. Since the well owner or farmer has to finally take the risk, he is the final decision maker, even though there might be better knowledge sources than him. In this process, the farmer may choose to get the expertise of different KSs, and sometimes not. At each stage of drilling however, a different set of KS are involved and they exercise their knowledge in helping the farmer. In all, 3 stages can be identified:

Stage 1: Well Location

Here, the farmer spots a location within his land or in some cases even buys land for drilling a well there. This decision of locating the spot of drilling is often the most crucial and perhaps, one of greatest risk. In some cases, the farmer might use the help of a water diviner. There is also a practice of performing exploratory boring which might cost up to Rs.10,000 for around 50 ft of boring. This could give a fair idea of whether to go for blasting at this spot or not. Following factors go into this decision of well location (not in the order of importance):

a) Farm topography: tendency to locate well at higher location on farm for water to flow under gravity
b) Connectivity to water source: The hint of being connected by a *Kahn* or *Pad* to a water source such as pond, check dam or river.
c) Isolated capture zone: To try and assure a safe capture zone for the well and avoiding well interference. In some cases, farmers also try the opposite i.e. to capture a known *Pad* which is already being tapped.
d) Possibility of being able to bore horizontally from this location and tap a *Pad*, *Kahn*, or a water source.
e) Minimizing well construction cost: The type of rock is one important factor in minimizing well construction cost. For this reason, many farmers prefer to drill in *Kahn* since there is no need to drill to deeper level in a *Kahn*. However, well stability is an issue for *Kahn* wells.

Stage 2: Vertical Well Drilling

This is the most important step in drilling which involves the RWDs and small rig owners. It is an interaction between these 2 KSs under the supervision of the well owner which results in vertical drilling. One important thing here is that since the RWD gets a full contract from the well owner for the well and rents equipment such as the well rig, he tries to minimize cost. But the rig owner gains by more boring. So there is a push-pull between these 2 KSs in trying to minimize-maximize the number of boring which are used for planting dynamites for blasting. A rough cost of Rs. 800-1000 is paid by the farmer to the RWD per foot of vertical drilling. The RWD then handles all other cost such as:

a) additional labour (which is also obtained from Rajasthan) and their upkeep
b) rent to the small rig owner at Rs. 30 for every 25 ft of boring
c) cost of dynamite sticks

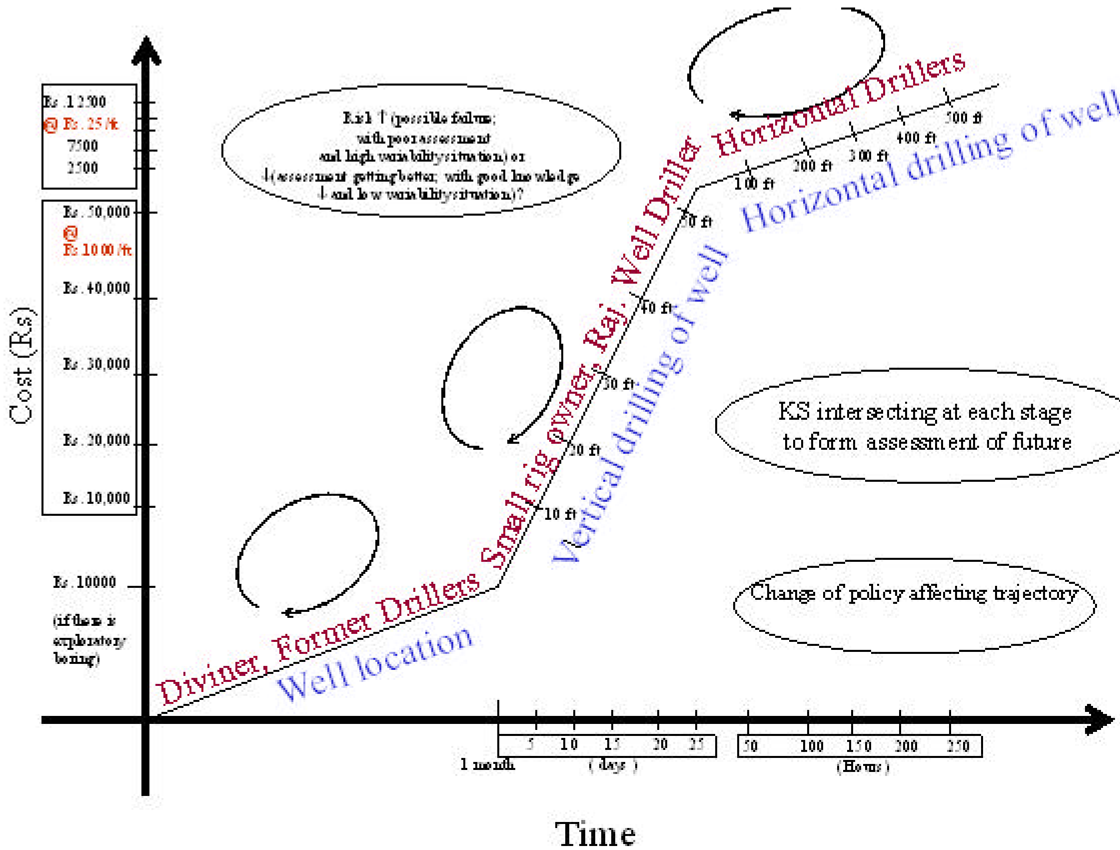
Stage 3: Horizontal Well Drilling.

Once vertical drilling is complete, the HD arrives in the scene to decide along with the farmer where to drill horizontally and at how much distance. Note that an important ethic followed here is not to drill outside the extant of the farm on the ground. There are exceptions, though, to this rule, as mentioned earlier in this paper for the example of well interference. The rate of horizontal drilling is around Rs. 25/ft. For every such direction, one might choose to go up to 300 ft and around 150 ft on an average. It is common to find 5-7 such bores placed at various levels within the well.

Figure 9 shows the following for each step of Well Drilling
a. Cost to the farmer
b. Time taken for that step to be executed
c. The KS involved in that step apart from the farmer himself

Note that the scales of cost and time vary with each stage of drilling, so one needs to accumulate the incremental time and cost at each stage to get the total time and cost. All estimates of time and cost shown here are from the primary survey made in this study. Note that these numbers are at best representative since they vary with the local hydrogeology. However, they can be useful for comparison across the 3 stages of well drilling since what matters is the orders of these numbers. Also, note that we have provided here for an iterative process at each stage.

Figure 9: Cost, Time and Knowledge Sources in Well Drilling
(estimates from primary survey)



This might always not be followed, for example seldom does one back off after starting vertical drilling. But here we offer that possibility for generalization. There are 2 important concepts to be discussed:

8.1 Perception of risk to well owner at each stage of well drilling

It is natural to perceive that the farmer is taking the biggest risk at the first step i.e. to drill a well or in choosing a location for the well. But, as the farmer commits more and more investment (Rs.10000 for the first stage, Rs.1000/ft for the second stage and so on), he is unable to back off from the drilling process and expects a good return from this investment i.e. good yield from the well. If the farmer is drilling within a hydrogeology of low variability and the combined KS-knowledge accessible to him is of a good quality, then this risk is well covered. But, in a situation of high hydro-geological variability and poor KS-knowledge, he is operating in a situation of high risk.

Therefore, the quality of combined KS-knowledge in informing about the potential well yield is critical to the farmer in making decisions on well drilling under an environment of high hydro-geological variability.

8.2 Impact of groundwater policies on this decision-making process

Within such a scenario, what happens when new policies are brought into this situation. For example, consider policies such as cap on depth of well drilling, ban on horizontal drilling and minimum well spacing.

a) A cap on depth of well drilling will result in the farmer to pay more attention to horizontal boring. In that case the HD acquires greater importance than before.

b) A ban on horizontal drilling on the contrary, would force the farmer to choose the well location more prudently since he has to strike a good *Pad* in that vertical drilling. In that case, the farmer would perhaps invest more in the initial exploratory drilling in the first stage. The water diviner could also assume an important role in that case if the farmer cannot afford such exploratory drilling and wishes to make a judgement based on belief.

c) Imposition of minimum well spacing will surely affect the well location, and therefore potentially more water-yielding locations. So the farmer will try to access these *Pad* locations by more horizontal drilling. Again the HD gains importance.

Therefore, policies will affect the trajectory shown in Figure 9 and the relevant KS would come to the help of the farmer in such a case. The farmer is interested finally in yielding maximally under a given budget of well drilling. For that, he has to utilize the appropriate KS at each stage of drilling. He continuously makes adjustments and adapts to new situations with the help of the KSs.

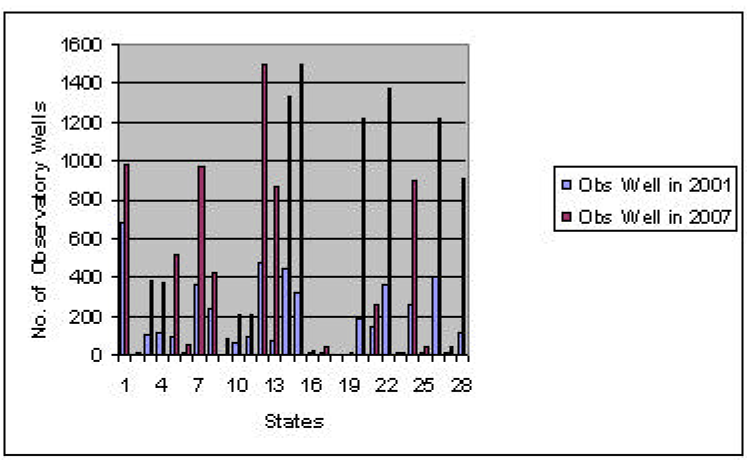
9. CONCLUSIONS

The local knowledge of this village in basaltic Saurashtra has been documented. Further, it has been confirmed from other conversations that the similar terminology, i.e. the hierarchical triplet of *Kanh-Aadwan-Pad* (K-A-P) is used widely in the region north of Junagadh and south of Chotila in Saurashtra. The basic ideas of well hydraulics have been interpreted in this context.

This understanding has been applied to the case of a single village by using a variety of Knowledge Sources. This picture of the village has been compared with a previous scientific study on surface lineaments and some coincide is observed, but this should be viewed with caution because of the possible uncertainties.

The role of Knowledge Sources in decision making, i.e. in well drilling has been described. We have looked at how cost and time build up at each stage of the well drilling process and how the knowledge sources would behave under different policy changes such as a cap on well depth, imposing ban on horizontal drilling and minimum well spacing.

Figure 10: State-wise number of CGWB Observation Wells in 2001 and 2007



1	Andhra Pradesh
2	Arunachal Pradesh
3	Assam
4	Bihar
5	Chhatisgarh
6	Goa
7	Gujarat
8	Haryana
9	Himachal Pradesh
10	Jammu & Kashmir
11	Jharkhand
12	Karnataka
13	Kerala
14	Madhya Pradesh
15	Maharashtra
16	Manipur
17	Meghalaya
18	Mizoram
19	Nagaland
20	Orissa
21	Punjab
22	Rajasthan
23	Sikkim
24	Tamil Nadu
25	Tripura
26	Uttar Pradesh
27	Uttaranchal
28	West Bengal

Finally, we look at this case study within the larger context on the national level. Figure 10 shows the total number of observation wells maintained by the Central Groundwater Board (CGWB) in India for every state in 2001 and now in 2007 with data obtained from the CGWB website and from the India Stat website.

Gujarat state had 359 observation wells in 2001 and had 1049 wells in 2007. On average, for each district, there would be around 40 such wells in say, Rajkot district and around 4 such wells in Jasdan taluka, for around 50 villages. Whereas, the current study looks at 17 wells in just 1 village and puts forth the view that each of the 300 wells in Thoriyali is an observation well. At the current rate of increase in number of observation wells across the country and the budget expense required to maintain the organization support to manage this monitoring, it seems to be more important to tap this inherent information within the village. If groundwater needs to be managed locally, then information needs to be generated locally, with a scientific basis. This paper shows one way to do it entirely with people's participation.

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APPENDIX

WELL DRILLER STUDY: TOOL FOR RAJASTHAN WELL DRILLERS (RWD)

CAREWATER, A Division of INREM Foundation
Elecon Premises, Anand - Sojitra Road, Vallabh Vidyanagar, 388 120 Gujarat

1. Personal Information

District: _________________; Taluka: ______________________; Village: _________________________

1.1 Name of the Respondent: ____

1.2 Address (in Saurashtra) ____

1.3 Address (in native place): ____

1.4 Telephone Nos. with STD Code / Mobile: ____________________________________

1.5 Age: _________ Sex: _________ Education ________________ Occupations__________________

1.6 Family size and its distribution:

Male	Female	Total	1-5 yrs		6-18 yrs		19-60 yrs		61 yrs & above	
			M=	F=	M=	F=	M=	F=	M=	F=

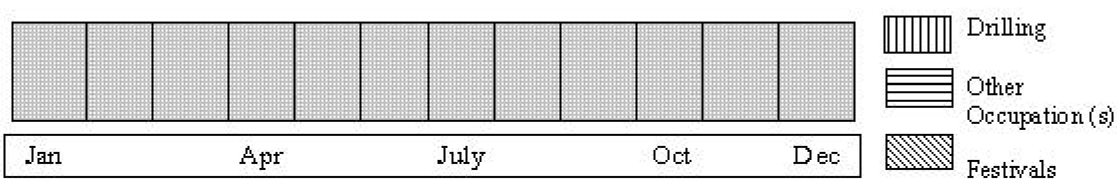
1.7 Do they own land in native? _____ Y/N

If Y, then how much land? _____ Bigha

2. Professional Information

2.1 Number of years in Well Drilling Profession: ____________ Years

2.2 Annual Cycle of Occupation/Migration



2.3 Which other profession, you are involved in? : ____________________

2.4 Does he own his drilling equipment? ___________ Y/N

2.5 If yes, when did he buy it? _______Year

2.6 If No, from whom does he rent? _________ , How much it costs ? __________ Rs.

2.7 Any injuries to himself during Drilling? _________ Y/N
If yes, what ? ______________________ Has he seen other injury in front ? _______ Y/N

2.8 How many well he drills in a season ________ Number

2.9 Depth of wells drilled : min ______ ft ; average ______ ft ; max ______ ft

2.10 In total since beginning, how many wells he must have drilled ________ Number

2.11 Does he see any slack/rise in rate of wells ________ 0 – slack, 1- rise, 2 – no trend

2.12 What is his estimate of total numbers of wells drilled annually in Rajkot ____ Number

3. On Process of Drilling

3.1 Who decides the well spot location? _____ 0- himself, 1- farmer, 2- other, specify

3.2 Is there any drilling done before ____ Y/N

3.3 How much dynamite is used per feet of drilling:

____ kg/ft (Rock type ________) ; ____ kg/ft (Rock type ________)

____ kg/ft (Rock type ________) ; ____ kg/ft (Rock type ________)

3.4 People and roles:

Sr no.	Person Name	Is Originally from 0- Sau, 1- Raj, 2- Other	Key Role of Person	How person is paid
1 2 3 4				

3.5 Time for drilling:

a) Initial Blasting ____ Days

b) Time for each foot of drilling/blasting ____ Days

c) Fitting Pump etc. ____ Days

3.6 Economics of Drilling Procedure:

a) Cost of Machine ______ Rs <u>or</u> Rental Cost of Machine _____ Rs

b) Total Labour Costs _____ Rs/day and/or _____ Rs/ft

c) Cost of Dynamite _____ Rs / kg

d) Other Costs : _____ Item ____ Unit Cost ___ Total Units

_____ Item ____ Unit Cost ___ Total Units

_____ Item ____ Unit Cost ___ Total Units

4. On Knowledge about Hydrogeology

General

Major layers of Stone and their Colours
Draw them pictorially

Regional

The trend of the layers in this region

Near and at Thoriyali

The layers at Thoriyali

5. Linking their knowledge to Groundwater Management

Do they advice farmers on spacing of wells ? _____ Y/N

Can they have a say on the depth of the wells drilled? ______ Y/N

Do they feel currently there are too many wells ? _____ Y/N

Wells are more deep than necessary _____ Y/N ?

Well Driller Study: Tool for Horizontal Well Drillers (HD)

CAREWATER, A Division of INREM Foundation

Elecon Premises, Anand - Sojitra Road, Vallabh Vidyanagar, 388 120 Gujarat

5. Linking their knowledge to Groundwater Management

5.1 When locating new well, does farmer keep into account future HD ____ Yes/No

5.2 How has horizontal drilling affected local hydrology?

a) Is the yield in single well more because of HD _____ Yes/No

b) How does overall yield in village affected due to HD _____ 0-Same, 1- more, 2- less

c) If there are 2 wells 500 ft apart, then what is minimum distance of HD so that yield of 1 well gets affected, 0: <50 ft, 1: 50-100 ft, 2: 100-200 ft, 3: > 300 ft

d) Do farmers do HD towards pond, WHS , water body ____ Yes/No

e) Should there be a limit on how long HD can be drilled ____ Yes/No

If Yes, then how much/well : _____ Number, _____ ft

5.3 Horizontal bores and well recharging

a) Just as water is pumped out of HB, can water also recharge through it? ____ Yes/No

b) Because of HB, would the rate of recharge have increased? ___ Yes/No

c) Because of HB, would the volume of recharge have increased? ___ Yes/No

If yes, then by how much % : 0: < 10%; 1: 10%-25%; 2: 25%-50%; 3: > 50%