Advanced Center for Water Resources Development and Management

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Technical Report

RAPID GEOHYDROLOGICAL APPRAISAL OF PURAINEE AND ORLAHA VILLAGES SUPAUL DISTRICT, BIHAR

with special emphasis on

drinking water management

Conducted for
Owner Driven Reconstruction (ODR) Collaborative

August 2009

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Rapid Geohydrological Appraisal of Purainee and Orlaha villages, Supaul district, Bihar, with special regard to drinking water management and alternative sources

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Chapter 1: Background

The role of groundwater in irrigated agriculture is a well-known fact. Groundwater irrigation has played a central role in enabling rural communities to transition from low-productivity subsistence agriculture to much more intensive forms of production, during the last century, and especially during the last few decades. This is a phenomenon that is observed from many parts of the world, but clearly more so in the changing agrarian economies of South Asia. Nearly 85% of all rural water use in India depends upon groundwater from aquifers, not just for irrigation needs, but also for their day-to-day domestic supply of water, the latter often being underplayed in discussions on groundwater.

The value of groundwater as a buffer drought and flood risk has been a major factor underlying rapid development of the resource in recent decades. While global estimates are unavailable, groundwater development has expanded exponentially in many regions since the 1950s, so much so that Tushaar Shah, an eminent economist and groundwater scholar, has termed the expansion of groundwater development as "anarchy". The impact that this has on the resource base is only now becoming evident. In many locations, groundwater resources are under threat with many states of India clamouring for a formal groundwater legislation. The impacts of over-pumping of groundwater has led to falling water tables, increased costs of lifting water, deterioration in quality of water available from wells and serious health consequences like fluorosis and arsenicosis. The variability in conditions controlling the accumulation and movement of groundwater, combined with the lack of a solid scientific understanding of mobilization dynamics, makes it difficult to forecast the impact of development on groundwater quantity and quality, raising basic questions on sustainability.

The more 'obvious' role of groundwater in supporting irrigation has implied that many of its other roles often go unnoticed. Most discussions on groundwater are linked to problems of dryland areas, almost ignoring its relevance in flood-prone regions such as the Gangetic plains of large parts of Northern India. In such flood-prone regions, groundwater is commonly the only source of perennial domestic water, especially for meeting drinking water needs of scattered habitations that dote the flat landscapes. The problem of *excess* during floods leads to difficulties in *access* to established sources in an habitation. In summer, problems of access are uncommon, but issues pertaining to *water quality* are surfacing in the region, with evidence suggesting a strong nexus between groundwater quality and related health problems. Clearly, in such areas, the quantity of groundwater is of secondary importance as compared to accessing *good quality* water. This is proving to be a particular challenge in initiatives undertaken as part of the flood-mitigation and rehabilitation exercise, especially after the deluges by the Kosi and other rivers in North Bihar.

Considering the peculiar 'typology' of groundwater conditions in the region, and the need to develop village-based strategies in provision of safe and sustainable potable supplies, a good understanding of local conditions is necessary to plan and manage groundwater resources in an area or a village. Information and data that often drive such strategies, are however rare in such regions. The absence of basic data and scientific understanding of groundwater from such regions only increases the risk society faces in the process of developing sound strategies of drinking water supply.

The plains of North Bihar are prone to flooding because they form an integral part of a complex river system, which itself is a part of the

Ganga river basin. The region is part of what is called the *Himalayan foredeep*. Hydro-meteorology, river morphology, neotectonics and afforestation of the sources areas are the main factors influencing flooding in the region. Rivers such as the Kosi, Gandak, Budhi Gandak and Bagmati run in spate almost each year and inundate large regions in North Bihar, causing misery to millions and resulting in loss of life, damage to infrastructure and displacement of communities. The floods of 2007 and 2008 were especially devastating with rehabilitation work still under progress. The rehabilitation mainly includes construction of robust houses and the process of setting up a sustainable and safe drinking water system in the villages of Bihar.

ODR Collaborative is an initiative by a group of organisations aiming to develop improved alternatives of drinking water supplies in the flood-prone regions of North Bihar. What has begun as an initiative during the peak distress flood period has matured into a much broader initiative looking into *risk free, sustainable* drinking water supplies, keeping the *flood vulnerability* of communities in mind. The MPA initiative in two villages - Purainee and Orlaha, Supaul district - includes developing a strategy for drinking water, a strategy based on *micro-level* understanding of water sources and their characteristics. These characteristics include quantitative and quality aspects, especially in the backdrop of the physical setting, including the flood-vulnerability of the areas within which these villages are located.

Most villages in the region of North Bihar depend upon groundwater for their domestic supply, including drinking water. The proliferation of the *chapakal* - a locally designed hand-pump assembly that fits into a shallow or deep 'augured' hole - has meant easy access to water in a village. There are chapakals for groups of households, or even more than one for a single household. The *dug well*, which used to be the traditional water access mechanism, has gone out of use. At the same time, dug wells remain unused but in place, in many villages. What then is the status of groundwater under this scenario? It is a well known fact that groundwater conditions tend to vary greatly, both spatially and over time, in any area. As a result, a good understanding of local conditions becomes necessary to plan and manage groundwater in a village. Data that feed into such planning are seldom available and groundwater management remains largely constrained as the *information domain* in large parts of India, especially in regions such as North Bihar, remains a blank.

MPA, a member of ODR Collaborative, is attempting to fill in parts of this domain, mainly through extensive water quality monitoring of sources, many of them tapping groundwater, in order to identify the main challenges in the provision of safe and secure drinking water. It is during this endeavour that MPA contacted Advanced Center for Water Resources Development and Management (ACWADAM) for technical capacity building support. ACWADAM has been interacting with MPA and made a reconnaissance visit to some of its project areas in the summer of 2009. As a first step in developing a concrete partnership, MPA's programme co-ordinator attended ACWADAM's basic training on groundwater in Pune in July 2009. The visit by ACWADAM in August 2009, was specifically to develop strategic steps in the management of groundwater resources in Purainee and Orlaha villages. This report is the result of a quick appraisal of the geohydrological conditions in these two villages, but also attempts to use findings in these two villages to strengthen MPA's work in other villages of Supaul as well as the other districts of North Bihar.

Chapter 2: Regional Setting

Study area: Location in context to regional hydrology

Purainee and Orlaha are flood affected villages in North Bihar. Purainee is located within Basantpur tehsil, while Orlaha is part of Triveniganj tehsil; these tehsils belong to Supaul district, located in the north-central part of Bihar. Both villages can be approached by road from Patna, via Khagaria-Saharsa-Madhepura. Purainee is located close to the border between India and Nepal, within close proximity to the town of Birpur. Orlaha is located close to its tehsil headquarters, i.e. Triveniganj.

Purainee and Orlaha represent the *micro-setting* of thousands of villages located in the North Bihar Plains. The physical setting of the region is defined by clearcut boundaries - the northern linear boundary of the Himalayan Siwalik foothills and the southern boundary of the meandering Ganga. The North Bihar Plains are said to cover an area of about 52500 km^2. These plains are mainly characterised by what is currently called a “megafan”, or in more common terms, an ‘inland delta’. The overall slope regime for the region changes from SE in the west to South in the east. The *tals* (ox-bow lakes) and *chaurs* (abandoned river channels or palaeo-channels) are important local-level features that influence water behaviour in the region. The North Ganga plains have been further sub-divided into a number of units based on fluvial geomorphology. Of this division, the particular areas of this study are located within the Gandag-Kosi-Mahananda interfluves, regions subjected to frequent shifting of river channels and floods.

The catchment characteristics of the North Bihar Plains have been presented succinctly by Mahadevan (2002). A summary table, based on their study is presented here.

RIVER	TOTAL LENGTH in km	TOTAL CATCHMENT AREA in km^2	UPLAND / PLAINS AREA RATIO
Gandak	625	45035	3.33
Kosi	736	59503	5.31
Burhi Gandak	431	13191	0.00
Baghmati	330	8439	0.68
Kamla-Balan	266	11347	0.19

RIVER	Length to Catchment Area Ratio in km/km^2	Relevance
Gandak	0.014	*Relatively higher flux of water and sediment load*
Kosi	0.012	
Burhi Gandak	0.033	*Relatively lower flux of water and sediment load*
Baghmati	0.039	
Kamla-Balan	0.023	

The length to catchment area ratios for Gandak and Kosi are much smaller than those for the remaining rivers, implying that greater fluxes of water and sediment loads are involved in case of these two basins; this, in simple terms, implies that the risk from flooding by these two rivers (including the stresses on structures like embankments) will be greater. This analysis also points to the fact that the dynamics involved in deposition of sediments from these two rivers is also quite complex; hence, various combinations of clay-sand-gravel sequences are likely to be found in these two river basins. Both Purainee and Orlaha are part of such systems, and even before venturing into surveys in these two villages, it was understood that the sedimentation sequences in these two locations, especially at the shallow levels, would be quite complex.

While much of the regional architecture of the North Bihar flood plains is determined by the main rivers, including the Kosi, numerous interconnected minor channels participate in carving out features of the plains by reworking and redistributing sediments deposited by the main rivers and their tributaries. The overall system of river alluvia in the region can only be estimated to be of the order of thousands of metres thick, especially when one considers that the Kosi alone carries a sediment load of 130 million cubic metres annually.

Overbank sedimentation is common to the region. This implies sediments deposited during and after the flood episodes during which river banks overflow and there is progressive *building up* of the banks. This is especially important in context to development of aquifer systems in the region. As Mahadevan (2002) sums up in his narrative: "...the Gandak-Kosi interfluve region exhibits a fining upward grain size distribution bottoming in sand or silt and interleaved with beds of coarse silt and sand; sediments show post-pedogenic alterations including decomposition of plant and shell material, carbonate dissolution and precipitation, iron oxide / hydroxide accumulation and illuviation of clays". Such sediments usually constitute the host-regime for groundwater accumulation and movement and aquifers are developed as a consequence of the geometry of overbank deposits. An understanding of such deposits becomes important in understanding groundwater accumulation, movement and quality, especially in context to the small and large habitations located in the region.

Groundwater occurrence in deep alluvial systems

A variety of factors affect the resilience and vulnerability of deep (unconsolidated) sedimentary groundwater systems. The main ones are:

1. that the volume of water in storage within deep sedimentary basins generally is many orders of magnitude larger than the annual volume of flow;

2. the complex changes in water chemistry and flow patterns that generally occur with natural and human-induced changes such as frequent floods, extraction patterns and the overall development in the region;

3. the large scale of such aquifers – most deep sedimentary basins underlie large areas and, thus, are subject to a variety of uses and are affected by decisions occurring across numerous administrative units (districts, states and even country boundaries);

4. that, in many regions, the temporal scale on which recharge and discharge from such aquifers occurs is unique and may involve orders of magnitude of years.

In general, deep sedimentary basins represent a myriad of physical and chemical dynamics. Distinctions between individual "aquifers" are often unclear, and experts often differ in the way they identify units for monitoring and analysis. It is now a well known fact from well-studied deep alluvial aquifer systems that the physical ability of users to continue pumping for long periods of time (often several decades) despite declines in water level and water quality creates long-term irreversible changes to such systems; such changes often take longer periods to manifest themselves. In simpler words. deep alluvial systems are not "self-limiting". Users can continue to pump long after aggregate extraction exceeds aggregate recharge. Some of the changes that can occur as a result of this, such as land compaction and quality declines, may be irreversible. Second, basin water balances are often poorly understood. Major components in the basin water balance, such as evapotranspiration by native vegetation and deep groundwater flow patterns, are difficult to measure with a degree of accuracy. As these can be major components of the basin water balance, the lack of information on them undermines the utility of water balance estimates, even in systems where there is no pronounced use of groundwater resources.

Hence, most significantly, due to the complex nature of flow regimes within such systems and the difficulties inherent in defining hydrological boundaries, it is often difficult to attribute changes in groundwater conditions to changes in use within specific areas as a consequence of natural and human-induced fluxes. It is also difficult to understand specific recharge mechanisms for a small area. While upper unconfined systems may receive direct contributions through vertical recharge from precipitation or return flows from overlying use, lateral flows from streams and other sources are usually significant, especially in determining groundwater quality. In many situations, surface and groundwater systems are linked in complex ways with, for example, some sections of a stream either gaining or losing water from and to groundwater respectively. *Particularly in case of the deep confined and semi-confined systems, groundwater is often released owing to compression of the aquifer material.* This has major implications for the viability of regional attempts to increase recharge, such as those occurring as part of the water harvesting movement in India. Basic questions on what a body of ponded water actually serves as – a percolation tank, an evaporation pond or an irrigation tank – are seldom understood, their utility falling under the general categories of "water harvesting" and "water conservation". Finally, water quality dynamics become complicated with changes occurring as different formations are tapped and as flow patterns evolve with development.

Methodology

The current study was undertaken keeping in mind the hydrogeological complexity of deep alluvial systems and the flood-context of North Bihar. Inputs to this study were generated from three main sources:

1. Field observations and limited measurements in the villages of Purainee and Orlaha.
2. Discussions with members of ODR collaborative involved in rehabilitation work including MPA partners.
3. Primary data on water quality analysed by MPA from the other five panchayats of the district.

Field observations were limited to observing surface exposures, stream cuttings, excavation sections and one test hole drilled for collecting sub-surface samples (as part of the foundation planning for construction in Purainee village). The other component of the field work involved opening the head-works of representative *chapakals* (hand pumps) to record water levels and depths. This enabled plotting water levels in the form of contours. During the earlier visit (May 2009), qualitative mapping of *iron* from different parts of both villages was undertaken through MPA; this distribution was compared to the water level distribution measured during the current visit to understand if there was any correlation between groundwater movement and water quality (especially iron distribution).

Fieldwork included use of instruments such as GPS, geological compass, tape measures and water tracers. Compilation of data and analysis was done at ACWADAM's office, using appropriate software. The report was compiled at ACWADAM's office after returning from the field and analysing the data collected. The following chapter highlights salient observations and inferences from this study.

Chapter 3: Observations

Topography and drainage

The topography in both the villages seems quite flat. However, there are gentle gradients even at the scale of the village. Figures 3.1 and 3.2 show 3-D surfaces of the topography in the two villages. In Purainee, the land slopes gently to the west and southwest, towards the stream located on the western margin of the village. The village itself is located around two mounds, on the eastern extremity, one in the north and the other in the south. In Orlaha, the village centre is on higher ground, with the land sloping gently outwards, in all directions. Topographic gradients are relatively gentler northwards and southwards. A canal flows along the western extremity of the village. The topography of the village, although magnified in the diagrams, is too gentle to support drainage lines (streams). Due to the loose, unconsolidated nature of the material (and much of it is sand or silt on the surface, in both villages), a large proportion of the rain falling on the ground is likely to infiltrate, although whether it recharges aquifers below, is another question.

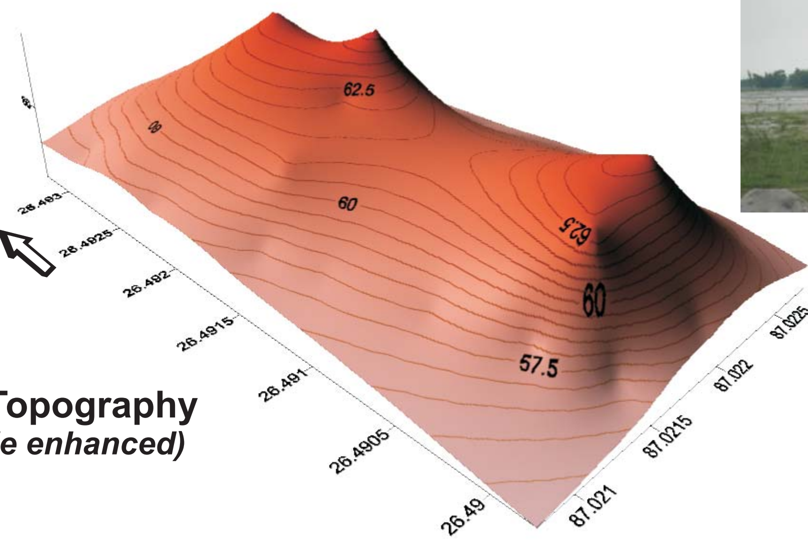
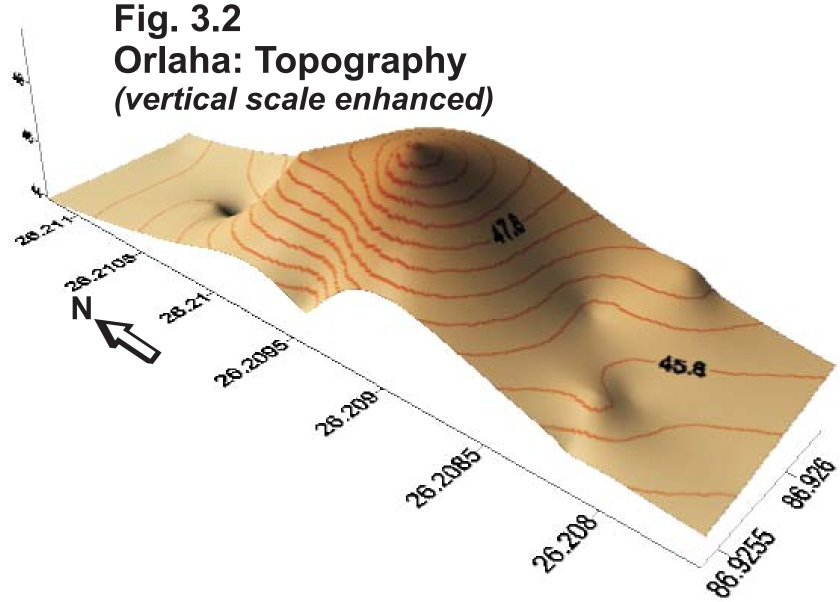


Fig. 3.1
Purainee: Topography
(vertical scale enhanced)

Fig. 3.2
Orlaha: Topography
(vertical scale enhanced)



Geology

It would be difficult to completely do justice to the complex geology at both sites. Moreover, this study was only a rapid appraisal of the two sites, and hence, only observations of direct relevance to the immediate need of ascertaining the groundwater conditions on a *generic* level are given below.

Purainee

Light coloured sand marks the surface of the ground in Purainee. The sand, clearly shows the presence of micaceous material, some of which is dark coloured. The presence of sand on the surface is reported to be sand brought along with flood waters that entered the village during the Kosi deluge of 2008. In Purainee, it was possible to undertake some sub-surface *logging* on the basis of shallow pits dug for construction and mainly also, on the basis, of samples collected from a 24 foot test hole drilled under a housing project in the village. The description of these samples is given below, in the form of two illustrative tables.

Table 1 is a *shallow pit log* for the excavation pit of the foundation of one of the house-construction sites in Purainee. Table 2, on the other hand, is the compilation of the *test borehole log* in Purainee. The *shallow pit log* shows that the sediments in the uppermost 1.5 m show a fining upward sequence, topped by silt or fine sand. The salient feature of the log is a clay horizon at 0.5 m below ground level - bgl (bearing a consistent thickness of about 0.2 m), wherein the clays swell after saturation and preclude major infiltration. The clays are underlain by *dark-coloured* silt at about 1 m bgl. The pit bottoms out with lighter coloured sands.

Table 2 shows the *test bore hole log*, which can be broken up into three main sections. At the shallow level (0 to 4 m bgl), it is dominated by clays, followed by dark coloured, relatively finer sand, which is followed by coarse, lighter coloured sand, probably with some lenses of (?)finer material. The main water bearing horizons are likely (from the bore hole log data) to be at 3.5 m and 5.5 m bgl, these two horizons separated by a layer of finer material.

Both the diagrams show that there are distinct layers of sediment, both in terms of the *size* and *composition*, the understanding of which would require more elaborate studies. However, a few observations can be made on the basis of the limited data gathered. In Purainee, the consistent clay layer at a shallow level indicates some degree of 'hydrostatic' pressure, implying at least partial confinement to the groundwater in the chapakals. Hence, water levels are likely to be representing a potentiometric surface, rather than the water table of an unconfined aquifer. This, would also have some bearing on the presence of iron in the chapakals.

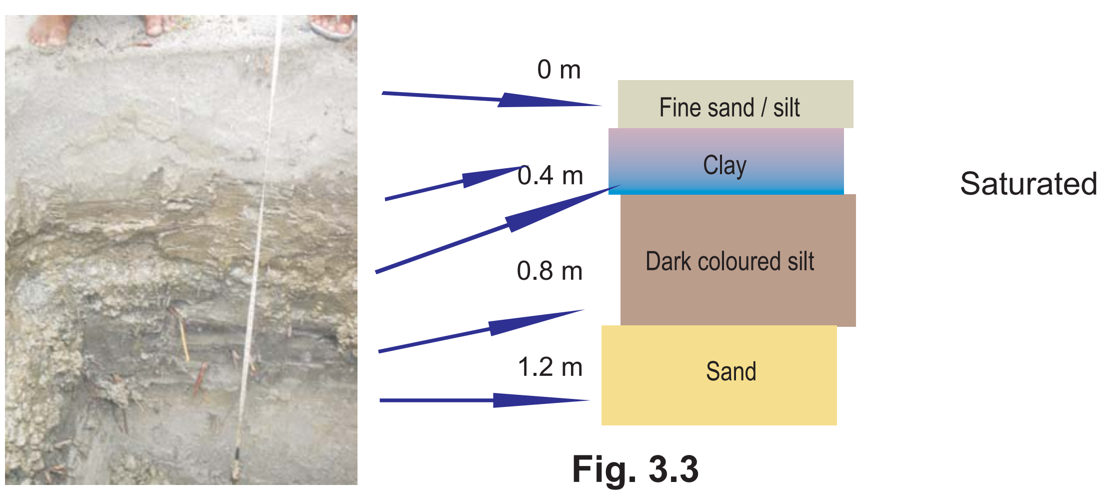
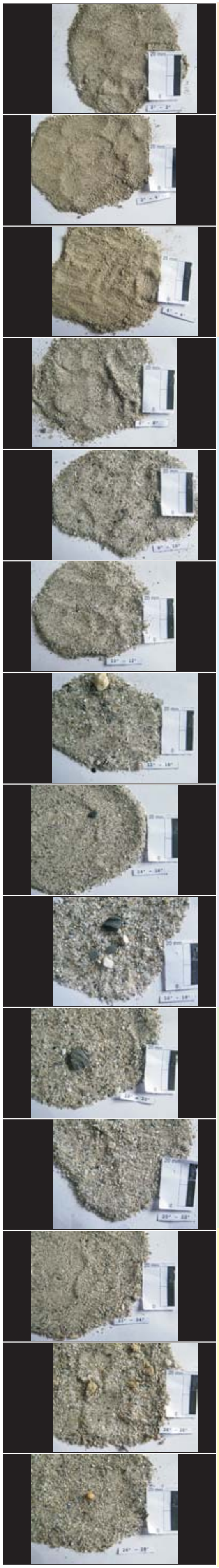


Fig. 3.3
Log of foundation pit - Purainee



0 - 2 feet (~0.30 m) 2 - 4 feet (~0.92 m) 4 - 6 feet (~1.52 m)	The upper section includes finer grained material, dominated by clays. Effect of weathering also noticed. The dominance of saturated clays at about 0.5 m bgl implies limited infiltration to deeper layers.
6 - 8 feet (~2.13 m) 8 - 10 feet (~2.74 m) 10 - 12 feet (~3.35 m) 12 - 14 feet (~3.96 m)	Coarser material, dominated by sand, with dark coloured minerals and rock-fragments; micaceous material apparent. This section corresponds to the water-bearing horizon.
14 - 16 feet (~4.57 m) 16 - 18 feet (~5.18 m)	Finer material, grading downwards into coarser material. Rock fragments also part of material at 5.18 m (coarsest material in the section). Also corresponds to water bearing formation, especially in deepened *chapakals*.
18 - 20 feet (~5.79 m) 20 - 22 feet (~6.40 m) 22 - 24 feet (~7.01 m) 24 - 26 feet (~7.62 m) 26 - 28 feet (~8.23 m)	More consistent sediments, as far as size is concerned. Mainly sand and some coarser fragments; grain size decreases below depth of 5.18 m - still mainly in the range of sand-sized particles.

Fig. 3.4
Borehole log - Purainee

Orlaha

Direct subsuface observations, on the lines of the ones made in Purainee, could not be attempted in Orlaha due to the absence of test pits (foundation work was already complete for most houses) and test bore holes. However, the overall landscape is flatter, bordered on one side by a canal. The landscape is probably less obliterated as an effect of the last flood, than in Purainee. Sediments are generally darker coloured (as appearing on the surface with the dominance of sand). Apart from this, the regional sedimentation patterns would not be significantly different from those in Purainee. The subtle differences in the conceptual hydrogeological model, again based on observations are presented in the following section. The dominance of sand-sized sediments is obvious, especially based on narratives captured from discussions with villagers about their *chapakals*.

Hydrogeology (brief)

In both locations, the hydrogeology (groundwater accumulation, movement and quality) is controlled by the host sediments - sediments that store and transmit groundwater. Both the areas are dominated by the presence of river sand, deposited as part of the Kosi river system. However, given the complexity of the flood regime in North Bihar, there would be several complex episodes of recycling. However, based on a limited set of observations and *narratives* from local villagers, development organisations and other such sources, it is clear that intercalations of clays in dominantly sand deposits control the behaviour of groundwater, especially at a local level. The geometry of the interbedded clays, in all likelihood, play a crucial role in the nature of aquifers developed as well as in the recharge and discharge processes in the region. The current, rather rapid appraisal clearly brought out the point about local characteristics within an otherwise regional system of groundwater resources.

In order to understand the variability within each site and across the two sites, water levels were measured in *chapakals* in Purainee and Orlaha villages. Water levels would have normally been difficult to measure in the *chapakals*, but MPA staff and villagers co-operated by allowing the head-works of representative *chapakals* to be opened so as to enable water level measurement. Water levels in *chapakals* were measured along with the locations (latitude, longitude) and elevations (height of measuring point from the mean sea level). Reduced levels were computed, subtracting the depth to water (water level below the ground, from the measuring point of each chapakal) from the elevation of the measuring point. These were then plotted as maps - water level contour maps - to understand the overall groundwater flow system underneath each village. While measuring water levels, basic water quality parameters were also measured using field-probes, at some of the sites. These data are presented in the following sections.

The water level data, plotted as water table contour maps (Figures 3.5 and 3.6) indicate the following:
1. In both locations, despite shallow water levels, distinct patterns of groundwater flow are evident.
2. Groundwater flow in Purainee is 'from the eastern portion towards the western boundary'. There is a distinct groundwater mound in the eastern portion of the map, implying that recharge occurs from that direction. The discharge of groundwater is towards a central line (roughly running east-west through the middle of the village), with the main discharge zone somewhere close to Jurilal Mandal's *chapakal*. The overall pattern of flow lines (red arrows) is indicative of the groundwater flow being part of a more regional system of groundwater movement.
3. Groundwater flow in Orlaha occurs from a central mound, outwards, mainly in the northerly and south-westerly directions. The recharge mound is located at the centre of the village and may be part of a system from the west (from the side of the canal, which was flowing at the time of the measurement). Hence, the recharge area lies in close proximity to the *chapakals* belonging to Rajendra Mandal and Ramchandra Mandal. There are two clear discharge areas in Orlaha - one along a north-south line, from Dhoolan Sardar's *chapakal* northwards and the other at the southwestern corner, around Jugeshwar Sardar's *chapakal*.

MPA has been conducting water quality surveillance, mainly centred around the testing of *iron* and *arsenic*. And although they will be testing for these and other parameters, in some detail, in both the villages under question, certain interesting patterns of iron (based on a crude methodology picked up by MPA from experienced locals) emerged during a *participatory testing* exercise conducted by MPA, during ACWADAM's visit to these two villages in May 2009. The testing procedure makes use of *crushed leaves of the guava plant - locally called 'amrud' or 'lataam' - that impart various hues of purple to water contaminated by iron…the darker the shade of purple, the higher the iron content*. Surely, this needs to be cross-checked with formal water quality testing; nevertheless, we developed a crude classification from a systematic process (testing by the 'lataam' method of representative samples from different chapakals in these two villages, and plotting them onto a map, based on the GPS readings recorded for different *chapakals*. These maps are presented as figures 3.8 and 3.9. It may be noted that the concentrations are **not actual**; ad-hoc values, based on the 'guava leaf' testing were generated for the plot - with darkest colour having higher values and ligher shades indicating lower values.

The distribution of iron in Purainee shows decreasing concentrations towards the southwestern part of the village. The maximum concentrations are noticed along the northern border of the village.

The distribution pattern of iron in Orlaha reveals two *maxima* - one at the centre of the village and the other in the southwestern corner. The minimum values are nearly in close proximity to the maxima, one in the north and the other in the southwestern corner. Comparison of water level data and the iron distribution pattern shows a close correlation, indicating iron maxima along the main recharge areas, whereas relatively lesser iron-content is found in association with groundwater discharge points / zones. And, although this theory needs to be tested with more rigorous hydrogeology and groundwater quality surveillance, the broad overlap of patterns would largely remain in place, at least for the season in which this study was conducted. Seasonal variability of groundwater flow is expected, but whether such variability also brings in changes in patterns of iron concentration will only emerge after continued testing.

The distribution of iron in groundwater conducted by MPA in other

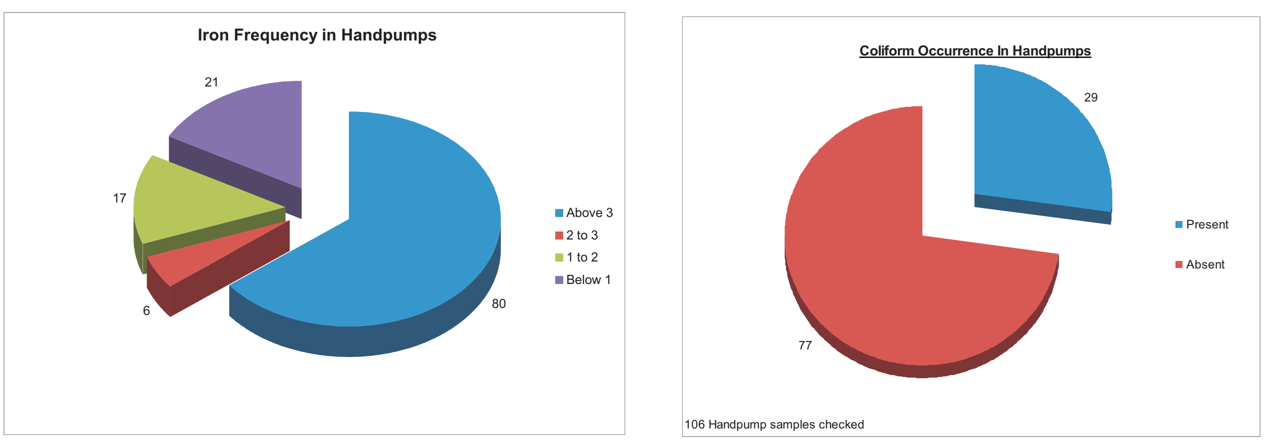


Fig. 3.7: Preliminary water quality results for representative samples from Supaul district, North Bihar (courtesy: Megh Pyne Abhiyan)

parts of Supaul district has shown interesting results. Some of these results have significant relevance to this rapid appraisal. The salient factors are:

1. A large proportion of chapakals show the presence of iron, sometimes significantly higher than the permissible limit.
2. Although not many dug wells were tested, the proportion of dug wells showing the presence of iron to the total number is small, especially when compared to the iron in chapakals.
3. And, although dug wells, which in most villages lie in a state of disuse, are likely to have a significant proportion of bacteriological contamination, chemically, they seem to be safer; incidentally, chapakals also show significant proportion of bacteriological contamination, which probably takes place through poorly maintained head-works.

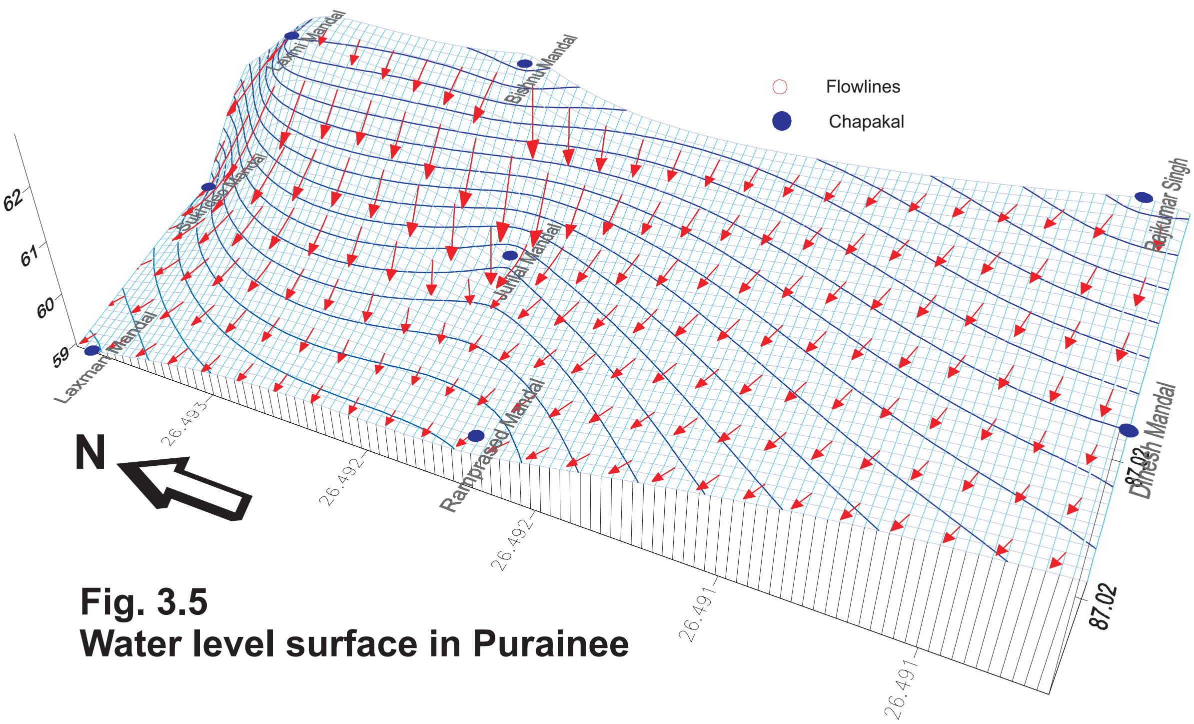


Fig. 3.5
Water level surface in Purainee

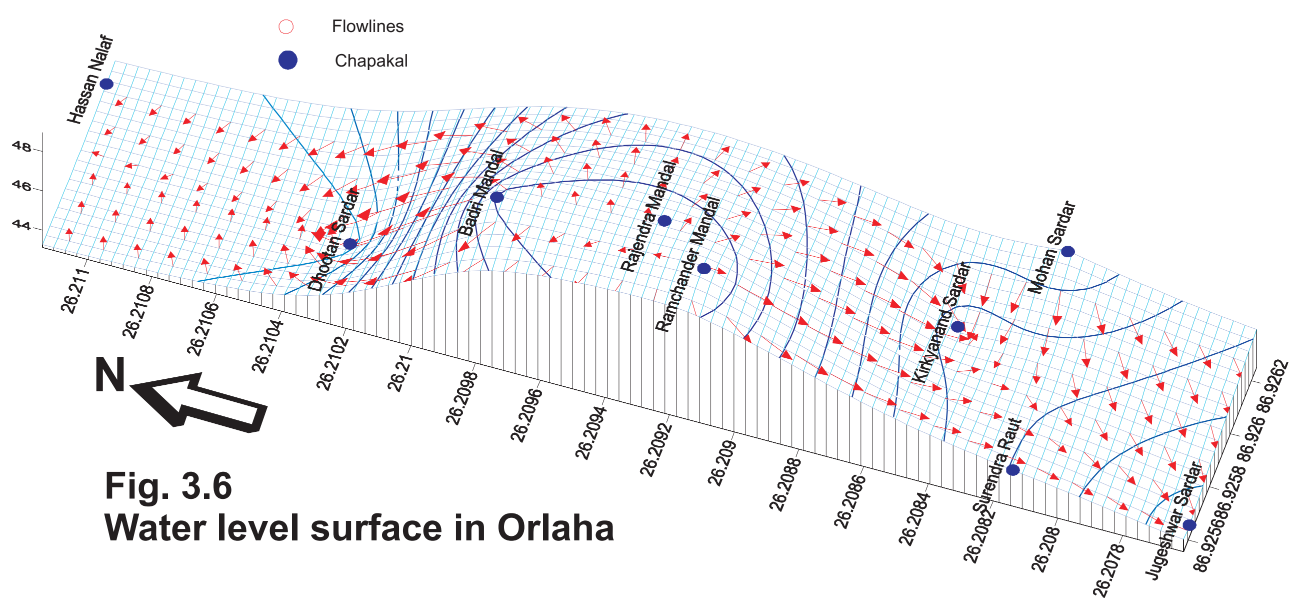


Fig. 3.6
Water level surface in Orlaha

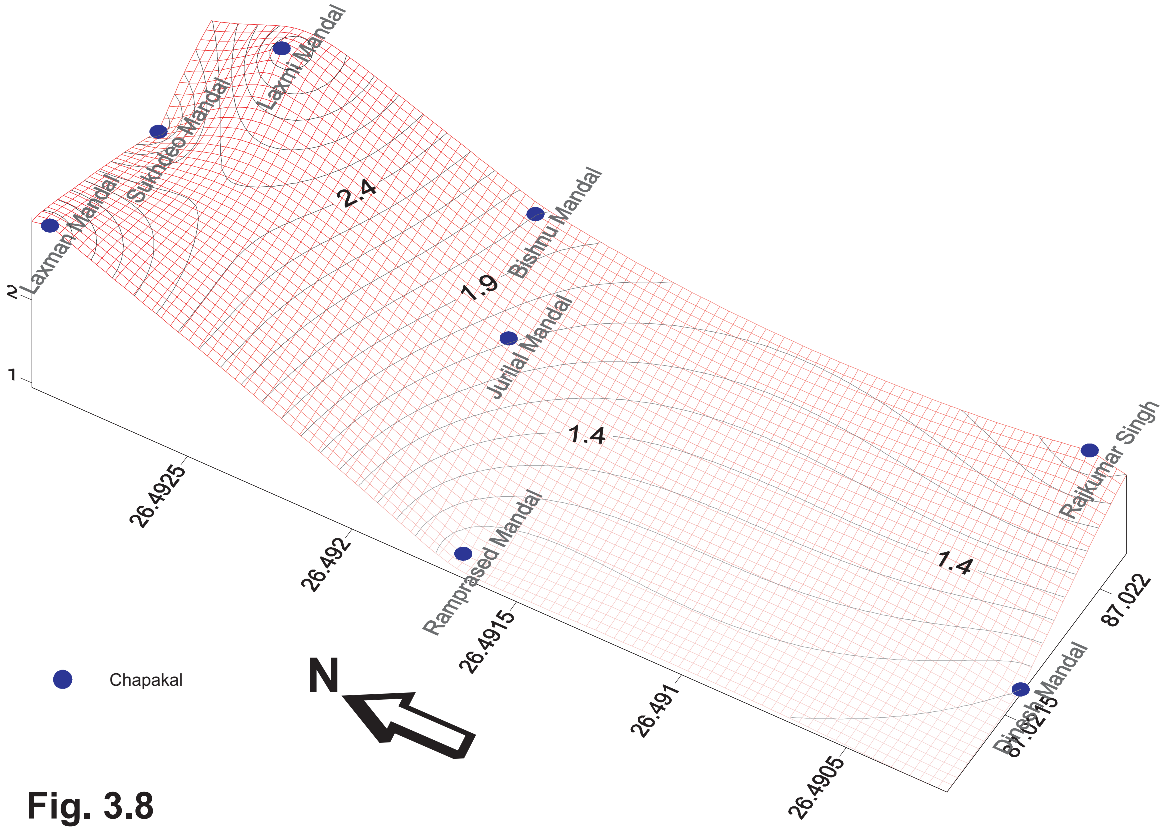


Fig. 3.8
Spatial distribution of iron in chapakals: Purainee

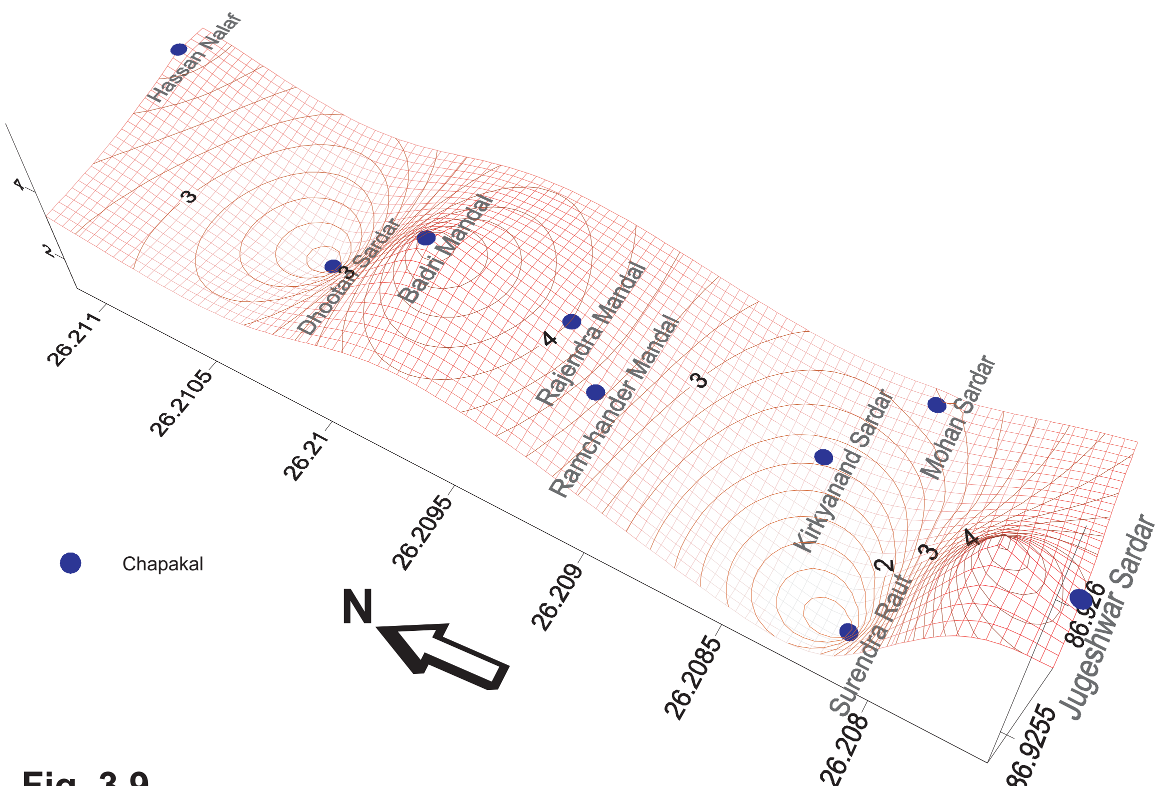


Fig. 3.9
Spatial distribution of iron in chapakals: Orlaha

Chapter 4: Inferences and recommendations

Brief background to iron in groundwater (*based on Driscoll, 1986)*

Iron is common to igneous rocks found in many parts of the world. Most importantly, it occurs in practically all sediments in *traces*. This clearly means it will be common to areas underlain by sediments, such as the Kosi sediments of North Bihar. However, if the source regions for sediments has rocks with high iron content, it is likely that sediments also possess a high proportion of iron. Concentrations can vary between 1 to 5 mg/l - a common range - falling to 0.1 mg/l in water that is aerated during pumping or treatment. It is common to find iron in the dissolved form in the more *corrosive groundwater* - groundwater with low pH and high oxygen content. Standing water is more likely to have iron as compared to flowing water.

In natural groundwater, with low oxygen content, and possessing pH between 6.5 and 7.5, iron is mostly dissolved as *ferrous (Fe++) ions*. When oxygen levels are nearly zero, even at a pH of 7, iron concentrations can be very high, peaking to 50 mg/l. Ferrous ions are unstable when in contact with oxygen; in presence of air, these ions change to *ferric (Fe+++) ions* and iron precipitates as oxides and hydroxides. Ferric iron is unsoluble in alkaline or weakly acidic waters. Aeration of water having a pH between 7 and 8.5 implies that iron becomes insoluble. *Sudden changes from the ferrous (dissolved) to ferric (semi-solid) state creates major problems concerning iron in groundwater.*

Inferences for Purainee and Orlaha

The geological observations in Purainee and Orlaha helped draw certain key inferences. These are listed below:

1. Although water levels in *chapakals* at both locations are shallow, it is expected that the water levels in Purainee represent certain hydrostatic pressure (Fig. 4.1) and recharge to the aquifer is from a location that is actually outside the boundaries of the village. In Orlaha, the limited observations indicate that water levels represent a phreatic surface (unconfined), wherein the water table is approximately at atmospheric pressure (Fig. 4.2). The recharge zones are in close proximity to (perhaps even within) the village.
2. The fact that most *chapakals* have iron content and dug wells do not, points to the fact that reducing conditions prevail in chapakals as compared to conditions in wells, where a certain amount of aeration takes place.
3. *Most chapakals showed a low dissolved oygen (DO) count.* Although it is difficult to state convincingly on the basis of limited observations and data, in all likelihood, discharging groundwater is likely to encounter oxidation conditions, leaving it with lesser iron than when the water levels lie slightly beneath the surface (Figs. 4.3 and 4.4).

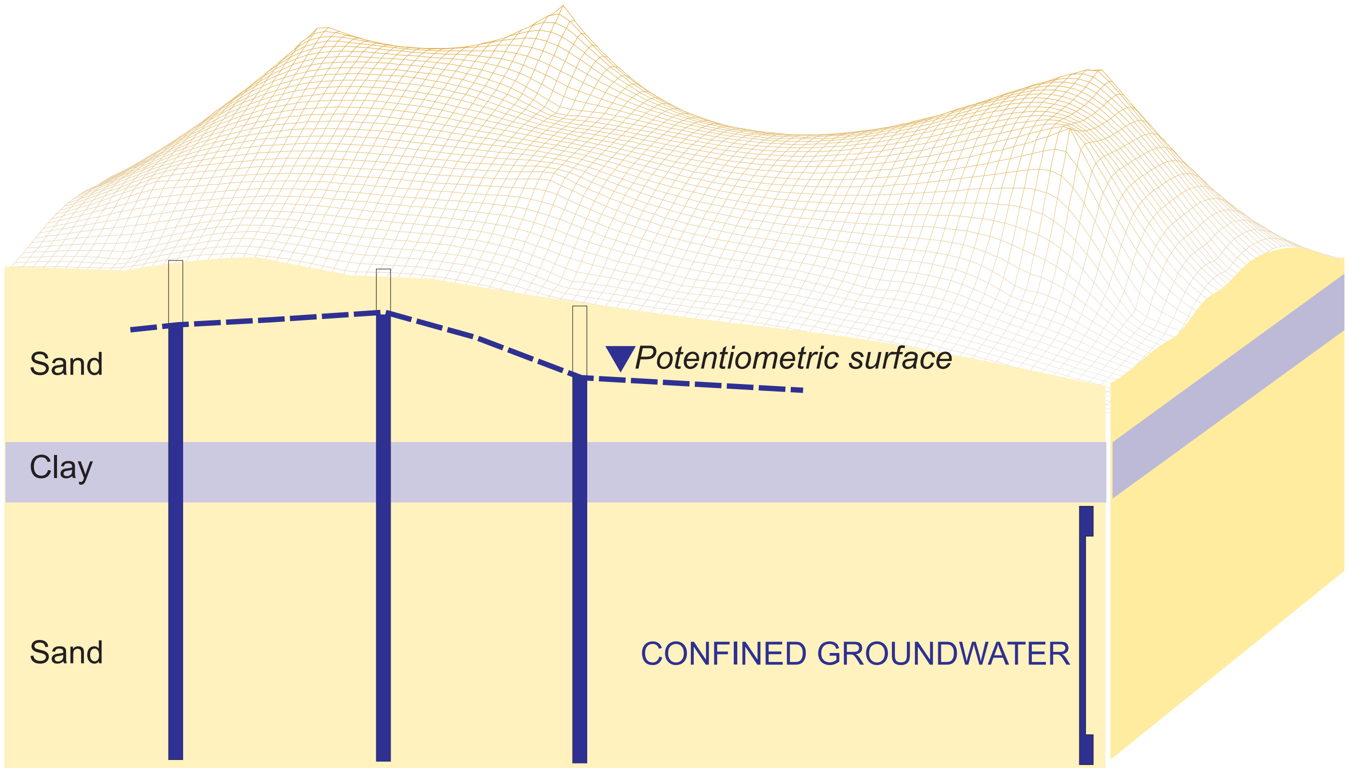


Fig. 4.1: Conceptual representation of groundwater in Purainee

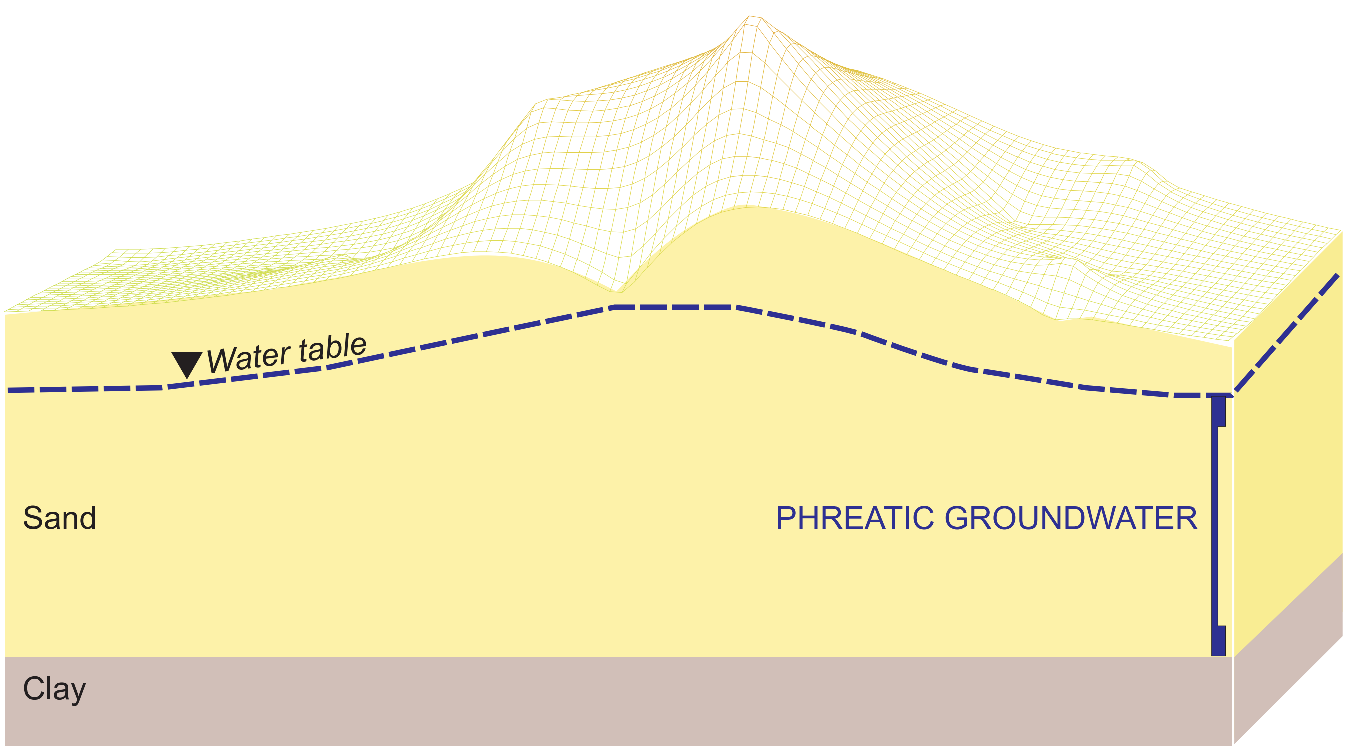


Fig. 4.2: Conceptual representation of groundwater in Orlaha

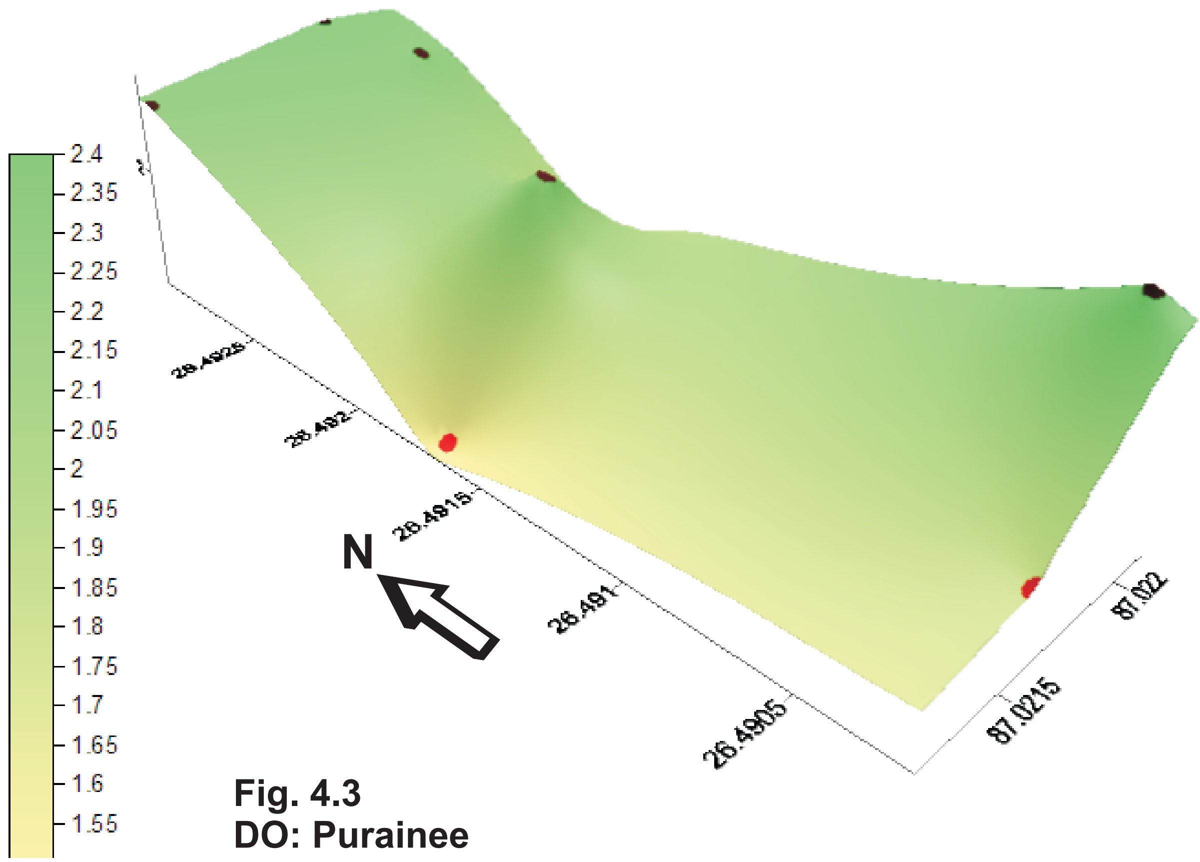


Fig. 4.3
DO: Purainee

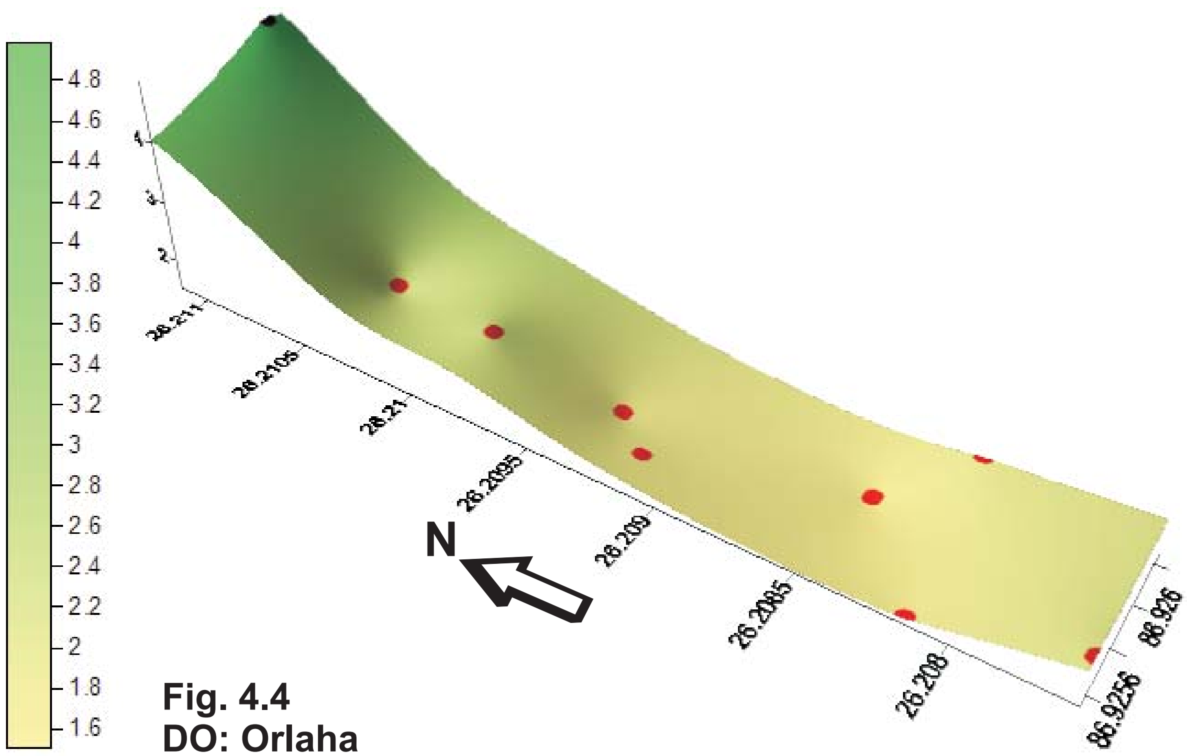


Fig. 4.4
DO: Orlaha

Recommendations

The following recommendations are being made with a view to develop a strategy - a set of *water use actions*, bearing in mind the flood-proneness of the villages as well as the analysis of the groundwater situation - emerging from this rather rapid study. The strategy, primarily seeks to provide improved 'quality' water to the two villages, bearing in mind the context and the situation.

Purainee and Orlaha are located in a flood-prone setting, underlain by thick stacks of sediments brought by the Kosi river system - sediments that show variation in grain size from clay to coarse sand, even gravel. These sequences of sediments create complex systems of groundwater occurrence and movement. Water levels remain close to the surface of the ground throughout the year (needs verification), but there are gentle gradients to the water level surface, inducing groundwater movement even under a single village. The levels of dissolved oxygen are low, implying that reducing conditions prevail. Consequently, one would expect iron to be prevalent too. In the absence of large scale sanitation facilities, the risk from on-site bacterial contamination remains to be high, especially during the rainy season, when the thickness of the unsaturated zone within the subsurface is bound to be at a minimum. With this background, the following is recommended as a strategy for Purainee and Orlaha:

1. Monsoon season: Rainwater harvesting *above the ground.* Sub-surface storage, including groundwater recharge to be avoided. Harvested rainwater should be used during the monsoon, and especially during floods. *A practice of using it as drinking water is already being promoted and there are positive vibes from the community in this regard...*

2. Winter and summer seasons: The dry season, following the monsoon could be a transition from using harvested rainwater to using dug well water. The areas which are likely to yield safe water (quantity and quality) for a dug well have been indicated in figures 4.3 and 4.4 for the two villages respectively, based on the geology, distribution of water levels, patterns of iron variability and dissolved oxygen. The exact site may be decided through a participative process involving the community in both villages.

3. It would be a challenge to move people from using *chapakals* to using dug well water, especially during the dry season, as access to water is rendered easy with the *chapakal*. However, a simple protocol of collecting water from a dug well and storing it at the household level - only for drinking - could be initiated. For other uses, *chapakal* use could continue...

4. Detailed water quality monitoring in both the villages would further consolidate the recommendations made here, even yielding a higher degree of specificity to the location of dug wells.

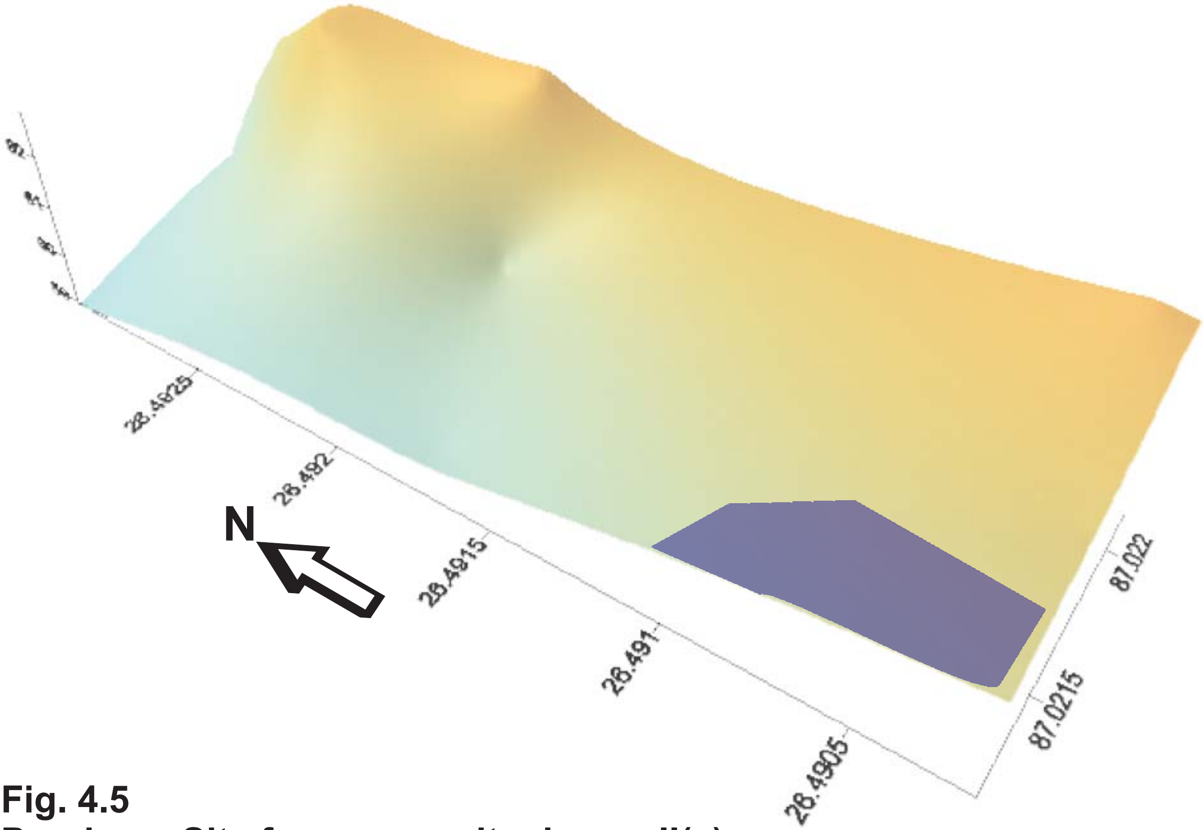


Fig. 4.5
Purainee: Site for community dug well(s)

LEGEND: *Area for dug well construction*

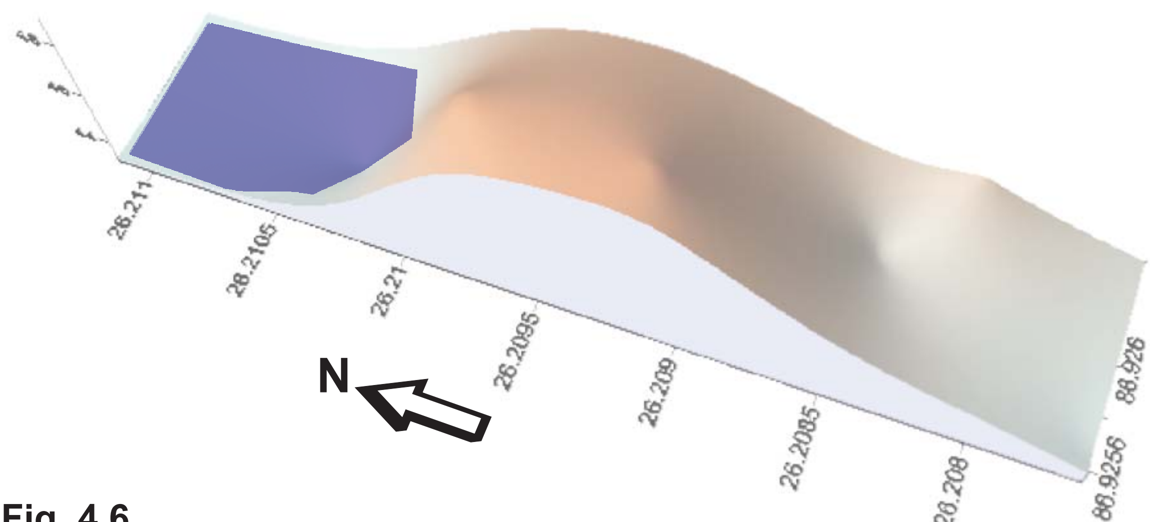


Fig. 4.6
Orlaha: Site for community dug well(s)

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