PARTICIPATORY AQUIFER MAPPING: CATALYSING A SOCIAL RESPONSE TO MANAGE GROUNDWATER

BIOME ENVIRONMENTAL TRUST

ACWADAM

2017

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PART I: Executive Summary

Genesis of this program

Wipro Ltd (Wipro) headquartered at Bengaluru, has long running programs focusing on social challenges in education and ecology. One of its initiatives, started more than three years back, focuses on the issues of urban water. This was a genesis for a partnership between Wipro and Biome Environmental Trust (Biome), also based out of Bengaluru. Biome Environmental Trust had been working (and continues to work) with many urban communities, especially in Bengaluru, to help increase water literacy and the uptake of sustainable water practices such as rainwater harvesting, groundwater recharge, wastewater reuse and demand management.

In this dialogue, two of Wipro's campuses (Sarjapur Road Campus, Bengaluru and its Campus in Sholinganallur, Chennai) were studied to understand how Wipro sources and uses its water and re-uses its wastewater. From this study, it became clear that Wipro is already striving to continuously increase its water use efficiency "inside its fence". However, these campuses were still highly dependent on groundwater a significant quantum of which was imported from "outside its fence". This dependency also stemmed from the larger context of rapid urban growth leading to urban India's increasing dependence on groundwater.

This dialogue then further evolved into a broader partnership between Wipro, Biome, ACWADAM (Advanced Centre for Water Resources Development and Management) and MapUnity. ACWADAM is a Pune based groundwater think-tank and advocacy group. It has been chair of the groundwater sustainability committee under the Planning commission under the UPA-2 central government. ACWADAM has been striving to bring to bear the science of hydrogeology and groundwater resources into water resource management concerns of the country. MapUnity is a Bengaluru based firm specialising in development and deployment of digital tools to enable civic participation and action by an active citizenry.

This partnership was developed to bring focus to the increasing use and dependence of urban areas on groundwater in the Indian context. More specifically this partnership set out on a 3-year program of "Participatory Aquifer mapping" meant to address the nearly complete void in deeper understanding of urban groundwater and its linkages with other urban processes.

However, the program was designed very intentionally to be an action-research program rather than just a research program – which engages with citizens and communities using groundwater. It was designed this way to serve many purposes.

1. Firstly, the nature of urban groundwater is complex - it involves extensive groundwater extraction and not necessarily always intensive (i.e. high density of wells with smaller extraction of groundwater per well and the inability to control pumping across these wells - unlike in irrigation). Further urban groundwater use is also very dynamic with new wells appearing and old wells drying up very rapidly - in the Bengaluru context almost on a daily basis. It is not easy to apply conventional hydrogeological research tools only (eg: static water level measurements or pump tests in wells) given this nature of urban groundwater. In this context, the knowledge emerging from the narratives of the lived experience of groundwater users and their relationship to their wells becomes a very important source of understanding.

2. Secondly, engagement with the community was also an equally important objective if Wipro's sense of responsibility needed to be fulfilled.
3. Thirdly, in the current context the formal institutions' approach to urban groundwater understanding is still based on data from non-granular sources (eg: sparsely located observation wells) that misses the complex and dynamic nature of urban groundwater.
4. And finally and most importantly the program was designed this way to enable outcomes from the program - in terms of demonstrated change in groundwater user practices towards sustainability - rather than focussing solely on knowledge and policy advocacy outputs.

Objectives of the program

The critical objectives of the designed program therefore were:

1. It was designed to engage and involve as much with groundwater users of the city to make them become a part of the knowledge generation process. Hence it was titled a "Participatory Aquifer mapping process".
2. The combination of the above participatory processes and secondary/primary data collection was designed to generate a deeper understanding of the groundwater aquifers in the defined boundary of the program.
3. It is meant to help inform these users with actionable knowledge that emerges, and help nudge them towards the actions that can contribute towards more sustainable groundwater use and its management.
4. Finally it is meant to use this entire process to help create new conversations with institutions of governance to (a) bring to focus the importance of urban groundwater use and integrate it into resource planning (2) demonstrate and envision alternative ways of managing water and groundwater - especially highlighting the role citizens (groundwater users), the informal and formal private sector watsan and related products/services that shape the waterscape of the city and the role good communication to citizenry could potentially play.

This program therefore had three critical elements:

a) A set of processes to drive the "participatory" dimension of the program : which was achieved through the combination of events, one-on-one interactions with citizens, communities (eg: Resident welfare associations, institutional campuses, schools etc), one-on-one interactions with service providers such as well & borewell diggers/maintenance service providers, fishermen at lakes etc, public education campaigns on various kinds of media, and formal and informal workshops with different stakeholders. This also involved facilitating dialogue between citizenry and institutions of governance such as the BBMP, BWSSB and the KSPCB. Biome has anchored and coordinated these processes.
b) A set of processes to collect data and groundwater stories – in which citizens and communities contributed in various ways through the above participatory processes – validate this data, and conduct analysis and arrive at inferences on this data from a hydrogeological perspective. The role of ACWADAM has been critical in enabling this.
c) An online space (which is www.bengaluru.urbanwaters.in) which was designed to be a common platform for the city of Bengaluru (replicable for any city) on which the learnings from this entire program would be available and be shared with the city and country at large. This space is meant to evolve with more contributions of stories, experience and data by the citizens of the city. This program will continue to live through this online space.

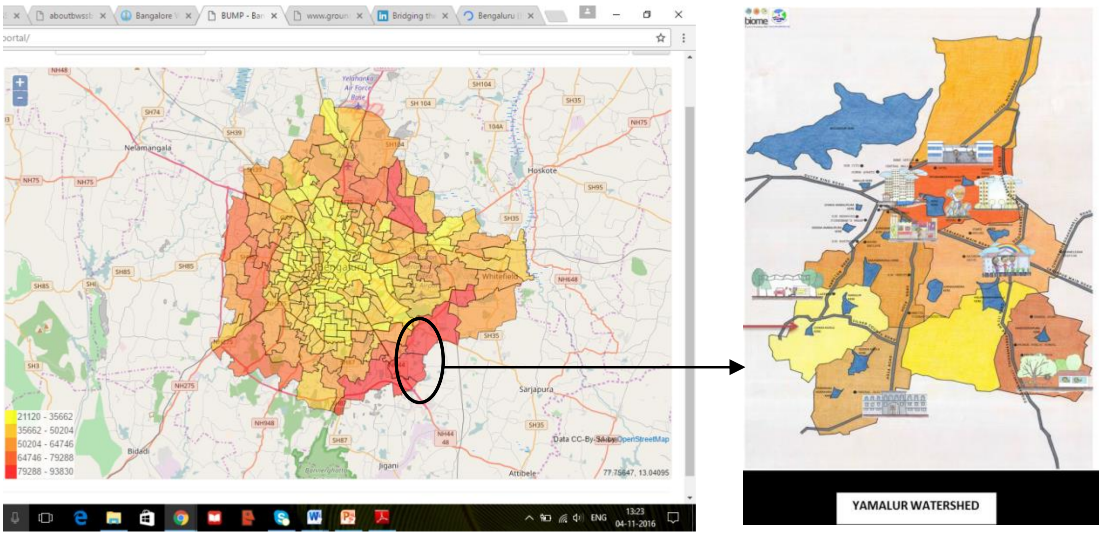
The Geographical focus of the program

Given the participatory nature of the program and the need to engage with proximate communities to Wipro's campuses it was important to find a geographic boundary for this experiment which satisfied the following key criteria:

1. Any of Wipro's campus is a part of the geography
2. It is small enough to develop an understanding and manage participatory processes at this stage of development of the idea of "participatory aquifer mapping"
3. The geography represents patterns of urban growth
4. Ideally the boundary is completely dependent on groundwater and has little influence by utility supply (during the action research). This means that subsidised water supply does not exist.
5. The geography also represents urban water features such as tanks, lakes and/or wetlands.

With the above criteria in mind, a contiguous block of 8 micro-watersheds in the larger Upper Ponnaiyar watershed of the south-eastern part of Bengaluru was selected. A large campus of Wipro is in this watershed. However, since we started the program, utility has started supplying water to some of the locations within the watershed.

These micro-watersheds of the Upper Ponnaiyar watershed (hereinafter referred to as the Upper Ponnaiyar watershed in this report) are shown in the map below:



The program area is in south east part of the Bengaluru city spread across 33.81 sq.km. These 8 micro-watersheds have a very mixed land use pattern of residential, commercial and institutional & business campuses. The area has 15 lakes that form two cascades. The majority area is groundwater driven and some piped water supply and no underground sewerage network. Administratively the area has multiple BBMP wards and the Halanayakanahalli, Kodathi Panchayat and Rayasandra and Chudasandra Villages which as per the census of 2011 accounts for populations of 117844 and 9797 respectively. The Halanayakanahalli Panchayat has some agricultural lands but is fast becoming urbanised. However, population has grown significantly since then and the area has a very high floating population coming in to work owing to the presence multiple commercial and business campuses.

The evolution of "Study clusters" within the watershed

While this participatory aquifer mapping process sought to establish a deeper understanding of the aquifers across the aforementioned Upper Ponnaiyar watershed, an interesting pattern emerged from the attempt to do so. Data and stories were gathered for analysis from across the watershed. A significant quantum of this data came from participatory methods. Therefore, data was collected in the following ways:

1. Through sharing of already available data from different communities that had gathered the data for their own water management needs.
2. Primary data collection of critical parameters in cooperation and with voluntary help from citizens and communities in their respective properties.
3. The collection of narratives of wells, borewells and their histories gathered from citizens and communities that was interpreted along with more quantitative data.
4. Primary data collection and secondary data collection by the program team through observations, literature review and consultation with other researchers.
5. The validation of some of the inferences through data collected specifically for validation (by the program team) through exercises such as Vertical electrical sounding and geological surveys.

Given the objectives of the program and the participatory dimensions involved, the program evolved to realise that:

1. Data is particularly valuable when it can lead to action – and therefore when there are citizens or communities who can then quickly act on the data and their inferences. In turn, this also catalysed some communities to engage in dialogue with some institutions of governance in the spirit of solving some critical problems for themselves and the city.
2. There were groups and communities whose participation was stronger and therefore this led to relatively richer data in certain sub-geographies albeit very micro-geographies.
3. The value of this "richer data" helped to focus on micro-geographies bringing in high granularity, and therefore to understand highly local groundwater issues and responses.

Therefore, while the 8 microwatersheds of the Upper Ponnaiyar Watershed was targeted, what was also done was to create "cluster studies" within this larger area which were data rich, and which had communities ready for "action" based on inferences. These cluster studies were attempts to understand in richer detail groundwater aquifers within smaller boundaries. While multiple clusters were scrutinised, the three clusters which were then studies in greater detail were:

a) Two gated communities (Rainbow Drive and Adarsh Palm Retreat) – both of them on a pathway to implement multiple investments and actions that helped solve not only their own problem, but also demonstrate sustainable groundwater (and in general water) management practices with many positive externalities for the city.
b) A cluster which connected the Kaikondrahalli Lake and its environs especially from the groundwater perspective. MAPSAS – a citizen driven Trust – has already entered a formal MoU with BBMP for the maintenance and management of a lake cascade in this watershed, of which the Kaikondrahalli Lake is one. This group could benefit in its work of lake management by the understandings of this cluster study.

The Watershed aquifer mapping process therefore has led to understandings at the level of the broader area, but has also led to the understanding of groundwater and related issues at micro local areas providing evidence of a rich mosaic of the groundwater drama in the city at very local levels.

Zooming out: taking a micro watershed view

The participatory aquifer mapping process has documented, enabled and catalysed individuals, communities and institutions to take a series of actions within their properties and "zones of control" in response to their own experienced water problems. Four kinds of demonstrated citizen and community actions have been identified within this larger watershed. They are :

- Better water demand management - reducing demand for water
- Making investments towards productive use of rainfall endowments through groundwater recharge, rooftop rainwater harvesting to supplement water supply, reduce flooding and help sustain groundwater sources;
- Making investments towards the responsible reuse and disposal of waste water;
- Engaging with local lakes to revive, maintain and help manage them.

It is important to explore the potential macro impact of all these actions. What do these combined actions mean for the city?. For the given nature of landuse in this part of the city, can the combined impact of these actions actually help solve its water problems? The following analysis and discussion "rolls up" the potential of these actions at the micro-watershed level. The Micro-watershed is chosen intentionally, as it is an ecological boundary. Further this analysis has been done on the Devarabeesanahalli micro-watershed for two reasons (a) It represents a very significantly developed micro-watershed within the larger watershed. (b) given the participatory approach and this programs engagement with various users within this micro-watershed, there is significant primary granular data available for this micro-watershed that has allowed demographic and water consumption data to be fairly well represented.

Consider now the example of the Devarabisanahalli micro-watershed in the area:

Devarabisanahalli micro-watershed has an area of 416.42 hectares, with an estimated mixed population (residential+floating / working population) of 157490 people of which 54% (85663) is a floating or working population and 46% (75827) is residential.

Area of the Devarabisanahalli micro-watershed	416.42 ha
Total Population (Residential+office)*	157490
Residential population	71827
Lake area	24.25ha

**(Arrived at based on primary data and land use analysis)*

Primary data collection and ground-truthing showed that the current residential water consumption is at an average of 200 lpcd, and that the floating population uses around 50 lpcd. Therefore, the total annual current water demand for this micro-watershed will be 7063 million litres a year under "steady state conditions" (i.e. without considering transient water use such as for construction). With an average assumed annual rainfall at 970mm in a normal rainfall year, the total rainfall endowment stands at 4039 million litres or only 60% of the water demand.

At the current water demand of average 200 LPCD or(250 LPCD @ higher end of consumption range) and 50 LPCD for Offices		
Total annual water demand	7063	ML/Year
Average Annual Rainfall	970	mm

Total rainfall endowment for the microwatershed	4039	ML
Rainfall Endowment is only 60% of the water-shed's current estimated "steady state" water consumption.		

If the most significant of the above four action by communities – demand management – is applied, the micro-watershed should bring down its residential water consumption by 65l pcd to 135 lpcd (as defined by town planning norms) and bring down the floating population water consumption by 10 lpcd, i.e. to 40 lpcd, we arrive at a total water demand of 4745 million litres per year. In this scenario, rainfall endowment represents a very significant 85% of the "steady state" water demand.

Bringing water consumption down (residential consumption to city norms of 135 lpcd and floating population consumption to 40 lpcd):		
Total annual water demand	4745	ML/Year
Average Annual Rainfall	970	mm
Total Annual Rainfall endowment	4039	ML
Rainfall Endowment ~85% of your total water demand		
Wastewater generated annually (@ 80% of freshwater used)	3796	ML/Year
If effective investment is made to productively utilize Rainfall endowment and resue waste-water where possible, at the micro-watershed level, for a normal rainfall year, water can be managed sustainably even for current land-use and demographics.		

In this context, the productive use of the water endowment becomes critical, which translates into investments into rainwater harvesting at various scales, from the individual, to the community, in institutions and at micro-watershed level scales such as in lakes. Additionally, from the hydrogeological analysis conducted, ***it is expected that the shallow aquifer can play a significant role in utilising the rainfall endowment effectively in this micro-watershed. The Adarsh Palm Retreat Cluster study – located in this watershed exemplifies this very well.*** The program has engaged with this community to transition their water supply to the shallow aquifer and ensure demand management is done. This is an ongoing engagement with the community. What cannot be captured from rainwater, has to be filled by efficient waste water reuse, in this case the remaining 15% gap between rainfall endowment and demand.

Given the above analysis (which can then be extrapolated to larger boundaries), creating an environment so that community actions which have been demonstrated are adopted widely and integrated into regular real estate development is a clear pathway towards better sustainability. Some of the learnings from the program about groundwater in these 8 micro-watersheds and more generally for the city are now summarised below. These learnings are presented also as key messages as the intent is to make these learnings actionable, and enable outcomes by catalysing community action.

The main outputs of the program

The main outputs of the program (of which this technical summary report is one) have been organised in the way described below. They can all be read or used as stand-alone pieces depending on the inclinations and uses of the readers. However, when they are interpreted as a whole they provide a much more holistic and richer perspective of Bengaluru and urban groundwater issues.

Technical Reports of the program

1. This Technical summary report
2. A report on the processes of data collection in the watershed

3. Hydrogeological analysis of the watershed and the three individual clusters

Papers written as a part of or in conjunction with the program

1. Citizens Demonstrate solutions: Rainbow Drive Layout and its water reforms (Published by GSI)
2. Urban Groundwater competition and conflict in Bengaluru and spaces of cooperation (Unpublished)
3. My well, our water : Can citizens become stewards of Groundwater (Published by Indian Society for Ecological Economics, 8th Biennial conference 2016)
4. Urban Water Systems in India (Published by EPW, July 25, 2015)

The replicable webspace "Bengaluru.urbanwaters.in"

In the original design of this program, a platform to communicate the learnings from this research and a platform to sustain a longer conversation with citizenry was conceived. This platform is beginning to take shape because of this program and it is called www.bengaluru.urbanwaters.in.

On this platform all the above outputs will be accessible. In addition this platform will contain various primers, guides and case studies (some of which are outcomes of this program) to help citizens and communities understand and adopt sustainable water practices. This web space is designed to evolve over time – with contributions from citizens, communities and researchers. This web space purports to be a "one-stop-information-shop" for all water issues of Bengaluru from the perspective of citizens, communities and institutions operating in the city. It hopes also to provide a window for institutions of governance to look at narratives emerging from the ground and valuable practices of progressive communities that governance needs to encourage and enable. This web space will continue to be managed and curated by Biome Environmental Trust post the program period. Biome will continue to help it evolve to make it more interactive, add content to make it relevant as time progresses and help it get a wider ownership from communities and relevant institutions.

It is also envisioned that as more cities begin and explore experiments of a similar nature, the "Urbanwaters.in" webspace will host the stories of other cities. It is that the current version has been designed as www.bengaluru.urbanwaters.in – any city can be a part of this as "city.urbanwaters.in". We invite cities to partner with us, learn from our program and collaborate to anchor similar experiments and conversations in their own cities.

Key Learnings and messages:

The most critical learning has been that groundwater is an urban common, a "common resource pool" on which everybody is dependent – and that users of groundwater and owners of openwells and borewells should start becoming a part of its management, if anything needs to be achieved. Moreover, it has also become clear that reviving and contemporising our open-well heritage and culture is the paradigm of groundwater management we need to move towards. In the contemporary context, this also means using water judiciously and treating and reusing our wastewater as much as we can.

The shallow aquifer(s): Openwells, recharge wells and lakes

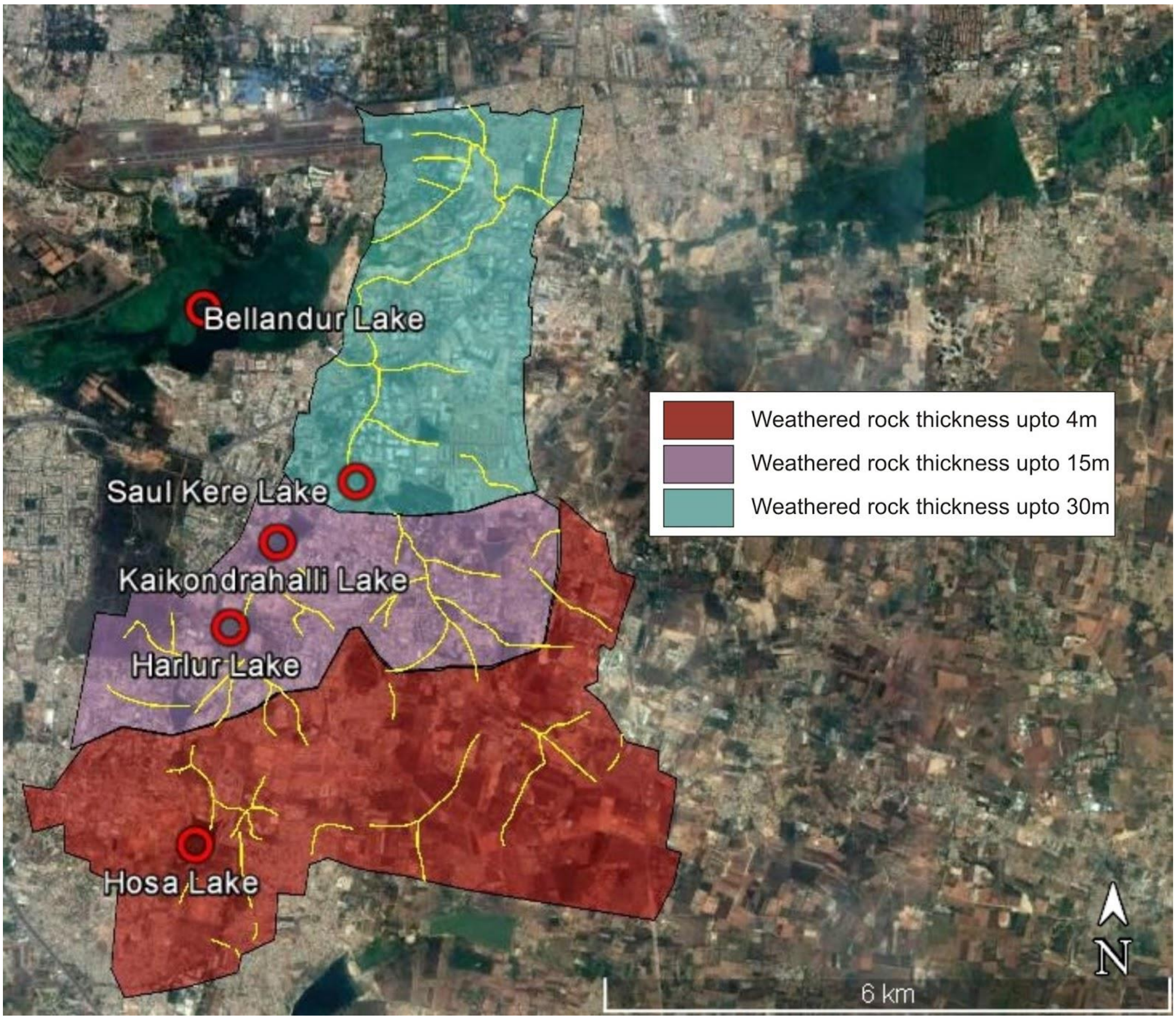
1. There are areas in Bangalore where open well (which get its water from the "shallow aquifer") has/can hold water. This is evident from the old open wells that are present in the city. This shallow aquifer can be a source of water by reviving and using the open-wells. This aquifer can be managed by a combination of withdrawal and "recharge".
2. Water from this shallow aquifer, accessed through open-wells, tends to be the cheapest source of water – both in terms of energy requirements as well as financial costs
3. A recharge well (A simple open-well of 20ft - 30ft deep, typically dry) is an efficient structure for shallow ground water recharge - this results in open-wells (shallow aquifer) and bore-wells (deeper aquifers) being recharged over time. Surface rainwater runoff can be channelled into a recharge well after some limited filtration - for groundwater recharge. This helps replenish the groundwater in the shallow aquifer.
4. Shallow aquifer recharge through a recharge well helps improve water quality in neighbouring open wells.
5. Dried up existing open wells should not be closed or used as garbage dumps - they can be used as very cost-effective groundwater recharge structures.
6. Good solid waste management and waste-water management is important to maintain the quality of water in the shallow aquifer. It should be ensured that no sewage or industrial effluent is let into the recharge wells.
7. Open wells near lakes tend to have water because the lake contributes to shallow aquifer recharge. These wells are good options as a source of water. The quality of water in the well is dependent on the lake water quality

The deeper aquifer(s): Lakes, borewells, recharge wells and open wells

1. Borewells in Bengaluru get their water from what are called "Deep aquifers" – which is water residing and moving in the cracks of fissures of rocks under Bengaluru. Water availability below 600 ft in Bengaluru seems limited. While sources may be found below 600ft, they are often not copious. Hence there does not seem to be a point in digging deeper. The financial investment in recharge structures is more judicious in such contexts.
2. Total Dissolved Salts of borewell water is found to be higher than shallow open well water. Hence the costs and energy requirement for treatment of borewell water is higher than that of shallow open well water.
3. Hydrofracturing does not necessarily increase water yield in borewells.
4. Deeper aquifers can be recharged by recharging dried up borewells which were once yielding. However, this kind of direct recharge should be attempted only with clean rooftop run-off rainwater only to maintain quality of water in borewells.
5. Lakes do not seem to recharge deep borewells in a 3-5-year time frame. Rejuvenation of lakes has not necessarily resulted in high yields from neighbouring borewells.

About the Aquifers in the 8 micro watersheds

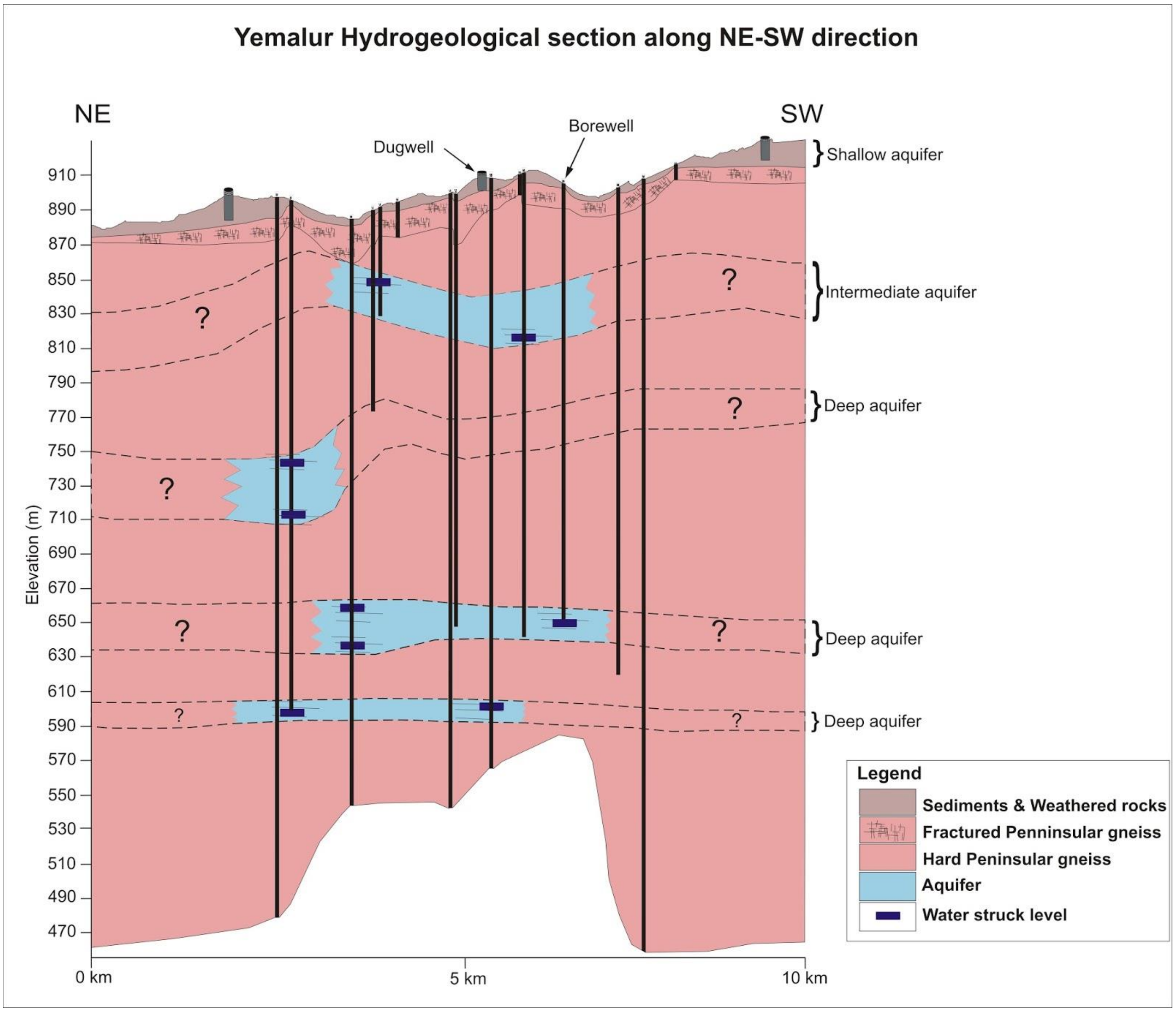
1. Central and northern parts of these watersheds seem to have thicker sediments and weathered granitic rock profile. Hence the probability of storage of shallow groundwater towards the Bellandur side seems higher. This is represented in the map below.



The area of the eight micro-watersheds in which participatory Aquifer mapping was undertaken and the "weathered rock" thickness. Where the weathered rock is thicker, the likelihood of openwells becoming a potential water source is higher.

2. The following aquifer systems can be categorised based on the depth below ground level

   Shallow Aquifer: 0-30m (in the shallow weathered zones)
   Intermediate Aquifer: 35-80m (in hard rock)
   Deep Aquifers: 100-152m, 180-205m, 210-250m, 290-335m and 366-396m (in hard rock)



Aquifers in the 8 micro-watersheds

The above is represented in a figure below:

3. Most areas in the watershed demonstrate good recharge rates (recharge rate is a measure of how quickly water can be put back into the aquifer through a recharge structure) into the shallow aquifer from recharge wells.
4. The lakes in the watershed are good recharge structures for the shallow aquifer - especially given the fact that shallow aquifer is largely dry
5. Shallow wells adjacent to rejuvenated lakes are yielding good quality water and people are starting to use shallow aquifer water as a supplemental source of water. Some of these wells

are perennial. The quality of well water is such that with limited treatment it can even be used for potable purposes

An openwell near Kaikondrahalli lake which was revived and is now yielding enough water to be the supply source of an apartment community

Other learnings on how groundwater can be managed

1. There is a need to monitor, collect, maintain and understand water related data (eg. Water demand, water supply, sewage treatment capacities and reuse, data on borewells, open wells and lakes) and share it with the city. This data can then help us understand and manage our groundwater better. Please do share your data and stories which will be reflected on www.bengaluru.urbanwaters.in by writing to us at: water@biome-solutions.com
2. The existing regulations on groundwater and rainwater harvesting are not very well understood by citizens as well as service providers. There is need for better dissemination of this information as well as enforcement. www.bengaluru.urbanwaters.in will soon have a section explaining existing regulations.
3. The learnings from this effort can be of relevance to other urban centres. The methodology can be adapted keeping in mind the institutions, land-use and hydrogeology of the other urban centres.
4. The well diggers, especially the shallow well diggers can be a treasure trove of information on the availability and usage of shallow aquifers in the city. Digging recharge wells provides them with livelihood as well as helps increase the groundwater table in a city.
5. The traditional livelihoods of the Manu-vaddar community can be revived by digging recharge wells, desilting of lakes and revival of old open wells

The reviving of existing openwells: The mannuvaddar community are specialised in well digging, revival and lake desilting.

The main outcomes of the program

During this program, several communities – both within this program area and elsewhere in Bengaluru – have been catalysed (At least in part due to this program) to adopt incrementally more sustainable water and groundwater practices. Some of these practices and community stories have been documented as case studies in the www.bengaluru.urbanwaters.in web-space.

In addition, important conversations with institutions of governance in Bengaluru have begun on some of the learnings emerging from this program. For example, staff of various levels (from foot soldiers to decision makers) of the KSPCB, the BWSSB and the BBMP have visited some of the communities showing exemplary water management practices. Similarly, visitors from all over India engaged in research, education and water governance have also visited these sites.

Finally, this program is beginning to contribute to a national discourse on urban groundwater. Bringing focus on urban groundwater and the need to understand how it can be integrated into planning and how it can be managed has been a subject that has hitherto not received any attention at the level of policy of wider practice from the institutions of governance. This program has contributed significantly by demonstrating a participatory pathway for knowledge generation as well as creating a case study with data of urban groundwater research and management. ACWADAM, has integrated and continues to integrate the learnings of these in its capacity as a national groundwater thinktank and policy influencer.

While the 3-year program supported by Wipro has come to a closure, the work of participatory aquifer mapping is far from over. All collaborators continue with their efforts to push the ideas and principles of this program in all their continued efforts. Further Wipro has also committed to support further work related urban groundwater to explore the role of wetlands for the city of Bengaluru as well as understand groundwater in the Peri-urban context of Bengaluru – near Devanahalli. This program therefore continues to be work in progress, striving to understand better and create longer term outcomes by influencing the actions of both citizens & communities as well as institutions of governance.

Part II: Participatory Approach and the Process

Data on Groundwater:

Data plays a crucial role in assessing groundwater resource and then in planning towards managing the resource. However, groundwater resources continue to be a 'blind spot' in urban planning on one side and 'Groundwater Management' on the other. City water agencies only provide estimates of the groundwater that they 'officially source' and 'officially supply' with no records of the amount of groundwater that is privately extracted in a city (Planning Commission, 2012).

Access to data on groundwater use or even availability in an urban setting is thus the biggest challenge faced. The answers to specific questions like Should I do recharge? Where to do recharge? etc. needs dynamic understanding of the resources in addition to the historical data. The important data points pertaining to the data on groundwater are rainfall, borewell, openwell, etc. However, lack of documentation about borewell from concerned stakeholders/beneficiaries as well as lack of land exposures/quarries for making geological inferences makes it difficult to develop an aquifer level understanding in urban areas at micro scale. While on one hand there were challenges in the data collection and new approaches were needed to be thought of, on the other hand the challenge of building a set of resources that can be actionable were needed as well.

Hence, an exploratory experiment of participatory aquifer mapping (PAQM) was initiated to understand urban aquifer in the Upper Ponnaiyar watershed.

Participatory Approach:

The following stakeholders were involved in the entire process:

Types of Stakeholders	**Processes of engagement** **& nature of participation**	**Contribution**
RWAs, POAs individual households and individual citizens	Contribution of data from their own records, permission to install regular monitoring devices, one-time measurements onsite. Engagement through events/workshops. Creation of "Citizen data Volunteers"	Data & stories about demand, supply, wells/borewells & waste water management Skills such as documentation, video/photo & communication design

Business campuses and their employees	Contribution of data from their own records, permission to install regular monitoring devices, events/workshops to engage further	Data about demand, supply, wells, borewells, STPs, employee data
Service providers (Borewell diggers, camera inspection etc)	One-on-one conversations, Events & workshops. They are citizens too.	Data from their service records, knowledge of what's happening in the region
Institutions of Governance	Sharing of the available data with the team, facilitating visits to share the existing practices, engaging for sharing existing 'pain points' and suggestions for adopting new ways to address the same	Data on water sources, citizen dialogue to address the 'pain points' though things could not move further
Research Institutions	Collaborating to bring in the research process and analysis, inferences of collected data	Citizen science project Kaikondrahalli Lake for facilitating informed citizen decision making

Process of data gathering for each data points:

The data was collected for existing natural resources and for understanding demand-supply in the watershed. While we started off with an objective of understanding water availability, and scenario building based on that, as the project progressed, we realized that with the participatory approach we were able to gather the rich and meaningful data in particular 'clusters' which would lead to actions. Thus, even though the data and narratives were gathered from across the watershed, meaning data was from the 'clusters' and hence the water availability and scenario building is done at the cluster level wherever possible and not at the watershed scale.

Natural Resources:

The following are the critical natural resources in this urbanizing watershed and the following table elaborates on the significance of each natural resource (what data), reasons for collecting the same (why data) and how they were collected (how data). The different approach followed to gather data about each of the natural resource has been a critical learning process.

Type of natural resource	**What Data**	**Why Data**	**How Data**

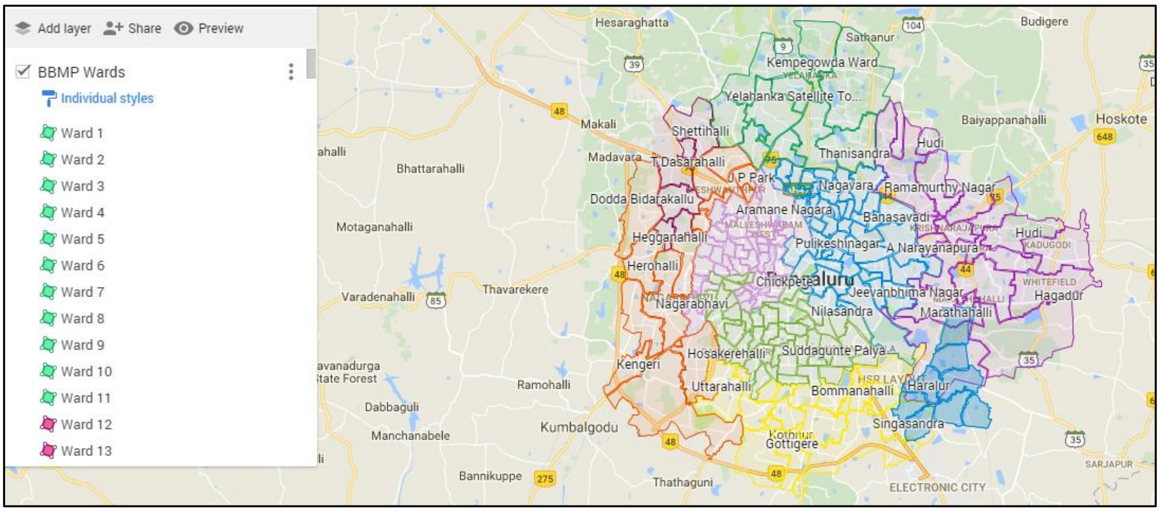
Watershed	Drainage	Flow of water, catchment	Secondary sources, KSRSAC remote sensing data
Geology	Exposures, Quarries, Borewell fracture, Rock type, direction of fractures, etc.	Aquifer depths, thickness, Type of aquifer, Connections between aquifer	Secondary data from Mines and Geology Department, CGWB. Primary data from quarries, excavation, service providers. A mix of participatory and secondary
Rainwater	Rainfall	Percolation/recharge of the aquifer, input to the watershed,	Secondary data from KSNDMC, Yuktix AWS (citizen networks for weather monitoring exists - WeatherOfIndia WA group) and Participatory data from one of the residents in RBD
Lakes	Well in the vicinity, water quality, sewage inflow, water flow, water balance, water level	Connections with the shallow aquifer in terms of water level, water quality	Secondary sources like Lake DPR, primary data from pumping tests, water quality testing, ATREE and citizen science project using automatic data loggers, MAPSAS
Aquifers	Borewell and Open well-water quality, yield, history, inventory	Aquifer Map, drive action	Primary data through participatory data collection on Facebook, Events, Clusters, Questionnaire. Direct measurement of water levels and quality regularly and VES for validation at macro level

Understanding Demand and Supply

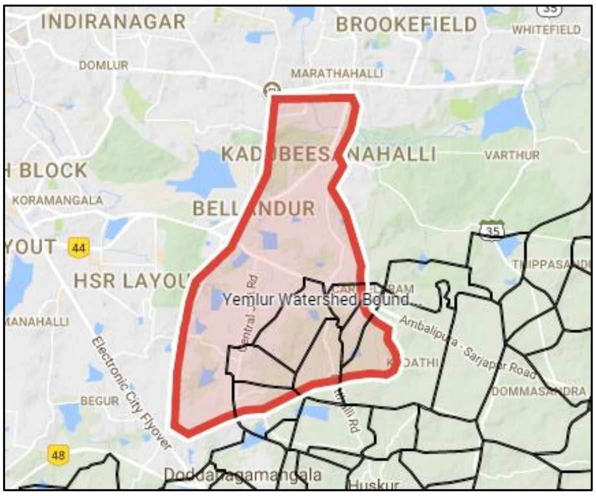
This geographical location was chosen because of the total dependence on groundwater. However, during the action research project, some of the locations started receiving utility (BWSSB) supply. As mentioned above, the nuanced understanding of the demand and supply is not available at the watershed level but at the cluster level. The below text explains the process of data gathering in the watershed to highlight the challenges involved in doing so and emphasizing the importance of cluster level understanding. Therefore, the following details elaborate on the process of understanding demand and supply at the watershed as well as representative clusters.

Demographics in the watershed:

The watershed is a mix of land use. The area covers residential, commercial, institutional establishments. Below map is an overview of the administrative units covered by the watershed. The watershed covers 7 BBMP wards and 7 non-BBMP areas under different Panchayats.



Watershed layer laid over BBMP ward map



Watershed layer laid over Non-BBMP areas

Ward Name	Ward Area (sqkm)	Intersection Area (sqkm)	Residential Population (2011)
HAL Airport	6.8	0.47	2697
Belanduru	24.2	15.03	49653
Marattahalli	8.34	2.15	9713
HSR Layout	6.56	0.06	485

Mangammanapalya	3.96	0.28	4815
Singasandra	9.41	5.48	50090
Begur	18.77	0.09	392
TOTAL	**78.04**	**23.56**	**117844**

Village Name	Area (sqkm)	Intersection Area (sqkm)	Residential Population (2011)
Halanayakanahalli	2.83	2.83	3648
Chikkanayakanahalli	2.11	1.69	1052
Hadosiddapura	0.86	0.77	824
Chikkanalli	1.02	0.82	46
Rayasandra	2.04	1.02	1169
Choodasandra	1.55	1.55	2476
Kodathi	7.14	1.43	582
TOTAL	**17.55**	**10.11**	**9797**

	sq. km	Residential Population
Total intersection area within BBMP limits	23.56	117844
Watershed area outside BBMP limits	10.11	9797
Total watershed area	**33.67**	**127641**

The residential population was available for Census 2011. However, the population could not be figured out for large and small scale commercial establishments, institutions, slum settlements, etc.

Water Supply:

When this study was initiated, the BWSSB water supply was negligible and most dependence was on borewells or tankers. However, some of the areas in the watershed have started receiving BWSSB water supply during the period for which the exact numbers are not known.

Even arriving at approximate information about water supply to this region was difficult. The watershed and ward boundaries and BWSSB divisions overlap and intersect each other. The secondary data therefore was not found useful. The primary data collection was again challenging since this is a dynamic data and people are cautious about sharing such data. The combination of participatory primary data and secondary data found to be less helpful. In further studies, this learning need to be taken and another approach to be tried.

The only conclusive mention can be made about this watershed is that there is multiple sourcing that happens in this area with groundwater, BWSSB and tankers being the primary supply sources.

Water Demand:

There were different approaches that were tried to arrive at the water demand in the area. The actual consumption varies greatly across the watershed owing to the land use pattern.

Water Demand based on the population data:

Only the residential population is known, therefore the water demand could be arrived for residential population only.

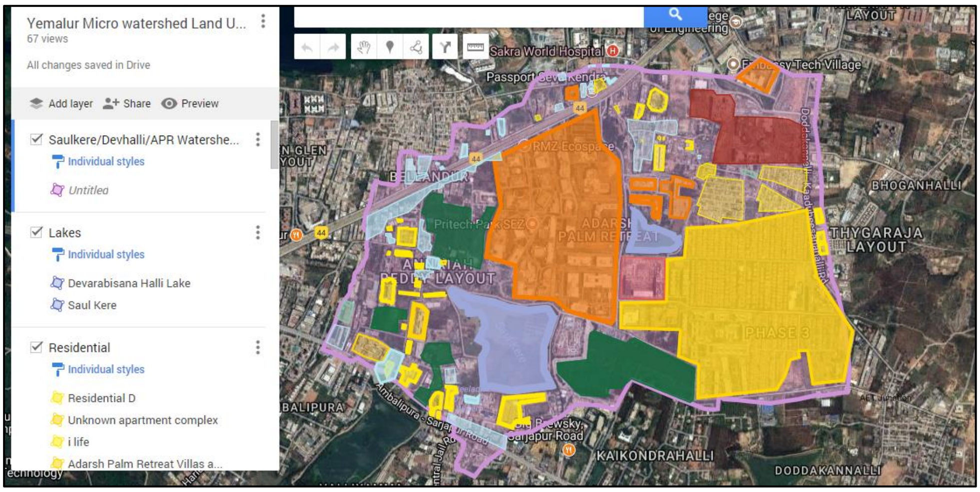
	Residential Population	**Demand (MLD)**
Total intersection area within BBMP limits	117844	18
Watershed area outside BBMP limits	9797	1
Total watershed area	**127641**	**19**

The residential water demand is 19 MLD in the watershed.

Water Demand from observing actual landuse in the micro-watershed:

Devarabeesanahalli Micro watershed (on 416 hectares) is one of the most populous watershed in the 33sqkm area under study as it proximate to the Outer Ring Road and hence has many office spaces as well as residential areas. An earlier population study based on 2011 census data had identified a population of between 1 -2 lakh people across the 8 micro watersheds on 33 sqkm area which seemed a little conservative. Hence a different approach was adopted to identify the population and then the water demand in the area

Properties in the entire watershed were named and marked on Google Maps. The markings were made based on site visits as well as an understanding of the place These properties were then categorized as Residential Spaces, Office Spaces, Commercial Spaces (like hospitals, hotels, restaurants) and lake/forest spaces. Population in the office and residential spaces was worked out based on interviews and secondary data. A domestic demand of 200lpcd and 250lpcd was assumed (based on multiple earlier demand studies). For the office spaces, a daily demand of 50 lpcd was assumed. Lake and Forest spaces were assumed to have no water demand. The demand for Commercial spaces could not be ascertained and hence no assumptions were made for the same. Based on this methodology, the water demand for the 416 hectares was arrived at to be between 19MLD - 20MLD. This demand was further extrapolated across the other 7 micro watersheds to arrive at a water demand of between 100-130MLD in the 33sqkm Upper Ponnaiyar watershed.



Devarabisanahalli Micro-watershed

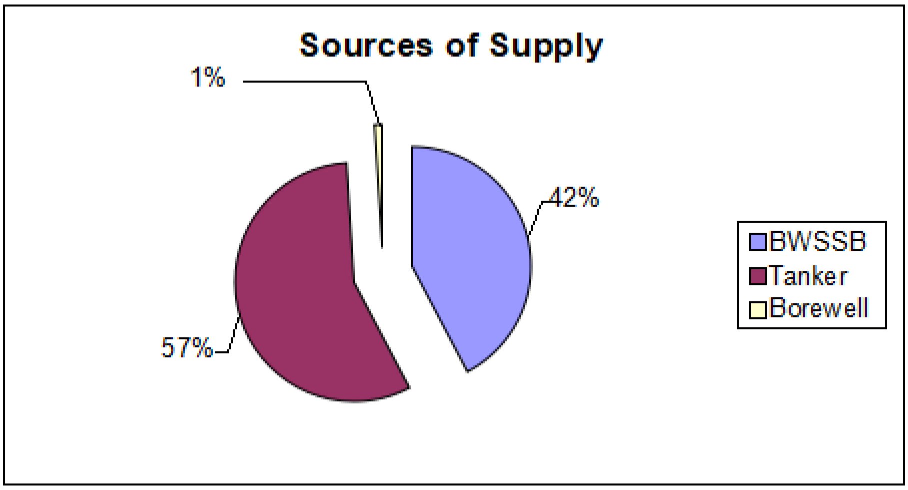
Water Demand and Supply at a Cluster: Adarsh Palm Retreat (APR)

Adarsh Palm Retreat (APR) is one of the clusters of this project. APR is located off Bellandur. The engagement with APR started with the residents complaining of basement seepages and flash flooding near the entrance. Further engagements with the community as well as hydrogeological study revealed that the shallow aquifer thickness is quite high in this area i.e. upto 30m there is a highly weathered rock.

Demand and Supply:

An assumption was made that demand is equal to the supply since the actual demand numbers were not known but the supply was known. APR is dependent on multiple sources of water i.e. BWSSB, Tanker and own borewells. The distribution for one year between Jan 2015-December 2015 is as below:

BWSSB	228836.7	KL/year
Tanker	306808.7	KL/year
Borewell	5394	KL/year



APR water supply

As can be seen from the graph above, maximum supply is from Tankers, followed by BWSSB and almost negligible by borewells.

Based on the above information, the total annual water demand of APR comes out to be 585 ML and 270 LPCD.

Since the shallow aquifer analysis was done, the aquifer characteristics were also known. A scenario building exercise was done to show total shallow aquifer availability, and how to utilize it sustainably.

Shallow Aquifer	Weathered zone of upto 12m	10	m
Specific yield of aquifer	0.060		
Therefore, this represents a storage of	310975.56	KL	
	600	mm of rain	

Almost 600mm of rain can be fit into the shallow aquifer with a conservative estimate of 10m thickness. If the current total annual water demand of APR (villas+towers) is converted into rainfall term, annually APR water demand is of 1129mm. In other words, the aquifer can be filled twice and enough supply from shallow aquifer is possible but it has to be managed well with combination of withdrawal and recharge.

	Total rainfall	80% of the rainfall	
Jan-June	255.1	204.08	Fits into the aquifer
July-Dec	660.2	528.16	Fits into the aquifer

Even considering the average rainfall of 915mm, and assuming 80% of it is captured, the shallow aquifer can provide for majority of the supply during rains and partial during non-rainy months.

Part III: Hydrogeological analysis of the watershed and the three clusters

Methodology

The method was a combination of basic geological mapping, capturing narratives of borewell owners & drillers and water level/quality data.

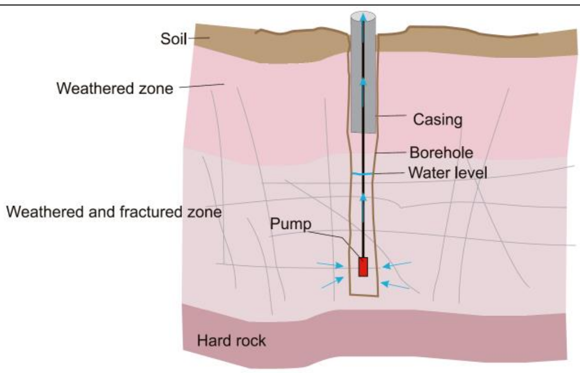
1) Geological mapping was carried out by traversing along road/rail cuttings, rock quarries and foundation dugouts getting basic information on the sub-surface geology and structures (joints/fractures) within them. Location, elevation, basic rock type, direction & dip amount of joints/fractures were documented.

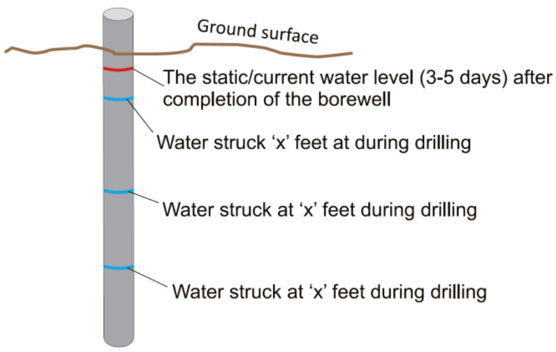
Rail cuttings

Construction foundation dugouts

Basic Geological mapping by traverse along available rock cuttings and exposures

2) An inventory of narratives (discussions and interviews) with borewell owners & drillers was captured. These narratives involve their observations/notes regarding soil and rock cutting samples and changes during well excavation and borewell drilling and also depths at which groundwater was struck during drilling. Although, the data collected through this process may not be 100% accurate, it provided fairly reliable information on the subsurface at multiple points in the selected area. The only other way of capturing such data is drilling new exploratory borewells which is a very costly affair.





Capturing narratives/real time information about geology and groundwater changes

3) During narrative capturing important information collected was water level and water quality (in-situ) of borewells and dugwells. This data is temporal and is being collected at different seasons, at-least 4 times a year.

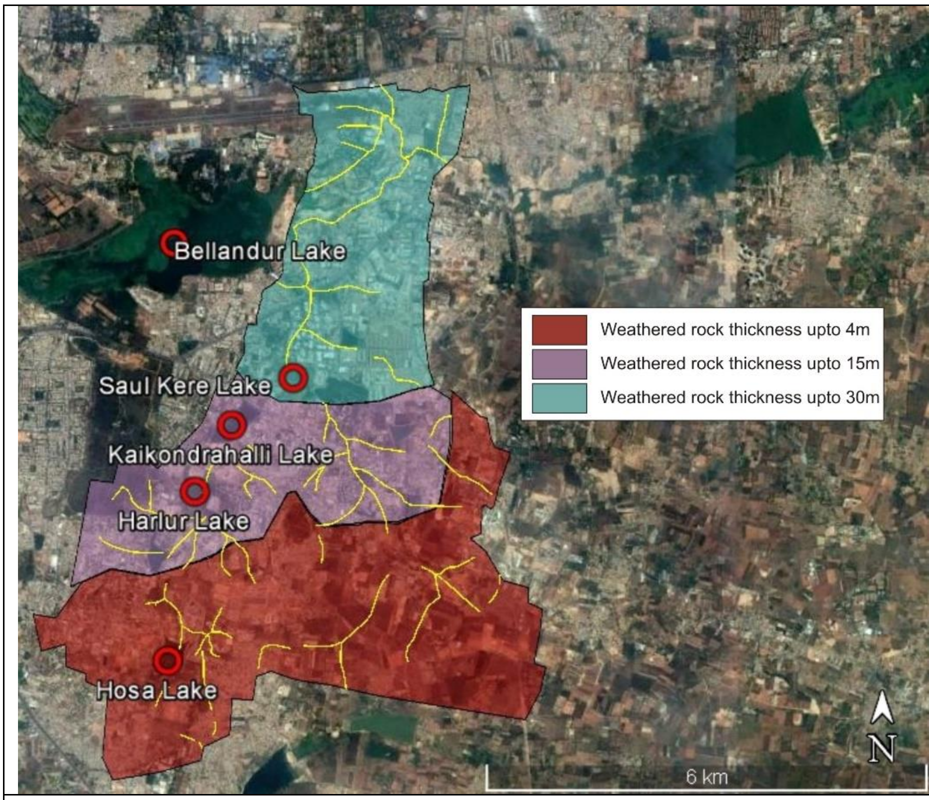
Sr. No	Codes	Latitude	Longitude	Elevation (m)	Well Depth(m)	Casing Depth(m)	SWL(m)	Sediments base (m) bgl	Weathered rock base (m) bgl	Hard rock base (m) bgl	Water struck 1st (m)	Water struck 2nd (m)	Water struck 3rd (m)	Water quality in-situ pH	TDS	Sallinity	EC	Diameter (m)	Purpose/Remarks	Owner/ Address
1	BW1	12.91331667	77.69526667	895				4	15	396		66	110						Uses- Domestic, Motor working for	Adarsh Company
2	BW2	12.91115	77.69478333	893			>60	4	15	304.8	34	85	133							
3	DW1	12.91098333	77.6946	892	11			7	20	305	58		95					2.25		
4	BW3	12.91136111	77.69448333	889	305			8	20	365	152	183	305						7hp pump, working for 20minutes	Panchayat BW
5	DW2	12.91041667	77.69475	895	11			8	20	259		168						5.5		
6	BW4	12.91328333	77.6968	898			>83	8	20	335	73	121								
7	BW5	12.91553333	77.67891667	884									286							
8	BW6	12.91548333	77.67946667	888				8	20	259	81								well not in use due to silt problem	
9	BW7	12.91565	77.67936667	888	305		57	10	30	274			290	7.38	930	660	1326		1.5 yrs. Old	Suburamms@gm
10	BW8	12.9155	77.67863333	885			33					78		7.16	920	700	1345			
11	BW9	12.91721667	77.67783333	891	366	32	18	10	30	274	18		244	7.25	920	700	1361		Pump running for 10hrs.	Abhee Construct
12	BW10	12.91675	77.6778	892	259	20	11	10	30	274	98	198	213						Eleven months old	
13	BW11	12.8977	77.69583333	904	335	40	>100				61	183	244							
14	BW12	12.89758333	77.69511667	896	335	40					61	183	244						Silted	
15	BW13	12.89806667	77.69518333	908	335	40	50				61	183	244							
16	BW14	12.89755	77.69553333	902	335	40	15				61	183	244							
17	BW15	12.89923333	77.69443333	902	274	15							244						4000 Lts. Of water extraction in two	Lake view public
18	BW16	12.89856667	77.69246667	897			43				45									
19	BW17	12.89803333	77.69275	892			44						110							
20	BW18	12.89768333	77.69343333	894			57				53									
21	BW19	12.89206667	77.69875	908								93								
22	BW20	12.89241667	77.69888333	904			40													Skanda shelters
23	BW21	12.89315	77.69818333	902	140														10 to 15 yrs. Old	
24	BW22	12.89351667	77.6984	903	140		43												10 to 15 yrs. Old	
25	BW23	12.89453333	77.69778333	904	335	57							274						hard rock 158.496	
26	BW24	12.89288333	77.69873333	900			34													
27	BW25	12.89323333	77.70023333	900	113	30	23				24	110							10 to 15 yrs. Old, 1.5 inch of water in 1st year	

Field data compilation in MS-Excel

Output – Aquifer mapping

Weathered rock thickness in the watershed

A broad geological map was developed for the study area based on the observed rock exposures within the watershed coupled with narrative data on soil/geology changes during borewell drilling/dugwell excavation.



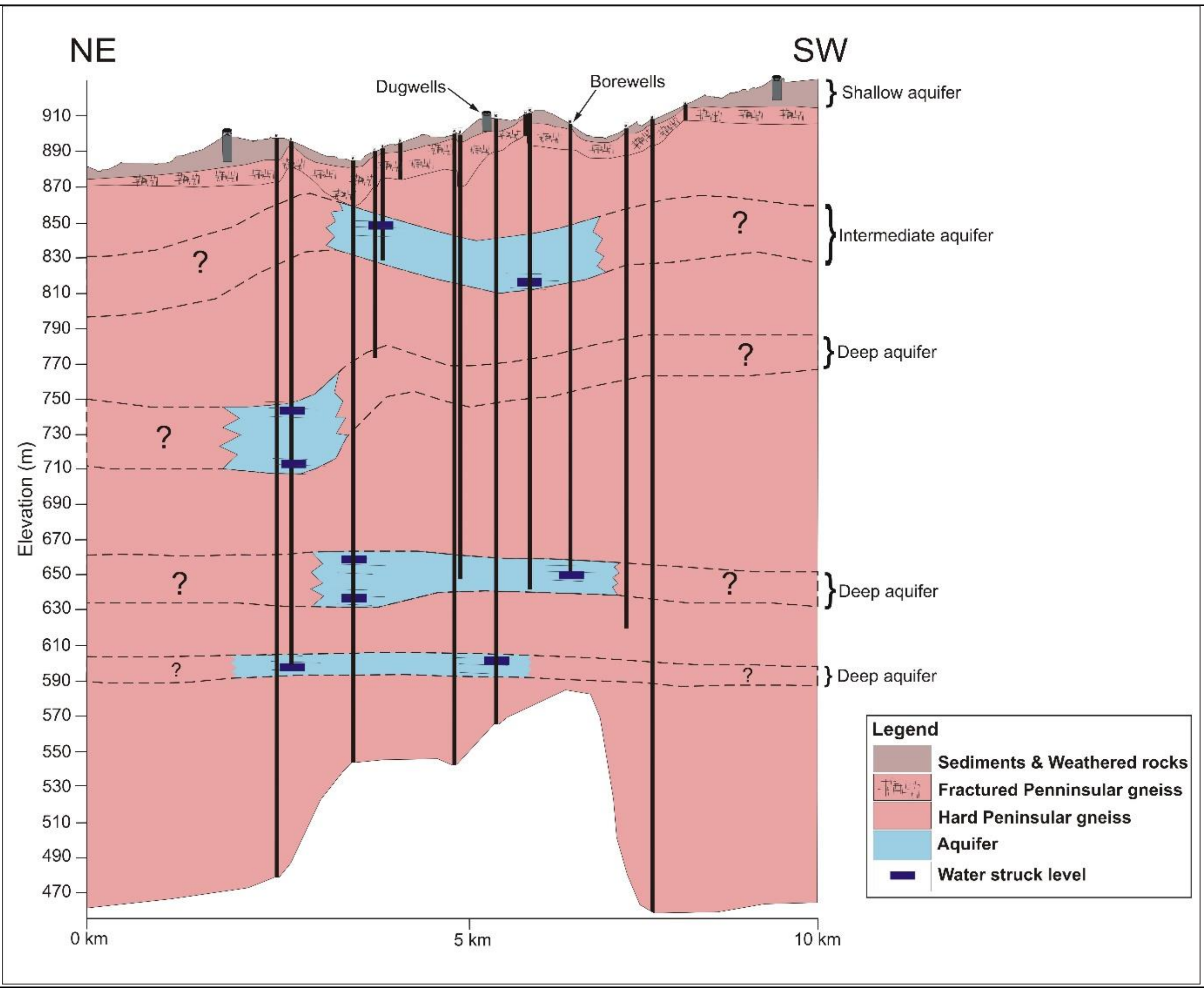
Generalized map overlays denoting differential weathered rock thicknesses across the watershed with major lakes & drainage

- The watershed is primarily made-up of granitic gneiss. However, the entire area exhibits different patterns of weathering and fracturing, laterally and vertically. Sediment deposits over the granites are also observed at places. These deposits are found to be thick at areas of depressions where lakes are formed.

- In the southern part, hard rock is encountered at shallower depths from the surface.
- In the central part, a mix of sediments and extremely weathered rock is encountered at the surface which is about 5m thick. These are underlain by weathered and intermittently fractured rock from ~ 5m to ~25m from the surface. Fairly hard rock is encountered below 30m in this region.
- The northern part has the lowest elevations than the other parts. A thick zone of sediments and highly weathered rock is encountered up to 30m from below the surface. Hard and fractured rock continues from below 30m.

Hydrogeological section

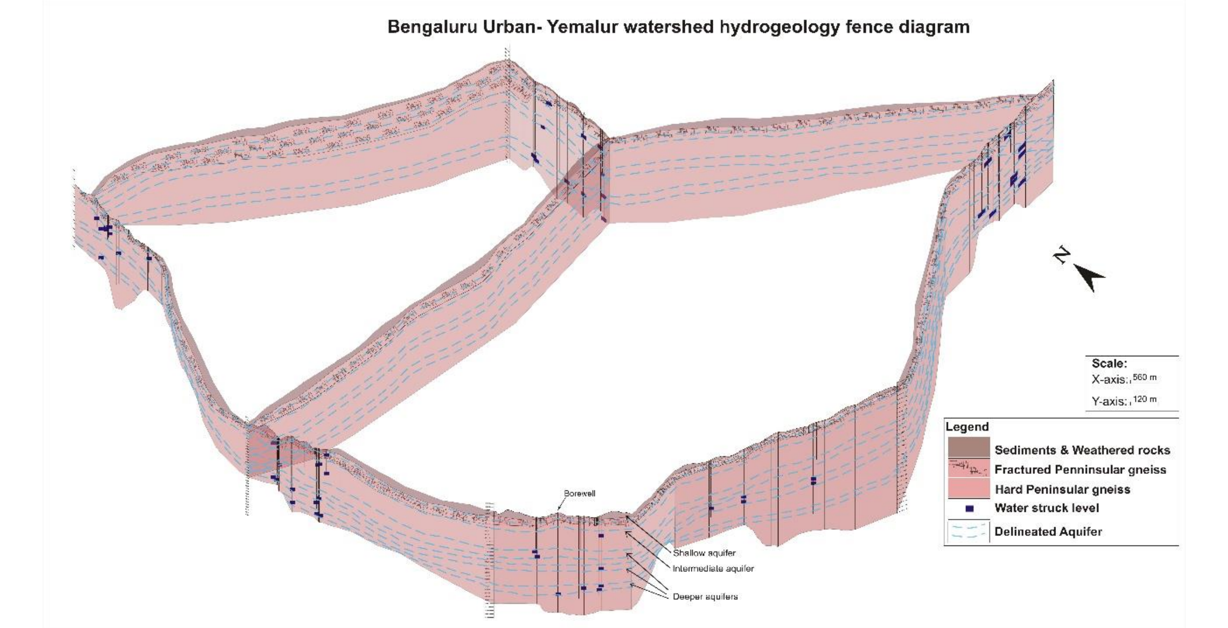
The compiled field narrative data is entered into MS-EXCEL sheet. After plotting all the observation points (borewells/dugwells) on GOOGLE EARTH, section paths were drawn intersecting maximum number of observation points along different directions across the watershed. Along such paths, hydrogeological sections were created as shown below.



Narrative data based hydrogeological section along NE-SW of the watershed

Fence diagram

Hydrogeological sections constructed using narrative information were further integrated using GOOGLE EARTH and COREL DRAW to produce a layout called "Fence Diagram" which helped in getting a better perspective of the general hydrogeology of the entire watershed.



Fence diagram of Upper Ponnaiyar Watershed

Central and northern parts of watershed seem to have thicker sediment cover & weathered granitic rock profile with lakes on surface. Towards south the massive hard granite is found at shallower depths. Thus, this diagram helps in interpreting the aquifer system in much better way.

Aquifer delineation

The hydrogeological section above has been constructed using a combination of field mapping data and narratives on depths at which water was struck borewell during drilling. Based on hydrogeological section and fence diagram, 3 distinct groundwater bearing zones can be indicatively delineated. These aquifers can be broadly categorized based on the depths at which they are encountered below ground level (bgl).

1) Shallow aquifer: 0-30m

2) Intermediate aquifer: 35-80m

3) Deep aquifers: 100-152m, 180-205m, 210-250m, 290-335m & 366-396m

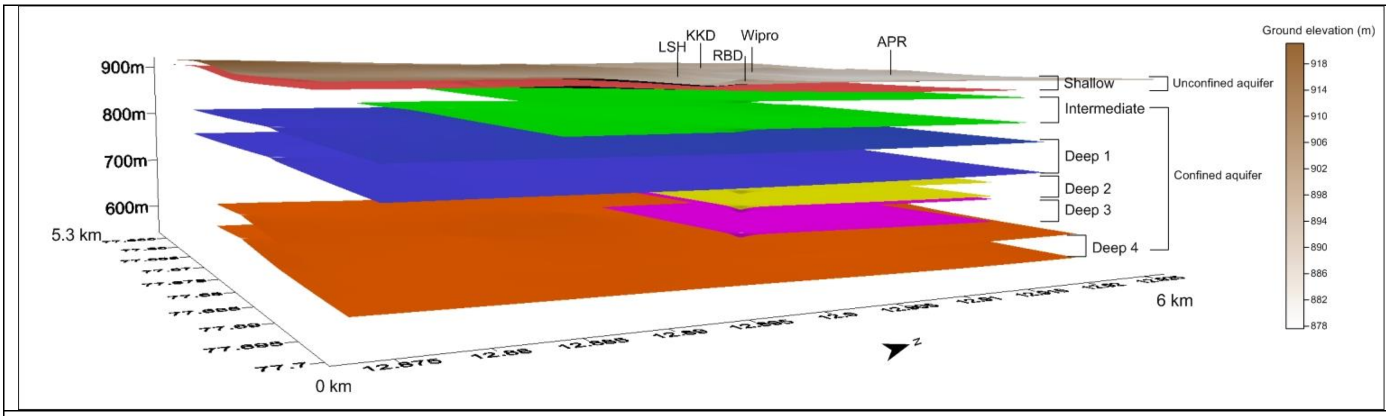
Note: approximate aquifer delineation is based on water struck levels and major water bearing fractures/fissures obtained from narrative data and its validity will be discussed in the following section. The thickness of aquifers varies significantly across the layout.

Shallow aquifer is constituted of surface soil, loose sediments and highly weathered/fractured granites & gneisses of Peninsular Gneissic complex. The aquifer is unconfined in nature.

Intermediate & Deep aquifers constitute of hard rock with water bearing fractures/fissures. These aquifers are confined in nature. Their lateral extent is not clear due to limited data in urban scenario.

3D Aquifer model

Once aquifers were delineated an attempt was made to produce 3-D aquifer layout in a different form. Top and bottom depths of aquifers were converted to reduced levels (RWL) to generate layers in SURFER software. Initially a topographical map (layer) of the study area is made using elevation points from GOOGLE EARTH followed by top and bottom layers of different aquifers and a 3-D layout is drawn by compiling all these layers to scale. The vertical and horizontal extent of these aquifers was validated with the help of a geophysical method discussed in next section.

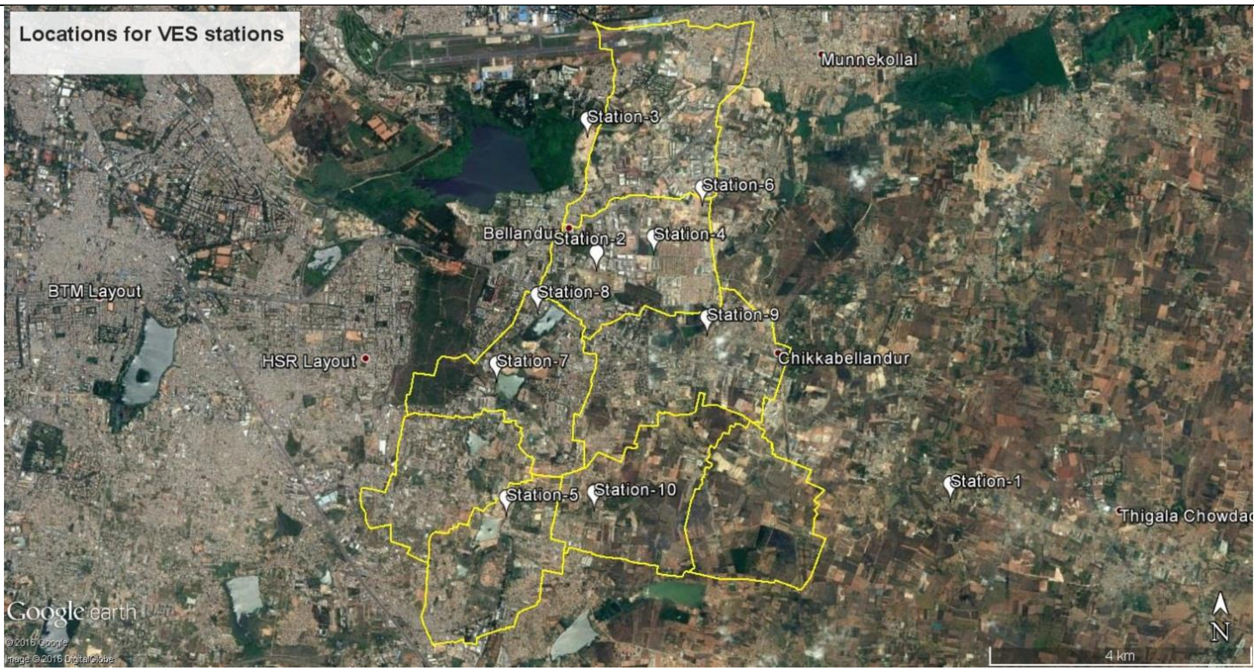


Aquifer layout in 3-D

Validation - Resistivity method

The indicative delineation of aquifers was coarsely based on basic geological mapping and borewell narratives and it needs further scrutiny and validation. Geophysical method (VES- Vertical Electrical Sounding) was employed to not only validate the narrative data based hydrogeological mapping but to also provide additional details for the study. VES survey work was outsourced to a professional agency with co-ordination from BIOME covering almost entire watershed and data was shared across.

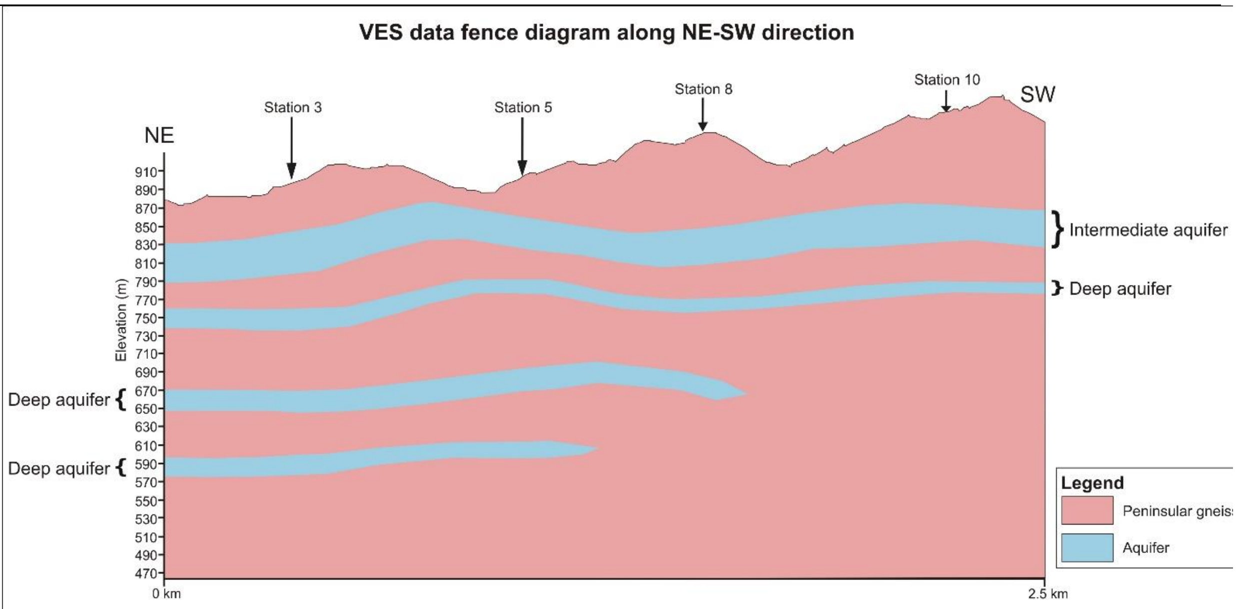
VES (Vertical Electrical Sounding) or Resistivity method takes into account the effects (resistivity) displayed by the subsurface formations on passage of electrical current through them. Surveys were carried out using Schlumberger array.



Location of VES stations across Upper Ponnaiyar watershed

VES fence diagram

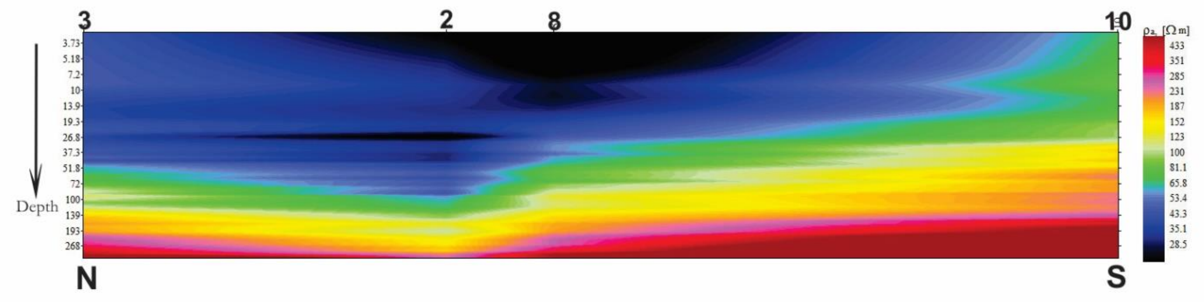
The resistivity data obtained was plotted against depth for individual stations. This graph plot was further used to generate cross sections. These cross sections were made for all the stations and later integrated along different directions across the watershed. Aquifers were delineated based on variations in the resistivity trend with respect to depth.



Consolidated fence diagram for Station 3, 5, 8 and 10 along NE-SW direction

Geo-electric section

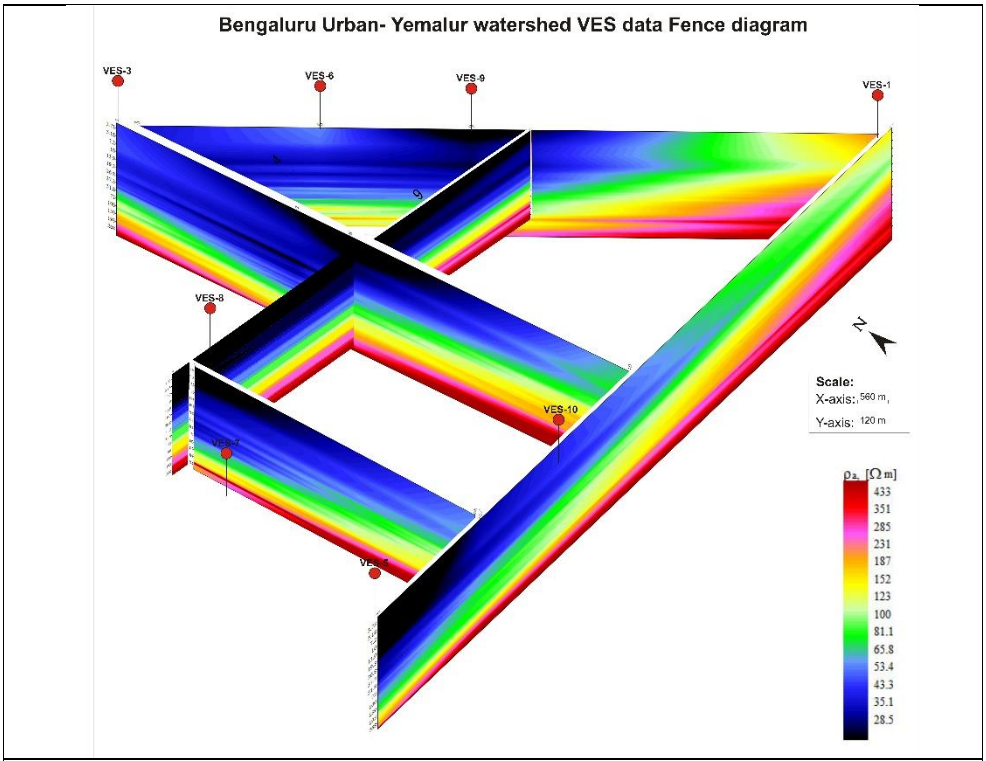
Furthermore, data was processed to yield apparent resistivity (ρa) values plotted against depth (AB/2) and further treated using IPI2win software to obtain VES sounding curve. These curves were obtained for all the stations and later processed using the same software to generate geo-electric section for multiple stations along different directions across the watershed.



Geo-electric section along station 3,2,8 and 10 made using IPI2win software

Geo-electric fence diagram

Geo-electric sections were further integrated using GOOGLE EARTH and COREL DRAW to produce a Fence Diagram layout called which helped in getting a better perspective of the sub-surface resistivity variations across the watershed.



Geo-electric fence diagram produced using Google earth and Corel Draw

Low resistivity layer with maximum thickness towards the North of the watershed indicates relatively thicker profile of weathered and fractured granites/gneisses. Central part also displays relatively low resistivity values indicated by station 2, 8 and 7 reflecting highly weathered profile along with sediments on the top. High resistivity values at shallower depths towards the south confirm the presence of massive granites/gneisses near surface.

A striking similarity is noticeable when one compares the narrative data based output with geophysical methods-VES databased output. Hence, the former corroborates fairly well with the later in this study. **This implies that simple techniques like capturing public/drillers narratives of borewells or crowd sourcing such data can generate significant information about hydrogeology (aquifers) of the area and should precede any expensive (in most cases) technology like VES.**

Once aquifers have been delineated it is crucial to find out how an aquifer will respond to pumping, discussed in following section.

Aquifer characteristics - Pumping tests

Concepts

The performance of a well depends on
1) Aquifer characteristics, i.e., Transmissivity(T) and Storativity(S)
2) Specific capacity (C) of the well itself.

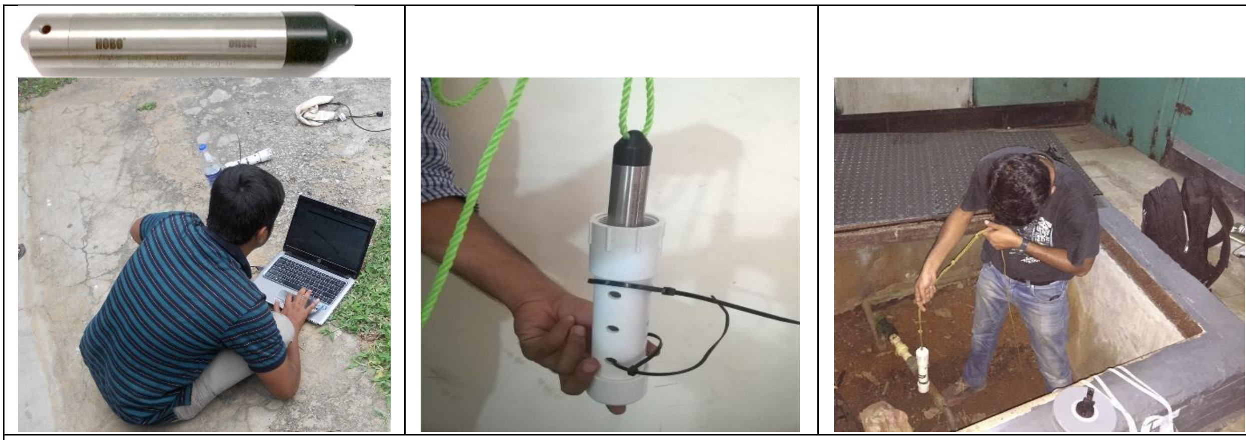
Transmissivity (T) is defined as rate of flow of water under unit hydraulic gradient through a unit cross sectional area over the whole saturated thickness of an aquifer. It is expressed as m^2/day. T determines the pumping rate that a well can sustain. Hence knowing the T can help decide safe pumping rate for that well. A high T means water moves quickly towards the well, while a low T means water moves slowly towards the well.
Storativity (S) is the capacity of the aquifer to release certain volume of groundwater storage within limit of aquifer. S governs the sustainability of a well- that is how long the water in the aquifer will be available to that well. It is expressed in % or a fraction (between 0-1). Large Storativity allows water available to the well over longer duration of time (throughout the year) while limited Storativity means water available for shorter duration of time (seasonal).
Specific capacity (C) is the yielding capacity of the well or capacity to derive water from the aquifer expressed as discharge per unit of drawdown (lpm/meter of drawdown).

Methodology

Pumping test: a well is pumped at a constant rate and water level measurements are taken in pumping well and/or observation well during and after pumping. Resulting drawdown and recovery data are used in several methods to estimate aquifer characteristics like T & S and well yield (or specific capacity).

HOBO water level sensors were used to acquire water level fluctuations during and after pumping test. These sensor records absolute pressure (water head) and converts into water level readings by its software after inputting initial SWL values. It also records temperature. The procedure has been summarized in a series of photos.

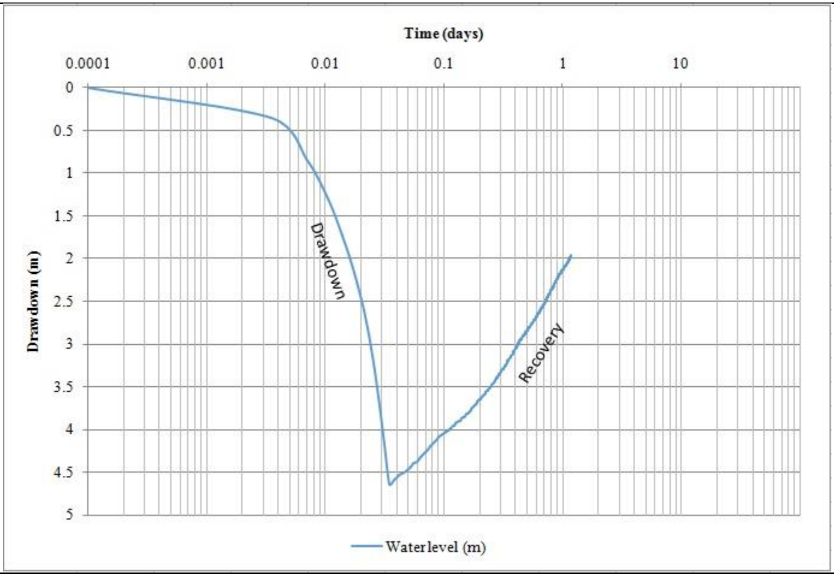
Launching/reading of sensor	Securing sensor in a housing	Installing sensor in the well



Procedure of installing & reading HOBO water level sensor

Pumping tests were carried out in dugwells and borewells in different parts of the watershed. And following methods were applied for analyzing the pumping test data to estimate the T, S and C values.

Cooper and Jacob's (1946) method was used for pumping test data of borewells where drawdown data is plotted on arithmetic scale against time (t) since pumping started on semi-logarithmic scale.



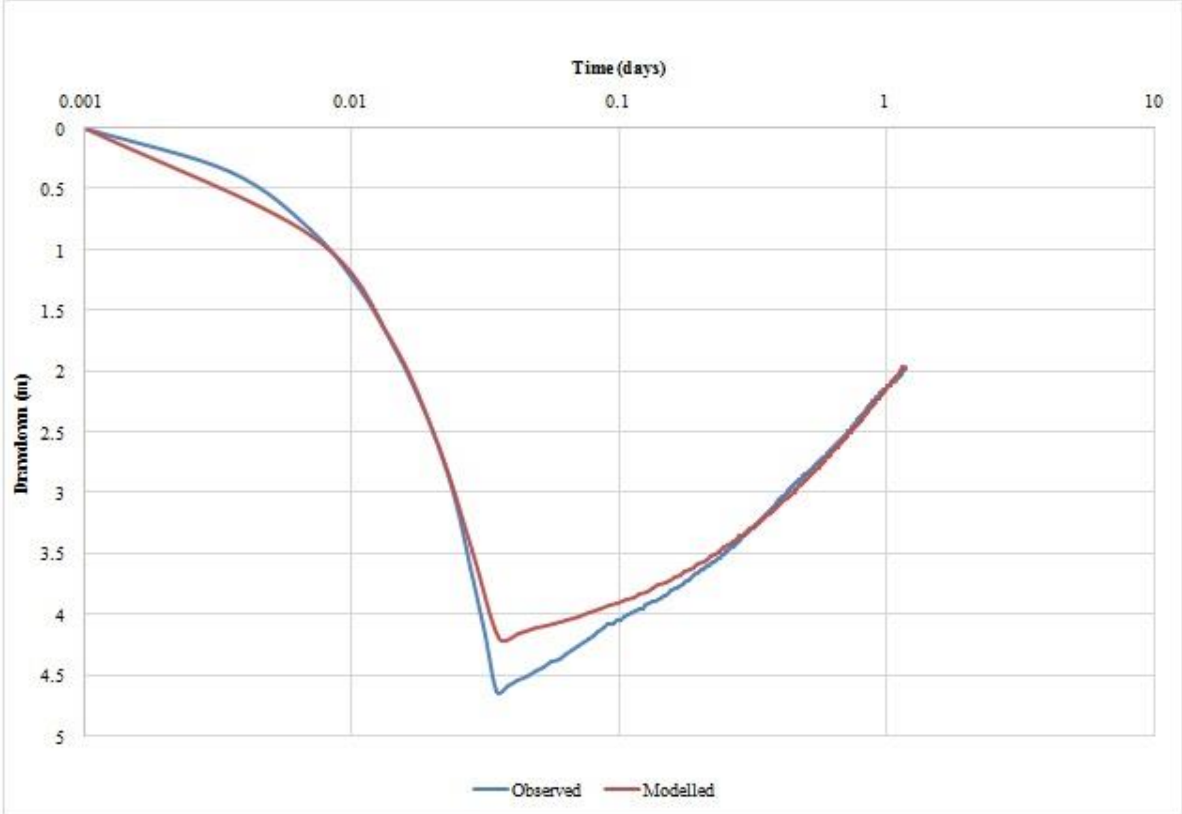
Pumping test drawdown-recovery curve (sample)

Transmissivity (T) in m^2/day can be estimated by using equation: **$T= (264*Q) / \Delta s$**
where, Q= average pump discharge in m^3/min
Δs= slope line of drawdown curve over 1 log cycle of time(t) in meters.

Storativity (S) in fraction can be estimated by using equation: **$S= (2.25*Tt_0) / r^2$**
where, T= Transmissivity in m^2/day
t_0= intercept of slope line of drawdown curve on time axis
r= distance of observation well from pumping well

Barker developed **BGSPT** (British Geological Survey Pumping test) program (Barker, J.A. and Macdonald, D.M.J. 2000) for analyzing the pumping test data from open wells. This simple dos-run program has 2 modules: a pumping test fitting routine (PTFIT), and a drawdown simulation routine

(PTSIM). PTFIT module attempts to fit the well function to a set of drawdown and recovery data from pumping well by automatic variation of aquifer parameters.
If the set of parameters calculated by the model falls within the specified range of parameters, an excellent to good match between the observed and calculated data will be generated (Upasani, 2015) as shown below.



Pumping test BGSPT PTFIT observed & modeled curve match (sample)

Based on such methods, the following estimates were calculated for the selected borewell/dugwells in the watershed.

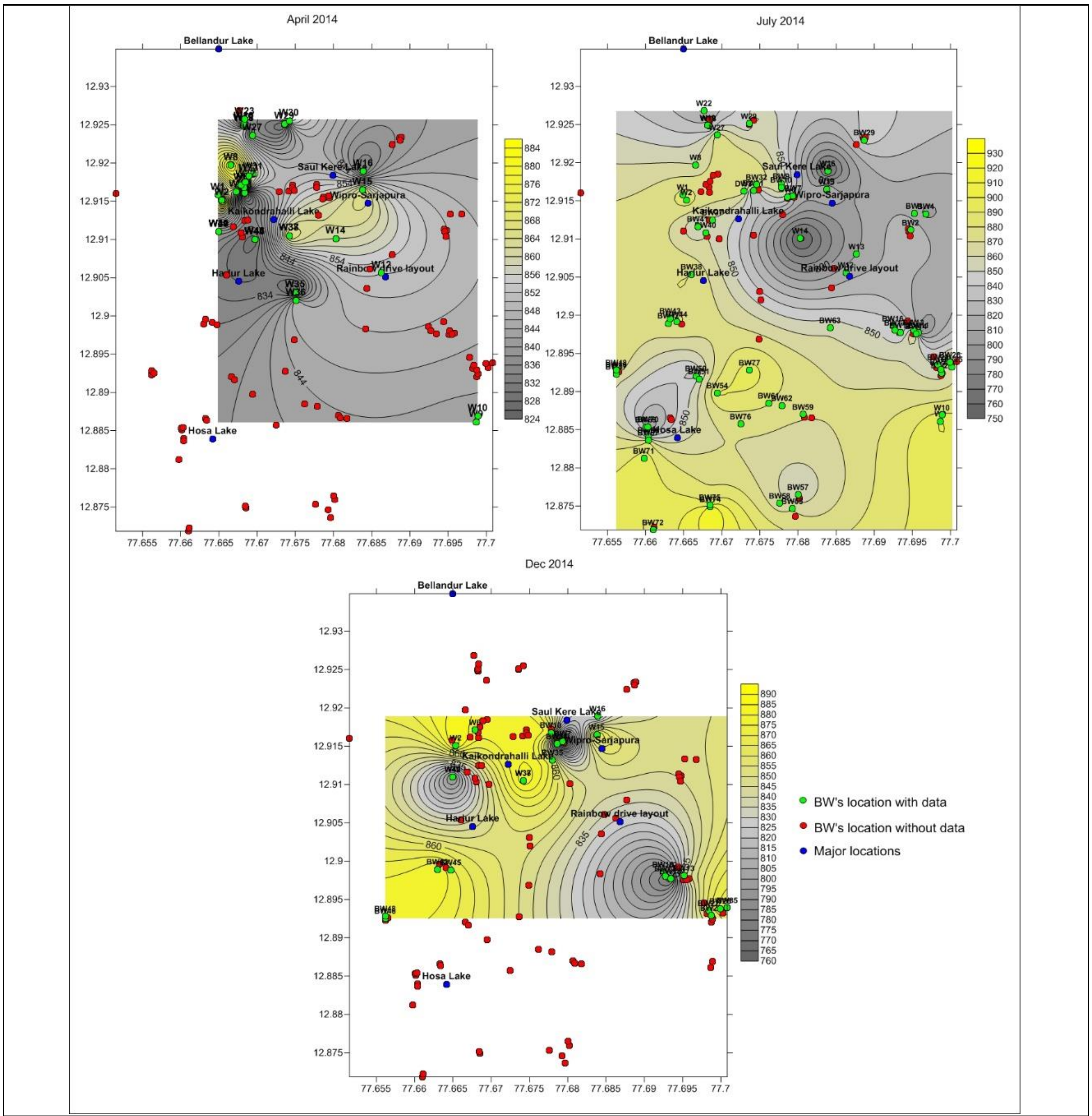
Aquifer system	Transmissivity (m^2/day)	Storativity	Specific capacity of well lpm/meter drawdown
Shallow	0.5 - 8.5	0.002 - 0.03	2.82- 5.5
Intermediate	2.01 - 36	0.026 - 0.042	9.5 - 135
Deep	8.8 - 61.6	0.033 - 0.042	18.52

Aquifer characteristics and well properties of observed wells in Upper Ponnaiyar watershed

Borewell water levels

RWL contour maps

Initially data was collected for about 138 borewells and dug wells during PAQM Phase-I. Water levels in select borewells were monitored in April-July-Dec for the year 2014. Reduced water levels (RWL) were deduced from these water levels and plotted in SURFER software shown below.

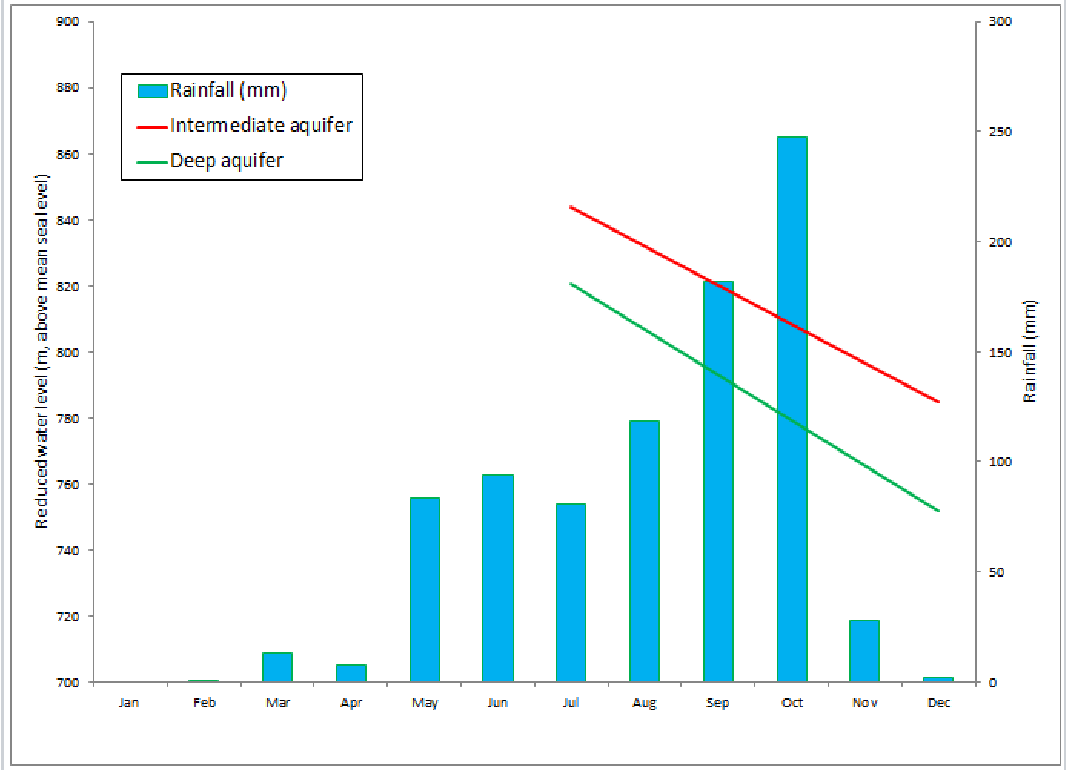


RWL contour map of monitored borewells in the watershed in April-July-Dec 2014

RWL contour map above shows discharge zone in the north, NE and central parts of the watershed where shallow aquifer thickness is relatively greater indicating storage potential. Basement flooding problem in few clusters which lie in the north of the watershed confirms the discharge zone for the shallow aquifer, while, the southern part is indicated as the recharge zone.

Aquifer-wise seasonal water level changes

An attempt was made to plot aquifer-wise seasonal changes in potentiometric water level of borewells. For such an exercise only borewells with consistent data for different seasons were shortlisted. Next these wells were categorized into wells tapping Intermediate and Deep aquifers. Out of these few wells, the ones with maximum water level changes were used for the plot. Rainfall for the same duration was plotted together to propose any relation whatsoever.

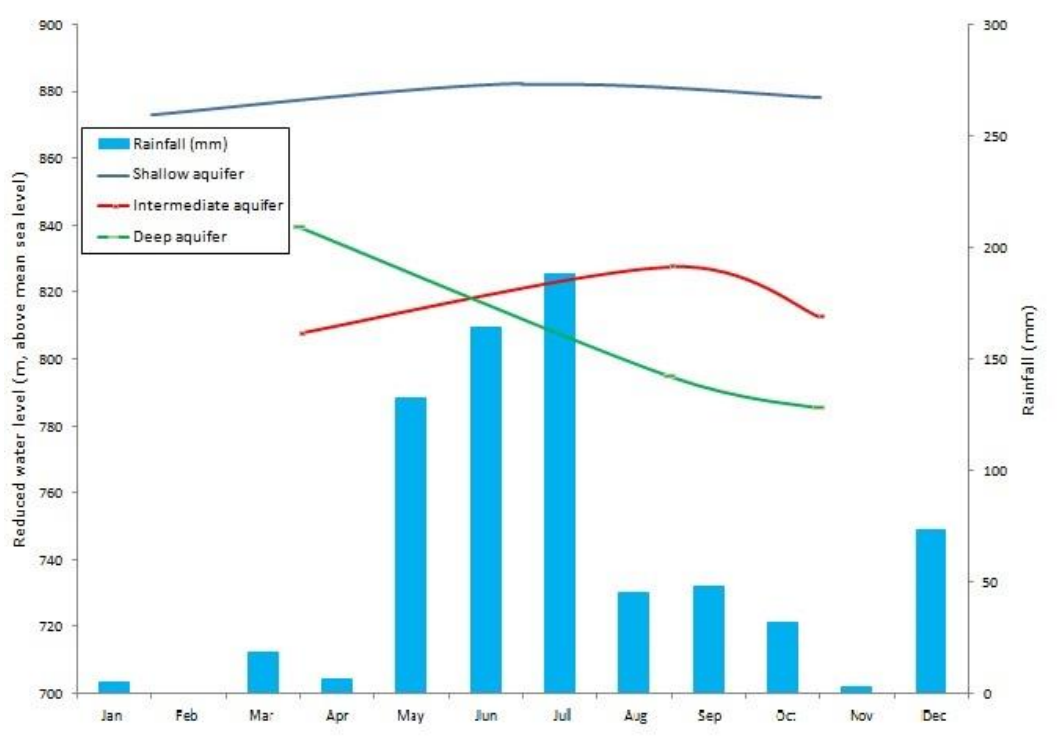


Aquifer wise indicative seasonal water level changes during 2014

From above graph, it is evident that water level of monitored wells tapping intermediate and deep aquifers decreased over time. **However, to conclude that intermediate and deep aquifers are depleting based on above analysis would be incorrect. Nevertheless, the emerging narrative from public domain suggests that count of borewells going dry is on the rise which inadvertently hints toward depleting trend of deeper aquifers.**

The effect of rainfall (recharge) on borewells tapping intermediate/deeper aquifers cannot be monitored in such short time and it would be scientifically unfair to reach at any conclusion. However, there is great potential of recharging and in some cases reviving drying borewells by artificial rainwater harvesting. Efforts in that direction from community level have shown some encouraging results which are discussed in next sections where the study moves towards more specific locations &objectives.

On similar lines with PAQM Phase-I, an attempt was made to plot aquifer-wise seasonal changes in water levels of borewells and dug wells monitored during Phase-II of PAQM and results are plotted in fig below.



Aquifer wise indicative seasonal water level changes during 2016

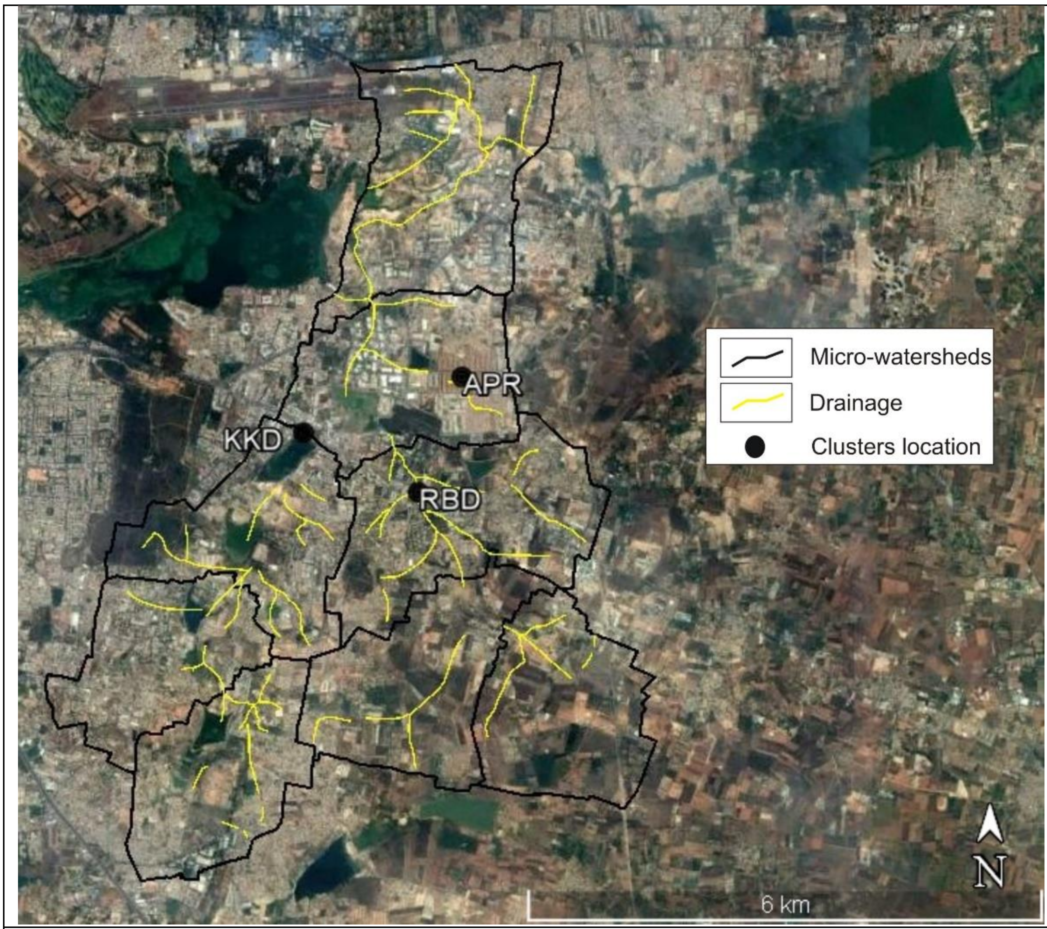
From above graph, it is evident that water level of monitored wells tapping shallow aquifer has remained relatively stable throughout the year. Wells tapping intermediate aquifer attained increase in water level during the monsoon period however show sudden decrease post monsoon. Deep aquifer sourced wells show a continuous decrease in water levels for the entire observation period.

This graph in conjunction with the graph in fig indicates at the status of different aquifers in the study area only. However, we take caution in hastily making conclusion that intermediate and deep aquifers are depleting based on above analysis. A scientifically sound and logical conclusion is possible based on a regular & robust monitoring system of widely distributed observation points within the watershed.

Cluster Location:

The location of small pockets of areas with unique nature and challenges which need further study within Upper Ponnaiyar watershed called as “Clusters” have been marked on a GOOGLE map below. The following clusters were subject to individual study:

Adarsh Palm Retreat (APR)
Rainbow Drive (RBD)
Kaikondrahalli lake cluster (KKD)



Location of Clusters in Upper Ponnaiyar watershed

Adarsh Palm Retreat (APR) - Basement Flooding & Shallow aquifer

Infrastructure

The Adarsh Palm Retreat (APR) layout lies near RMZ Ecoworld between 100ft ring road in Bellandur and Sarjapur road. It comprises of villas and towers covering an area of 128 acres and abuts the Devarabisanahalli Lake. The villa portion of APR is divided into three phases, based on the timeline of construction. There are a total of 850 villa plots, with phase 1 having an occupancy of 173, phase 2 being 214 and phase 3 with 50 during the study. With respect to the towers, there are a total of 2,080 flats, having occupancy of 939. The average number of people residing per villa is taken as 5 and per flat in a tower is taken as 4; which gives a population of 5,941. However, attention must be given to the future rise in the population within APR which at full occupancy, would be home to total population of approximately 12,570.

Issues

The entrance to APR villas and towers from the lake side is known to face severe water logging issues in instances of heavy rain. A backwash from the lake is noticed that leads to flooding on the road that is used to enter the premises itself. There is also known to be considerable amount of basement seepages occurring in various villas of APR. Groundwater has been noticed to be seeping through the constructed structures, resulting in-accessibility and usage of the basements in such cases. Some villas are known to be in a lot worse situation than others. This was known to be a highly prominent and troublesome situation during rainy seasons. Certain residents have taken it upon themselves to identify a solution, by constructing dewatering wells with installed pumps in their premises that are programmed to remove the water into the stormwater drain whenever they reach a certain water level.

Water demand & supply

APR has 3 forms of water supply to meet their demand: Cauvery water from BWSSB, tanker supply from various vendors and the in-house borewell supply (total 6 drilled, 2 are yielding). APR is currently receiving a total of 2,28,837 KL/year from BWSSB while the tanker supply is amounting to 3,06,809 KL/year. The in-house borewells, now currently 2 yielding wells, are providing a supply of 5,394 KL/year. Summing up the total amount of supply that APR currently receives gives a figure of 1.48 MLD/year.

BWSSB	228837	KL/year
Tanker	306809	KL/year
Borewell	5394	KL/year
Total	**541040**	**KL/year**
	1482.3	KLD
	1.48	**MLD**

Sources of water supply in APR

As the demand numbers were not available, the calculations for demand are based on the supply side numbers shared by the APR team. The tabulated version of these numbers is given below:

LPCD	270	Total Freshwater Demand
LPCD	263	Freshwater Demand- Villa
LPCD	213	Freshwater Demand- Towers
LPCD	309	Gross water Demand for villas
LPCD	286	Gross water Demand for villas+ Towers
LPCD	17	Reuse for garden

Supply in LPCD to various construction types in APR

Objective / Intention

On one hand, APR is witnessing the water logging issues at the entrance and basement seepages in many villas; on the other hand they are dependent on 100s of tankers to suffice their water needs. The community is dependent on Cauvery water, borewells within their campus and tanker water which is outsourced for their daily needs. The issues of frequent basement seepages, even in summer and the evidence of water seeping in continuously into the dewatering wells in the basement was directing towards the presence of water at shallower level unlike the pattern otherwise in the Upper Ponnaiyar watershed.

Moreover, the layout is located upstream of a water body called Devarabisanahalli lake which overflows continuously into Bellandur Lake. A citizen group has been actively working on the lake restoration work since sewage inflows seem to affect the water quality of the lake. Several researchers from Indian Institute of Science have been studying the physical characteristics of the lake as well as water quality and pain points while recommending certain measures for betterment of the lake.

Given this context, the primary objective for this cluster was to devise a sustainable strategy for utilization of shallow aquifer within the layout. In tandem with the PAQM objective, hydrogeology science is used to understand the subsurface situation and shed light on aquifer characteristics.

The text that follows in this document details out the methodology, aquifer characteristics, thickness, water quality, learning's and way forward for the cluster.

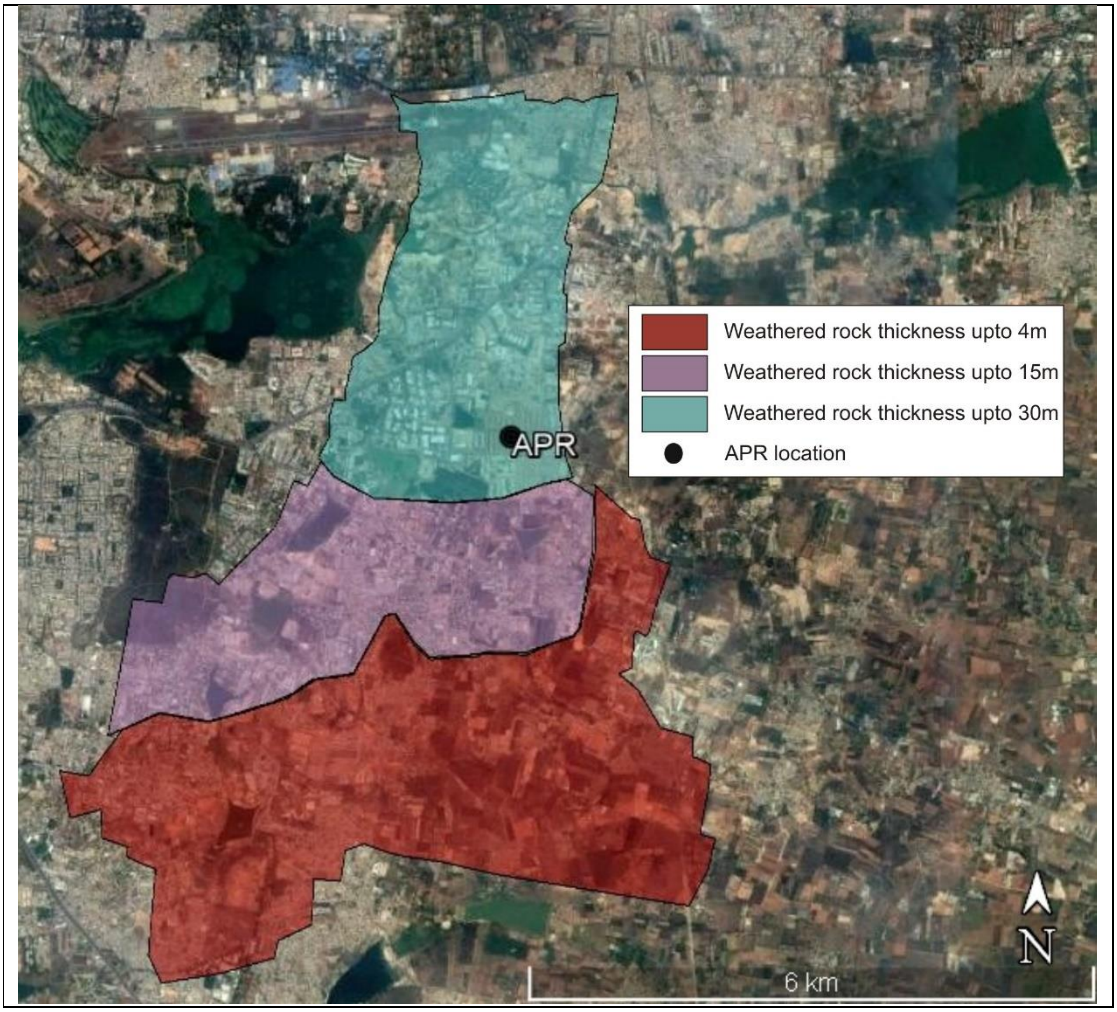
Hydrogeology & Aquifer characteristics

Data

As explained in PAQM Phase-I section, information was collected through interviews and dialogue with people through a structured questionnaire. Information regarding soil/rock samples excavated/drilled and the depth at which groundwater was struck during drilling the old and new borewells was obtained from the community. It provided relatively adequate information of the subsurface at multiple points in the selected area.

Weathered rock thickness

A general idea of degree of weathered rock strata can be deduced when location of APR is plotted on a GOOGLE image of the area superimposed with weathered rock thickness. It clearly indicates that north of the watershed where APR cluster falls has relatively higher thickness of weathered rock upto 30m.



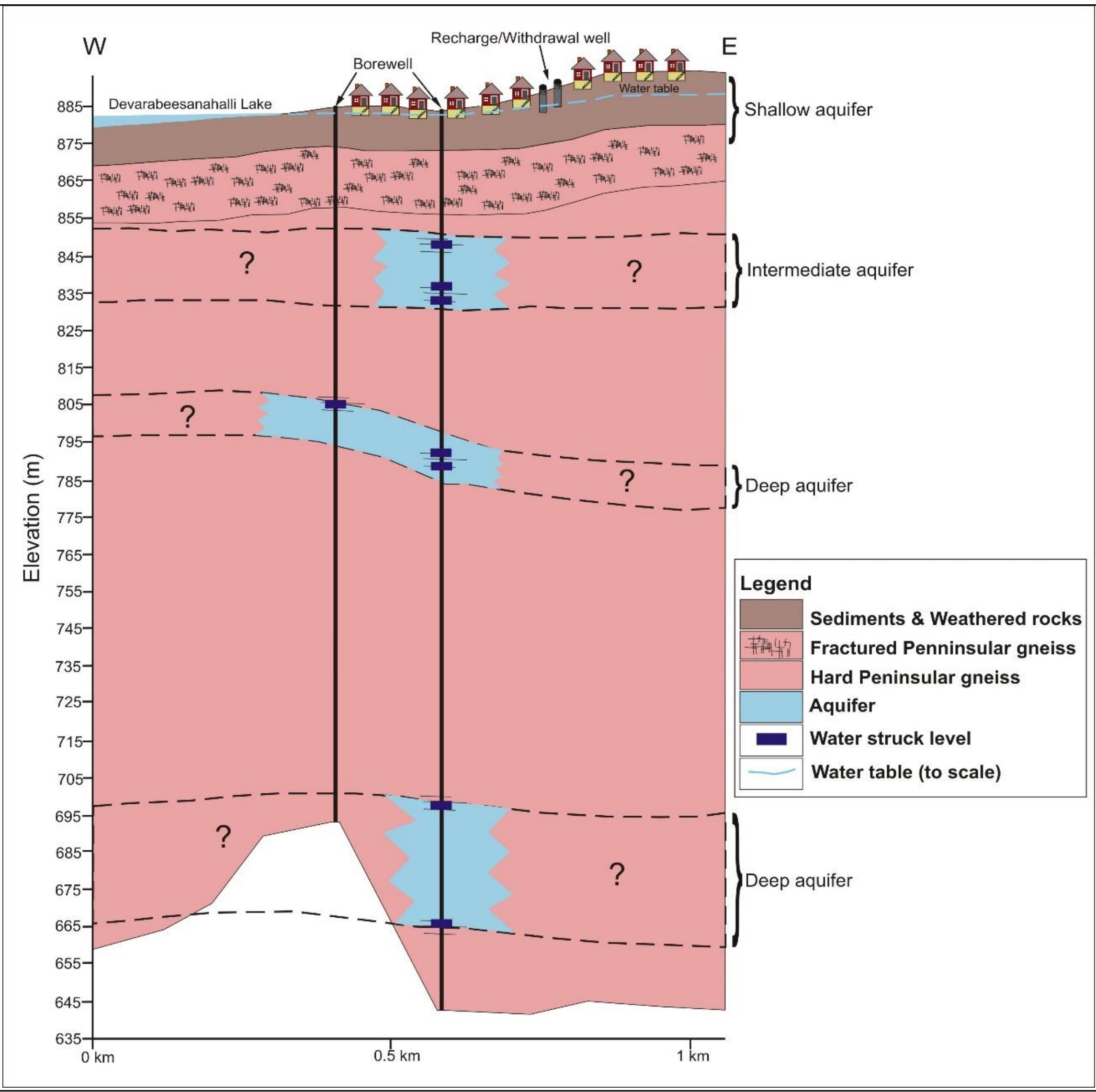
Location of APR with respect to weathered rock thickness across the watershed

Aquifers

Based on borewell narratives a hydrogeological section along E-W direction was drawn shown in fig below. A thick zone of sediments and highly weathered rock is encountered upto 30 meters below the surface. Hard and fractured rocks extend from below 30 meters to greater depths. 3 distinct groundwater-bearing zones can be identified as shown in fig.

Based on the water struck levels and major fractures and fissures, top and bottom of different aquifers were indicatively delineated but with uncertainty (?) regarding their lateral extent due to limited data.

The water table is drawn from the January 2017 water level data of recharge wells in APR. This water table cuts the surface topography near the Devarabeesanahalli lake in the form of water body. APR villa foundations and basements intersect this water table and some are exposed to water seepage and flooding. This shallow aquifer is crucial for APR.



Hydrogeological section along E-W direction

These aquifers can be broadly categorized based on the depths at which they are encountered below ground level (bgl).

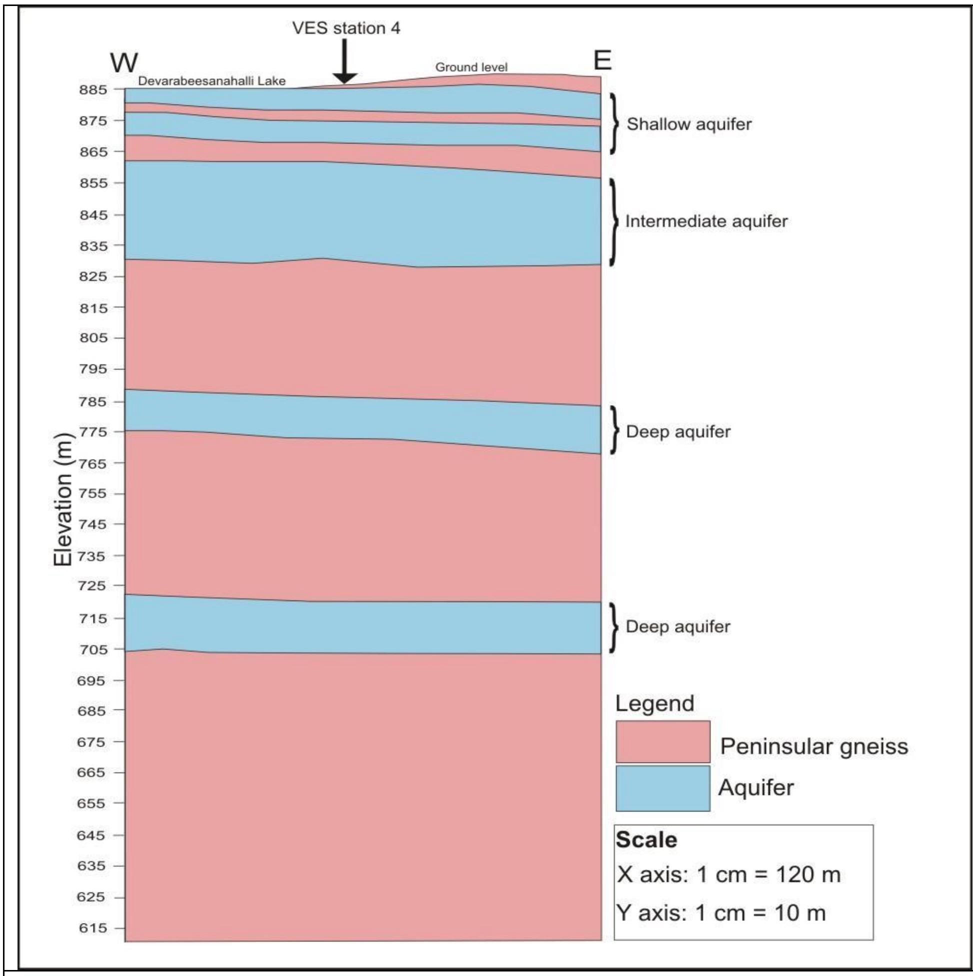
1) Shallow aquifer: 0-30m (approx. 30m thick)

2) Intermediate aquifer: 32-53m (approx. 21m)

3) Deep aquifers: 77-90m (approx. 13m) and188-221m (approx. 33m)

Note: The intermediate aquifer is relatively thicker and most borewells in APR are tapping it.

Geophysical method of Vertical Electrical Sounding (VES) survey was done by a third party in the Upper Ponnaiyar watershed and one such station 4 was located near the lake along the main road in APR. A plot of the resistance data recorded vertically was plotted on excel and one could clearly see areas of relatively low resistance and draw a lateral line along these variations in the trend. A section is drawn based on this plot and different aquifers were indicatively delineated as shown below. VES based output clearly validates the narrative based output in this case too.



VES section along E-W direction based on data from Station #4

Aquifer characteristics

Pumping tests

Once these different aquifers are identified and delineated, next step forward is estimating their characteristics -Transmissivity (T) and Storativity (S). Pumping tests were carried out to evaluate the response of the aquifer to pumping and the estimates are as follows:

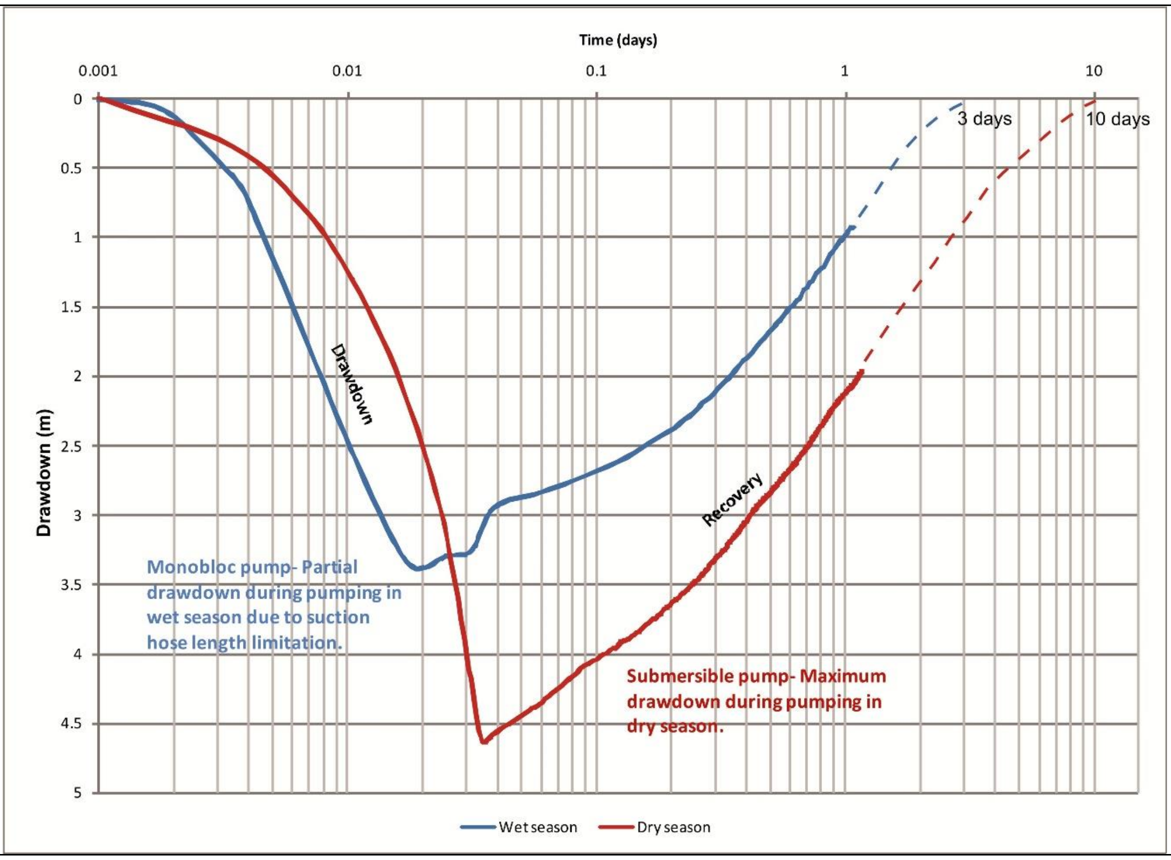
Aquifer system	Transmissivity(m^2/day)	Storativity
Shallow	8.45	0.031-0.036
Intermediate & Deep	11.06	0.0005

T & S values of aquifers in APR

And the **Specific capacity (C)** of the pumped dug well estimated to be 2.82 lpm/meter

Recovery results

The pump test results from wet and dry season were plotted together on a graph. Recovery curves were however, extrapolated due to limited data for 100% well water recovery. The extrapolated recovery trend of the observed well will take approx. 3 days in wet season and 10 days in dry season as shown below.



Comparison of recovery time during Wet & Dry season

Withdrawal wells, Pumping simulations & Experiment

Withdrawal wells

Many of the Villa basements have water seepage and sometimes flooding. In order to mitigate this problem residents have constructed private shallow “Withdrawal” dug wells with motors installed to pump out the excess water and dewater that portion of the aquifer within which the basements of such homes intersect. Additionally, the resident's management has constructed common withdrawal wells (photo 3) with 4 ft (1.21m) diameter and depth of 20 ft (6.09m) along the internal roads with same objective.

Interestingly this flooding problem can be turned around to the benefit of the residents by pumping out this water and integrating into formal water supply system. A major component of this study was to assess if such pumping would be efficiently done in conjunction with the recharge strategy that is being separately discussed in upcoming section.

1) To remove water from shallow aquifer to stop water seepage/flooding into ground floor/basement of Villas.

2) Utilize this water as a potential source of supply by integrating it into formal water supply system.

Common withdrawal well in APR

The following sections summarize the key activities, results and analysis that are linked to this strategy.

Steady State Pumping

To keep the water level below the basement floor level and prevent water seepage/flooding, type of pumping in the shallow aquifer should be ideally Steady state pumping. It can be achieved when water level in the well attains a steady state, i.e. during pumping there is no further or only a little drawdown in the well. In other words, the rate of withdrawal of water from the well is equal to the water contributed by the aquifer into the well.

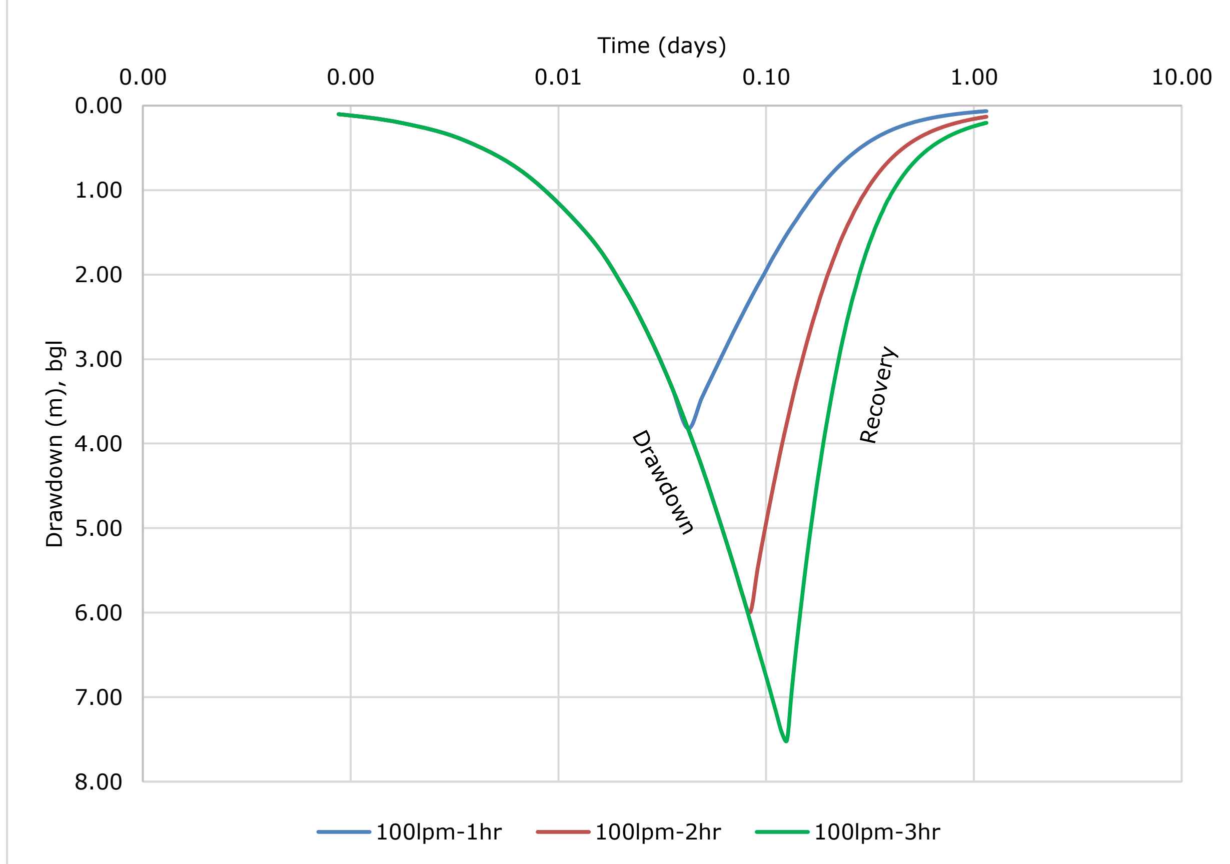
Q (pump discharge) = q (aquifer contribution into the well)

To put in a simplistic way, normal fast pumping will only remove water from the well i.e., well storage. However, steady state pumping will remove well storage water and also water contained within the shallow aquifer feeding the well. Steady state pumping can be achieved with fine tuned discharge rate and pumping duration.
In that context, various simulations were run to get correct pumping discharge rates & duration, maximum drawdown and radius of influence which are shown in next sub-section.

Pumping Simulations

Simulations at well

Numerous simulations were run in the DOS program PTSIM of BGSPT to achieve near steady state pumping with maximum drawdown to keep water level below villa basement level as illustrated below. Aquifer estimates T=8 m^2/day, S=0.03 and Well specific capacity, C=2.82 lpm/meter were used for simulations at well.
The closest possible steady state pumping was obtained when simulations were run with 100lpm rate for various pumping duration as shown below.



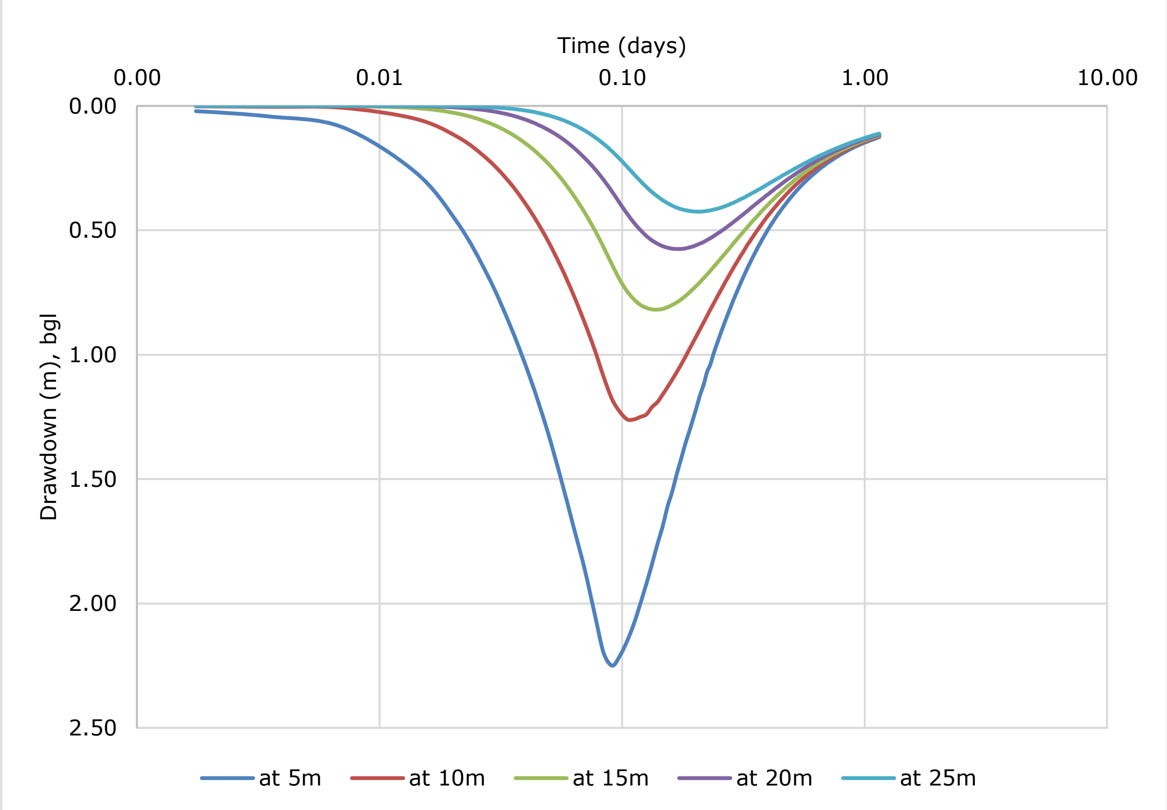
Drawdown simulations at 100lpm for various pumping durations

Pumping rate (lpm)	Pumping duration (hrs)	Max drawdown (m) bgl	Potential volume of water (m^3 or KL)
100	1	4.03	4.63
100	2	4.86	5.58
100	3	5.04	5.79

Maximum drawdown in 100lpm pumping simulations

Radii of Influence simulations

Radii of influence or Cone of Depression is the effect of pumping resulting drawdown in the surrounding wells at a given radius (distance) from the pumping well. Various simulations were run to get an estimate of maximum drawdown at fixed distances from pumping well. 100lpm pumping discharge rate for various pumping duration was found to be the most effective.

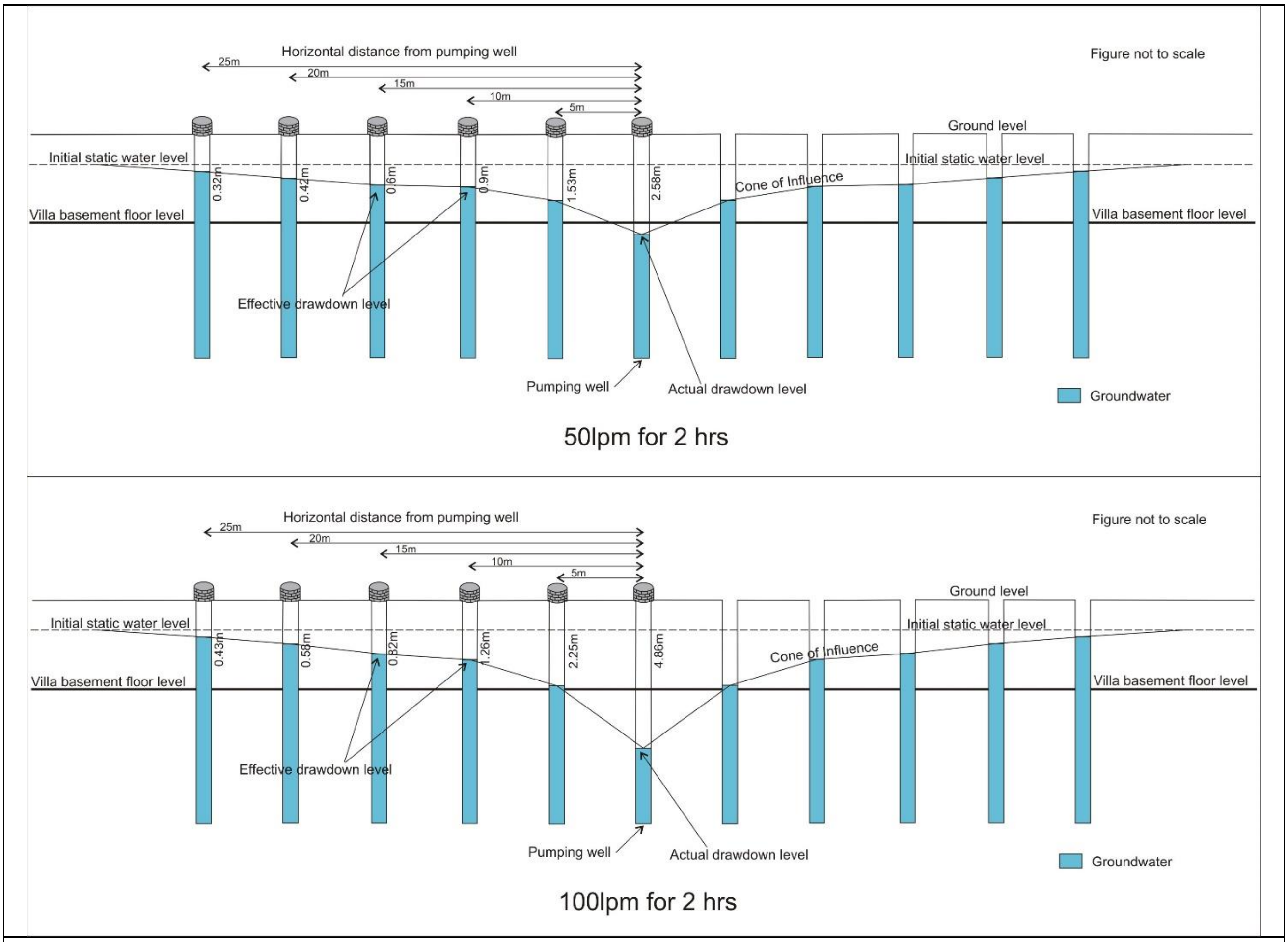


Radii of influence simulations at 100lpm for 2hrs

Pumping rate (lpm)	Pumping duration (hrs)	Distance from pumping well (m)	Max drawdown (m) bgl
100	2	5	2.25
100	2	10	1.26
100	2	15	0.82
100	2	20	0.58
100	2	25	0.43

Maximum drawdown in 100lpm radii of influence simulations

Simulations with 50lpm and 100lpm were run to get maximum drawdown at well and at fixed distances from pumping well. The radii of influence concept and the simulation results can be explained with the help of a conceptual model shown below.

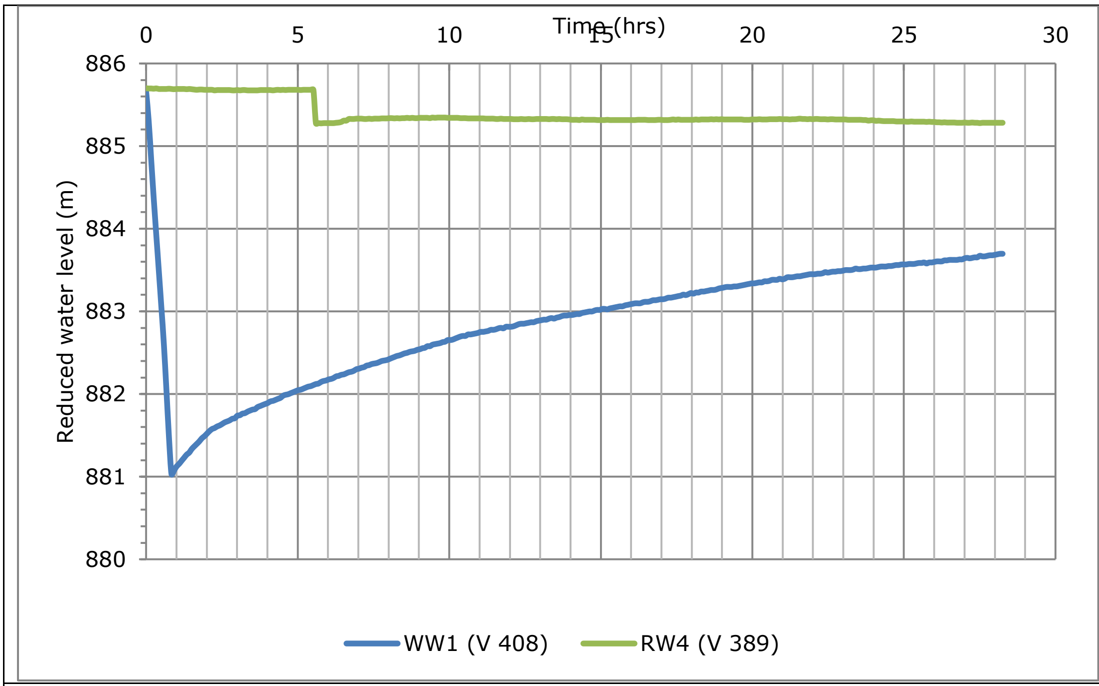


Conceptual model showing influence of pumping at fixed distances in surrounding area at 50lpm & 100lpm for 2 hrs

To get an estimate of the actual effective drawdown after pumping in the surrounding well at fixed distance, a small experiment was done which is discussed in next section.

The experiment

A small experiment was conducted in and around common withdrawal well WW1 near Villa 408.
HOBO water level sensors were installed in withdrawal wells WW1 and Recharge well RW4 near Villa 389 for recording water level changes. Ground distance between WW1 & RW4 is 12m.
Prior & post test, no pumping/de-watering was carried out in WW1 and in recharge well.



Actual influence of pumping during the experiment in lane-8

Observation:

- During pumping test, there is 4.629m of drawdown in pumping well WW1. Observation well RW4 water level shows a very steady continuous decrease until it drops suddenly (0.425m) 4.5hrs after pump stopped and resumes very steady decrease until observation ends.

Analysis:

- WW1 showed a classic drawdown-recovery curve.
- RW4 was affected by the pumping, but showed a delayed response (no other pumping well in the vicinity to affect its water level).

Inference:

- With continued systematic pumping of water from withdrawal wells will eventually increase the effective drawdown level in surrounding wells and help dewatering of aquifer near villa basements.

Recharge wells

While a plan for withdrawing water from shallow aquifer has been formulated, it can only be sustained for longer time by a concurrent groundwater recharge system. To achieve an overall sustainable plan, artificial recharge by rainwater harvesting is a good option since layout is spread over larger area and most of the ground surface of the layout is concretized. A robust rainwater harvesting system will need to have wells which can directly recharge the shallow aquifer.

Several recharge wells (photo 4) are constructed along the internal roads of the layout next to storm water drain line with 4 ft (1.21m) diameter and depth of 25 ft (7.62m).
More details are provided by the Biome team in the collective report.

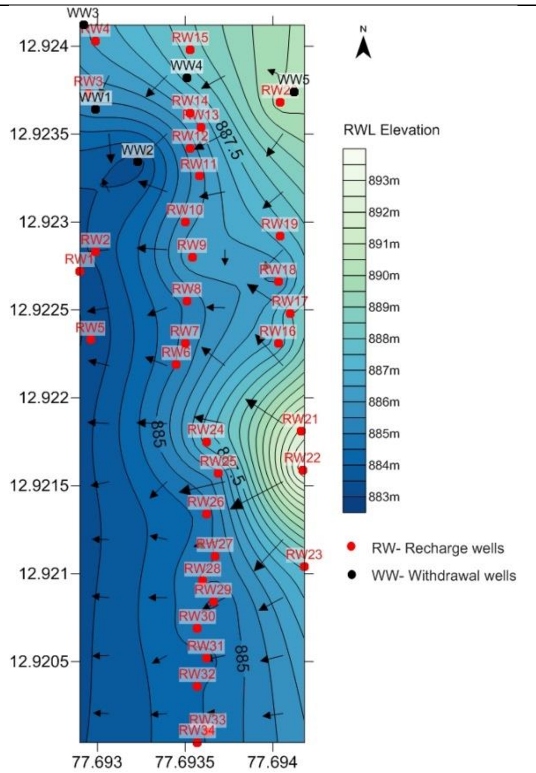
Common recharge wellsin APR

Data: Static water level measurements were taken in all common recharge & withdrawal wells by Acwadam and Biome team in January 2017. These static water levels were converted to reduced water levels (RWL).

RWL means Reduced Water Level (m) = Ground elevation(m) – static water level(m)
wherein ground elevation (above mean sea level) of recharge well is recorded using GPS and static water level or depth to water using simple measuring tape.

Groundwater contour map: Using computer software, points (wells) of equal water level elevations were joined by lines called water level contours. Arrows drawn perpendicular to such contours are called groundwater flowlines which indicate the groundwater flow direction. Water table contours and flowlines constructed on the basis of water levels of different recharge wells give an idea about general groundwater flow and recharge/discharge zones in the area.

In fig, groundwater movement is generally taking place from East to West indicating recharge areas in the East and discharge areas in the west of the observation area. Generally groundwater flows downstream toward the Devarabisanahalli lake on the west of the plot.



RWL contour map of recharge/withdrawal wells

Discharge & Recharge areas: Based on the direction of movement of the groundwater, recharge and discharge areas were demarcated as shown below.
Recharge area is where groundwater flowlines (arrows) move away from each other or diverge.
Discharge area is where these groundwater flowlines (arrows) move towards each other or converge.

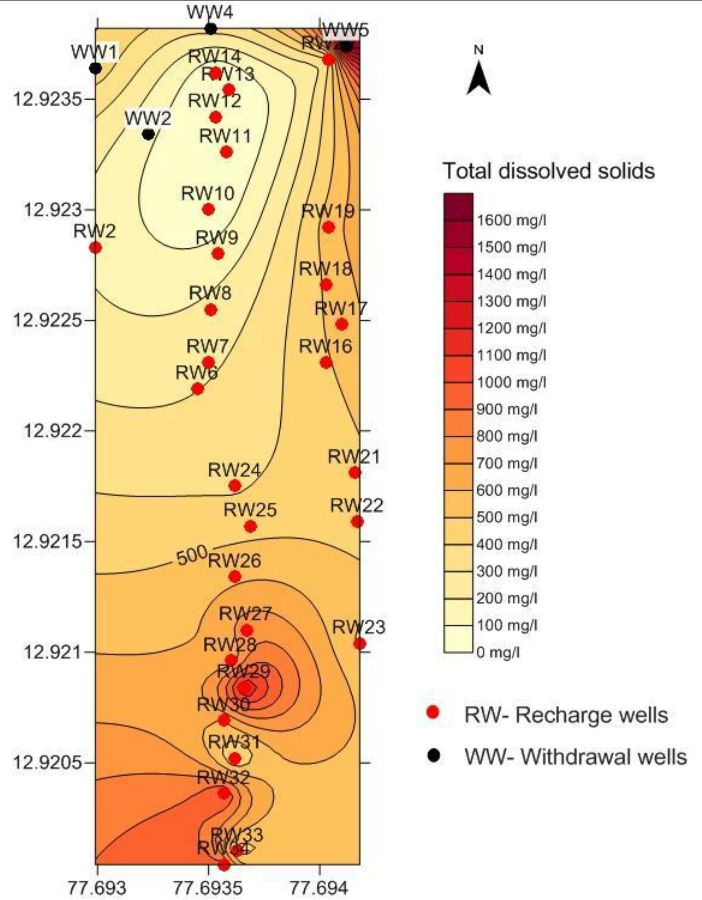
Recharge & Discharge areas

Majority of the villas with water seepage and basement flooding are located in the discharge zone in the west. And most of the newly constructed recharge wells lie in the recharge zone inthe east. And some in the transition zone in the central part.

Water quality

Total dissolved solids

TDS measurements were taken in all common recharge & withdrawal wells in Jan 2017 by APR management and data is plotted in the form of a contour map showing general distribution and trend in the area.



TDS distribution in open wells based on January 2017 data

Excluded wells: WW3 and RW1,3,4,5, 15

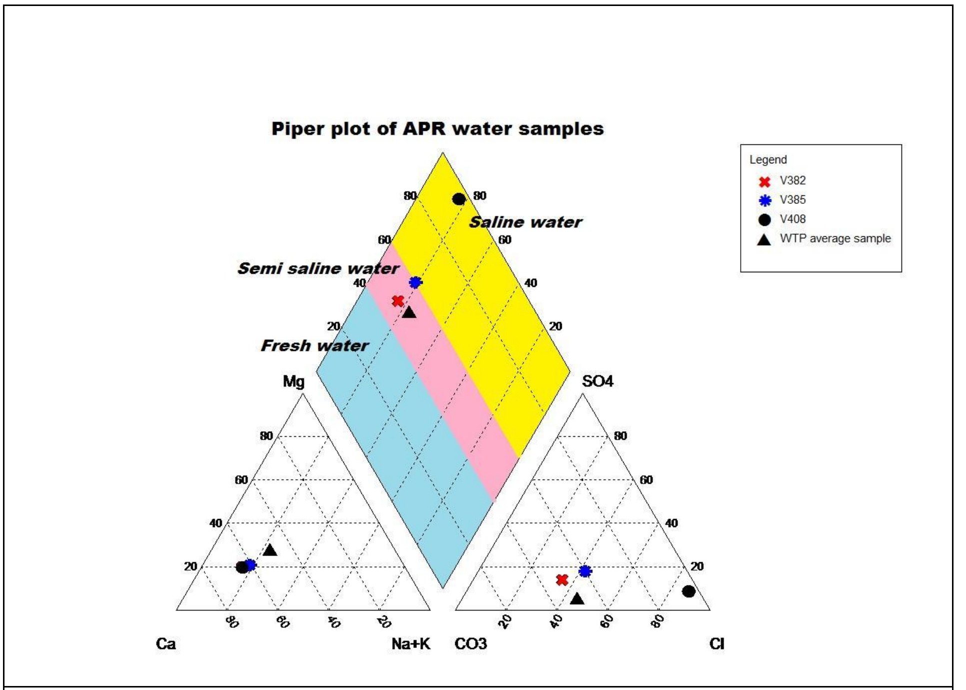
The NE part (WW5 & RW20) of the monitored area is TDS prominent and southern part is relatively high TDS area. Most of the withdrawal wells and Phase-1 Lane-9 recharge wells fall in zone of TDS permissible limit.

Look ahead

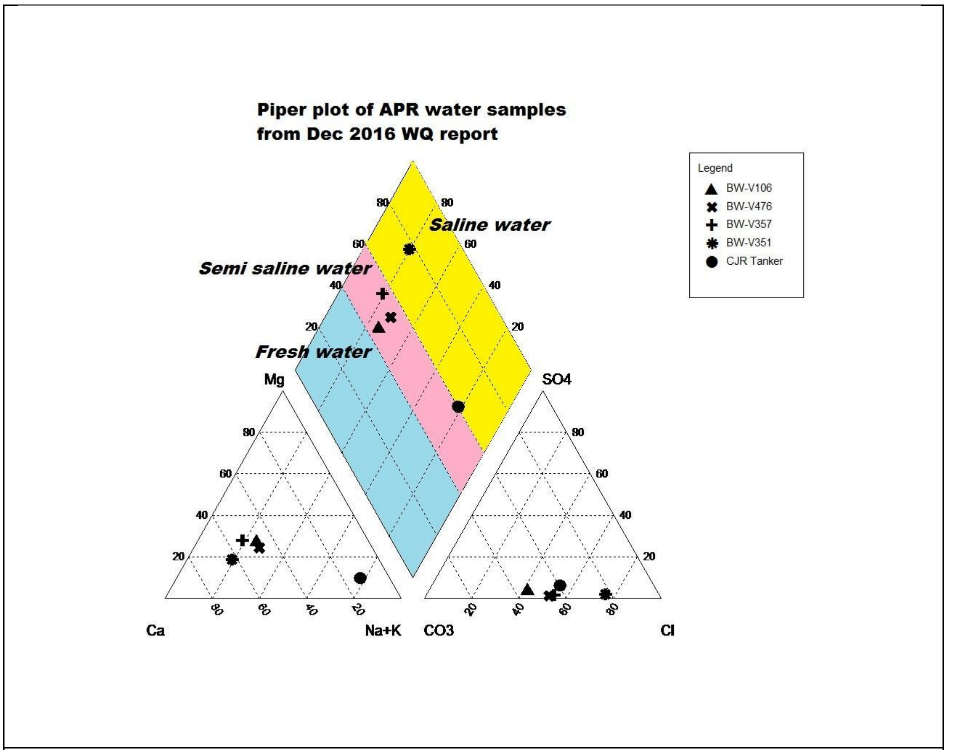
A better picture of the TDS distribution and soluble salts movement can be obtained by getting the TDS values of pre & post-monsoon of all the wells. Best recommended to record values every quarter for entire year.

Water quality tests: A few lab quality tests were done on selected water samples in APR. Appropriate chemical parameters were input in software called AQUACHEM which has several plotting systems for desired categorization of water sample. Piper diagram was chosen which plots the water samples in 3 different types: Fresh, Semi-saline and Saline water.

In the adjoining fig, groundwater samples from common and private withdrawal wells were plot and it can be clearly seen that majority of the samples fall in the semi-saline water type.



Piper plot of Oct 2016 water quality test results



Piper plot of Dec 2016 water quality test results

In adjacent fig, groundwater samples from borewells in APR were plot and it can be clearly seen that majority of them fall in the semi-saline water type.

Recommendations

- ***Pumping schedule:*** Based on the simulations the best model that gives near steady state pumping, maximum drawdown and effective radii of influence would be pumping at 100lpm rate for 2hrs with approximately 3 days of recovery time in Wet season and 1hr pumping with approximately 10 days of recovery time in Dry season. This pumping system will most probably need tweaking after the actual execution of the system.

- ***Slug tests:*** The next way forward once shallow aquifer is recharging and discharging adequately will be estimating recharge rates of the defunct borewells and designing system for recharging the intermediate and deep aquifers.

- ***Withdrawal & Recharge wells:*** A more systematic placement of withdrawal wells is crucial. There needs to be relatively more number of withdrawal wells in the demarcated discharge zone. Otherwise, a more practical option will be treating existing recharge wells in the discharge zone as withdrawal wells for pumping out water.

- ***Pilot area:*** The lanes with existing recharge and withdrawal wells should be taken as Pilot area with systematic pumping of water with concurrent groundwater recharge by RWH through recharge wells. And the volumes of all the components involved need to be monitored for at least a year for further scaling up of model.

- ***Water quality:*** Systematic pumping of water from withdrawal wells and introduction of fresh rainwater through recharge wells will eventually bring the essential quality parameters within desirable limits and improve the overall quality of groundwater in longer run.

Messages

- It is very clear that APR seats on relatively thicker weathered rock strata and consequently possesses greater thickness of "Shallow Aquifer".

- "Water seepage and flooding problem is a blessing in disguise". This problem can be turned around to the benefit of the residents by systematic pumping of water contained in the said shallow aquifer and its formal utilization. This will considerably lower the dependence on Formal corporation supply & Tanker water.

- Leveraging the vast area of APR by artificial & natural rainwater recharge through recharge structures will keep the shallow aquifer revived and improve its water quality eventually reducing the net cost/energy per KL of water.

- Borewells are drying out and reviving them is relatively expensive than maintaining, conserving and reviving the shallow aquifer, associated wells & surface system.

Rainbow Drive (RBD) - Water management & Aquifers

Infrastructure

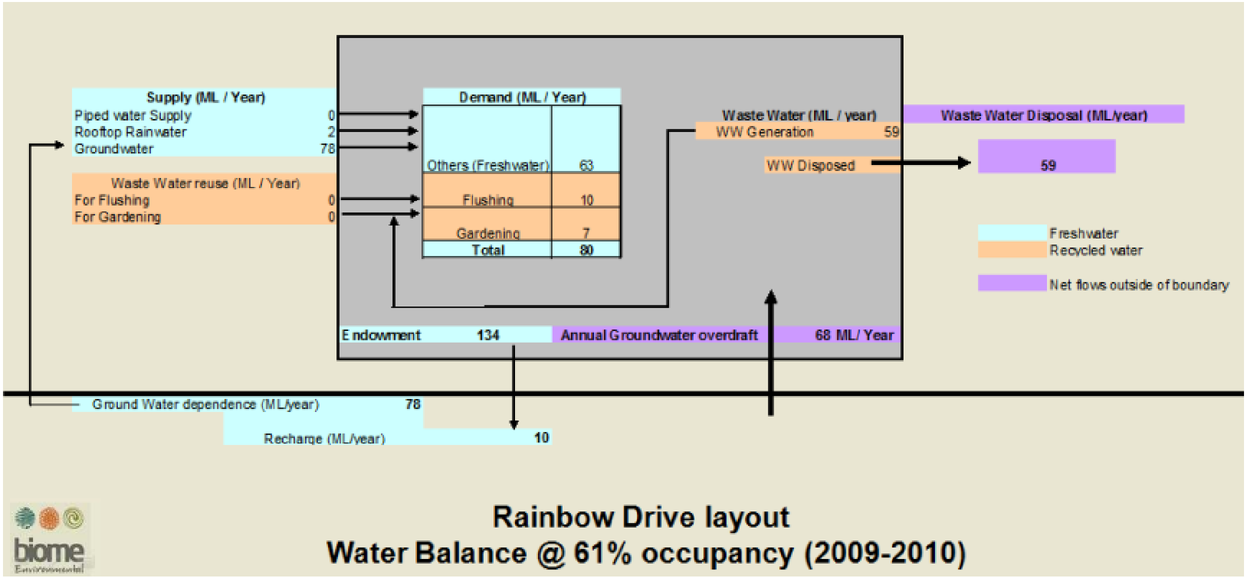
The Rainbow Drive (RBD) layout situated on Sarjapur road is a private gated residential layout with an area of 34acres and a total of about 360 housing plots of which 260 plots were occupied at the time of the study. The layout gets no formal water supply from city's water utility, BWSSB. It is completely dependent on its borewells as a water source. The Plot owners' association (POA) manages water supply and sanitation since the handover from the builder.

The builder had provided the following water related infrastructure for the layout:
a) A storm water drain network that carries storm water to leave the layout
b) 6 community yielding borewells (of depths varying from 60m to 244m)
c) Two overhead tanks to store water in the layout
d) Piped water supply connections to all plots from these overhead tanks
e) Piped sewage connection to each plot
f) Two Sewage Treatment plants where the sewage is supposed to be treated.

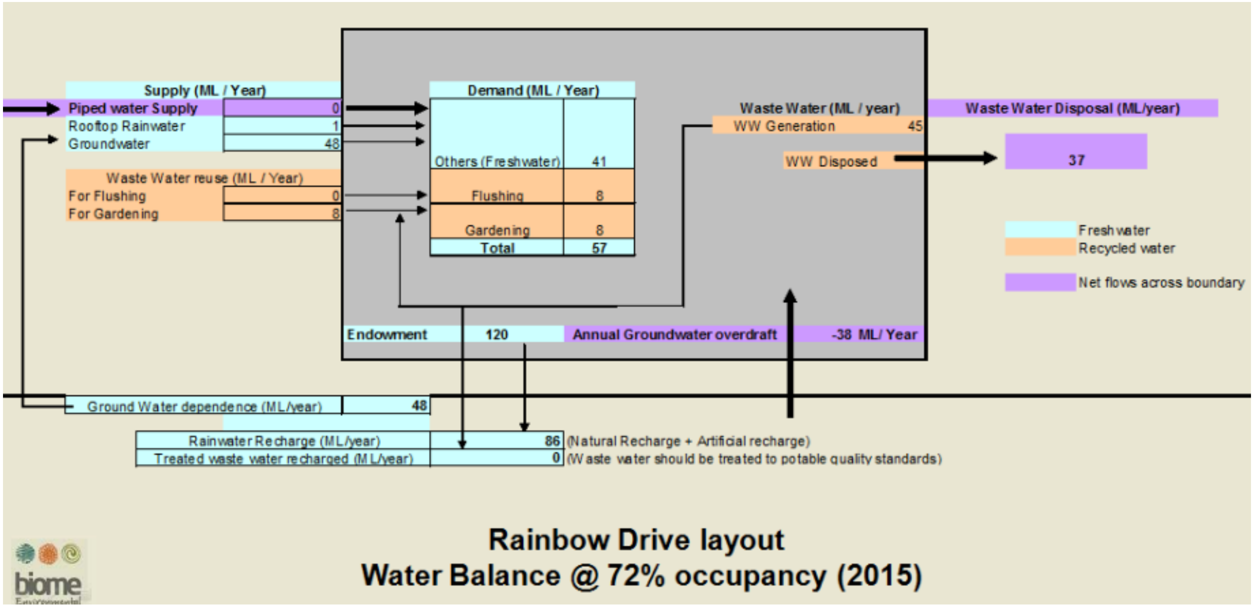
Water demand & supply

RBD has only 1 form of water supply to meet their demand i.e., groundwater through their yielding borewells. This groundwater resource is exhaustive in nature, however it can be replenished by organized & efficient long term recharging efforts through RWH.

The current and historic demand and supply numbers can be schematically put below.



Water Supply and Demand @61% occupancy



Water Supply and Demand @72% occupancy

Challenges & Actions

By 2006 the layout had nearly 60% occupancy. As occupancy increased, the layout began to face number of challenges with respect to water and sanitation. These challenges, which now the POA had to respond to, can be summarized as below:

1. The area had already begun to experience water shortages. Community borewells drilled by the builder began to dry up.
2. The Sewage treatment plants were dysfunctional and did not treat the waste waters adequately. Some of the waste water stagnated in the low elevation end of the layout (which is also the entrance to the layout).
3. During heavy rains upstream storm water entered into the layout and caused significant flash flooding at the low end of the layout. This got mixed with the stagnating sewage and caused a lot of problems.

In short, the POA which is effectively the layout's water utility functionary faces problems of flooding, water scarcity and waste water management.

Actions/Reforms undertaken to address the challenges:

1. Banning of community borewell for domestic consumption.
2. No borewell water supply for construction purpose
3. Mandatory Rainwater Harvesting (RWH)
4. Construction of community and private Recharge wells
5. Block Tariff System and source water metering
6. Judicious Demand Management
7. Reinvesting in wastewater management and installing Phytorid system.

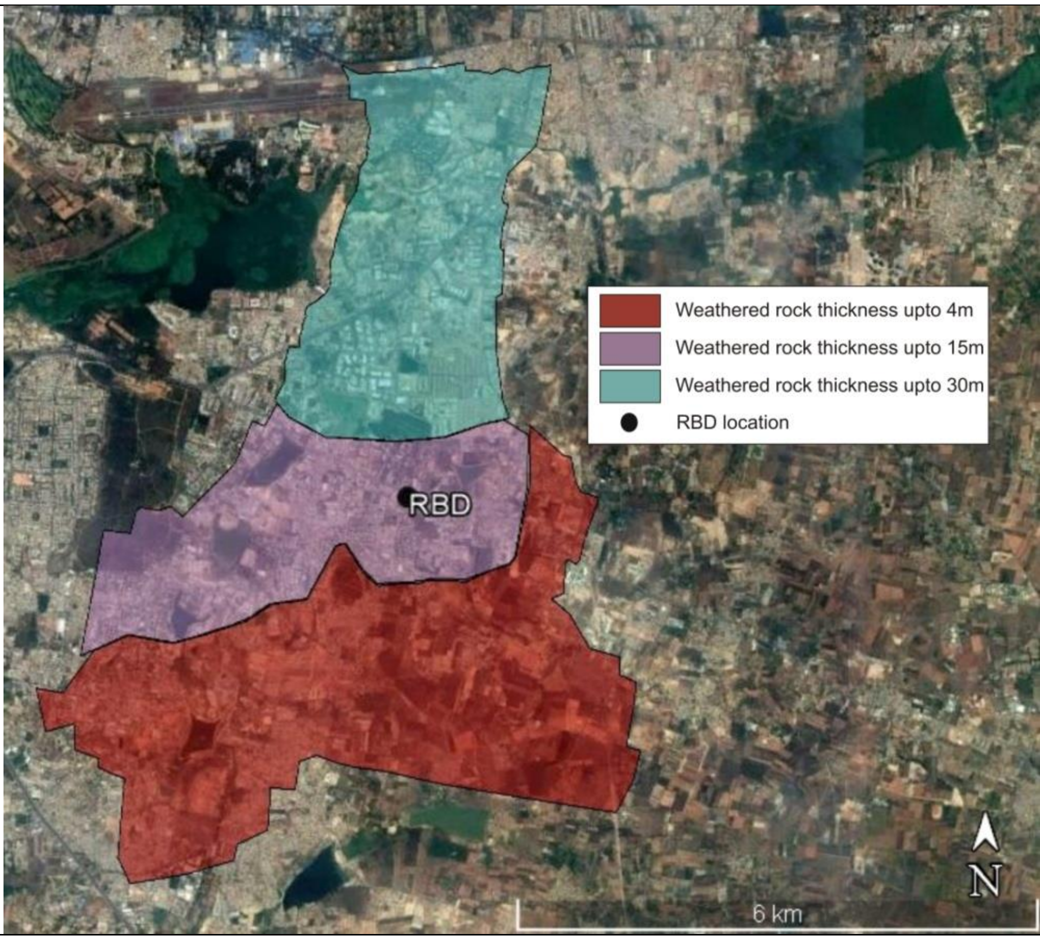
Objective / Intention

The community in RBD made appropriate interventions to sustainably utilize and manage their only source of water- groundwater as outlined in previous section. However, the groundwater management system needs further fine-tuning to get the most efficient long-term solution. Given this context, the primary objective for this cluster was to evaluate the existing groundwater recharging efforts and devise a sustainable strategy for utilization of shallow aquifer within the layout. The text that follows details out the methodology, aquifer delineation, thickness and its characteristics, evaluation of recharge measures, learning's and way forward for the layout.

Hydrogeology & Aquifer characteristics

Weathered rock thickness

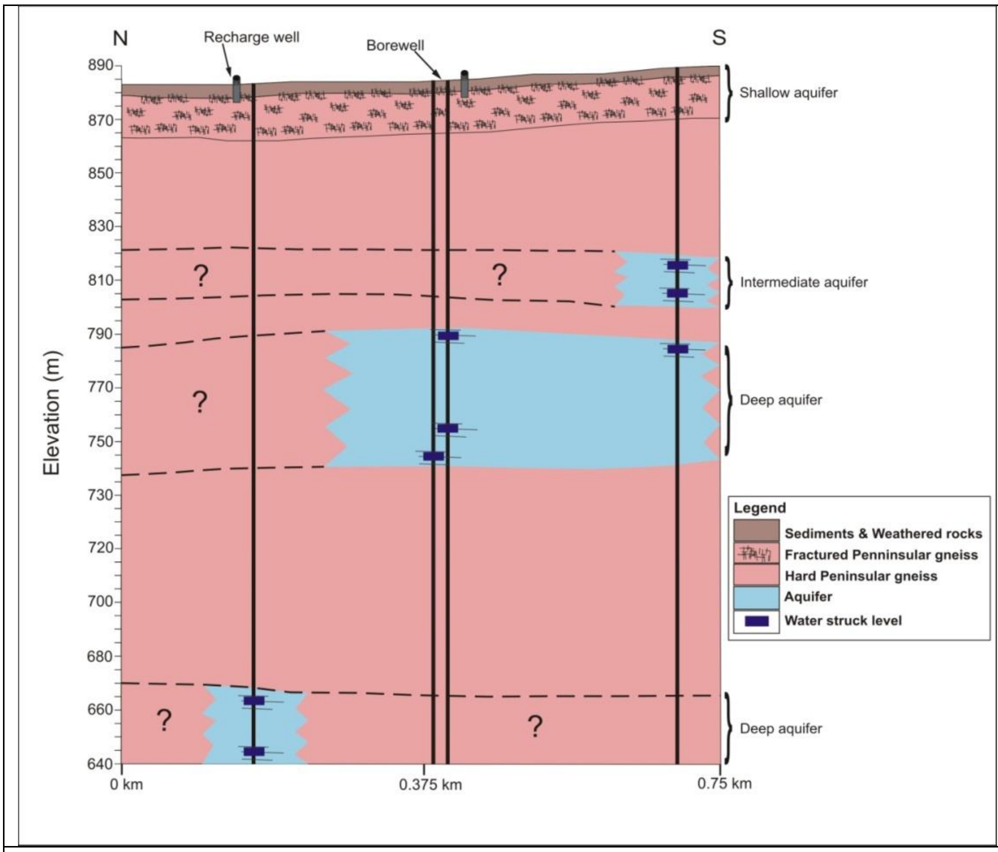
The location of RBD was plot on a Google image overlaid with varying weathered rock thickness in the watershed. It falls in the area which has relatively lesser thickness of weathered rock upto 15m compared to APR cluster. Nevertheless, the subsurface has considerable thickness of strata that makes the shallow aquifer.



Location of RBD with respect to weathered rockthickness across the watershed

Aquifers

Based on borewell narratives a hydrogeological section along N-S direction was drawn shown in fig below. A thick zone of sediments and highly weathered rock is encountered upto 15m below the surface. Hard and fractured rocks extend from below 15m to greater depths.



Hydrogeological section along N-S direction

3 distinct groundwater-bearing zones, corresponding to different aquifers can be identified and delineated as shown in fig. Based on the water struck levels and major fractures and fissures, top and bottom of different aquifers were indicatively delineated but with uncertainty (?) regarding their lateral extent due to limited data.
These aquifers can be broadly categorized based on the depths at which they are encountered below ground level (bgl).

1) Shallow aquifer: 0-12m (approx. 15m thick)

2) Intermediate aquifer: 65-82m (approx. 22m)

3) Deep aquifers: 100-148m (approx. 48m) and 215-245m (approx. 30m)

Note: The first deep aquifer is relatively thicker and most borewells in RBD are tapping it.

Aquifer characteristics

Pumping tests

Once these different aquifers are identified and delineated, next step forward is estimating their characteristics -Transmissivity (T) and Storativity (S). Pumping tests were carried out to evaluate the response of the aquifer to pumping and the estimates are as follows:

Aquifer system	**Cooper-Jacob method**	
	Transmissivity (m^2/day)	**Storativity**

Intermediate	2.019	0.026

T & S values of aquifer in RBD

And the **Specific capacity (C)** of the pumped borewell was estimated to be 22.5 lpm/meter

Recharge wells

The northern part of the layout near the entrance experiences water logging especially during monsoons. General topography of the layout shows approximately 8-10m elevation difference between southern most boundary and northern part of the layout generating downward slope towards the north. Water logging/flooding can be attributed to such northwardly slope.

To releave the layout of such issue and also as a proactive action toward groundwater recharging, several common open wells (photo 5) of 1.25m diameter and 7-8m deep were dug by the POA. And later private recharge wells in individual plots were made mandatory complimented by incentives in water bill as stated in earlier parts of RBD cluster section.

		
Common recharge well	Well with filtration system in storm water drain	Top view with post-filtration storm water inlet.
Common recharge wells in RBD		

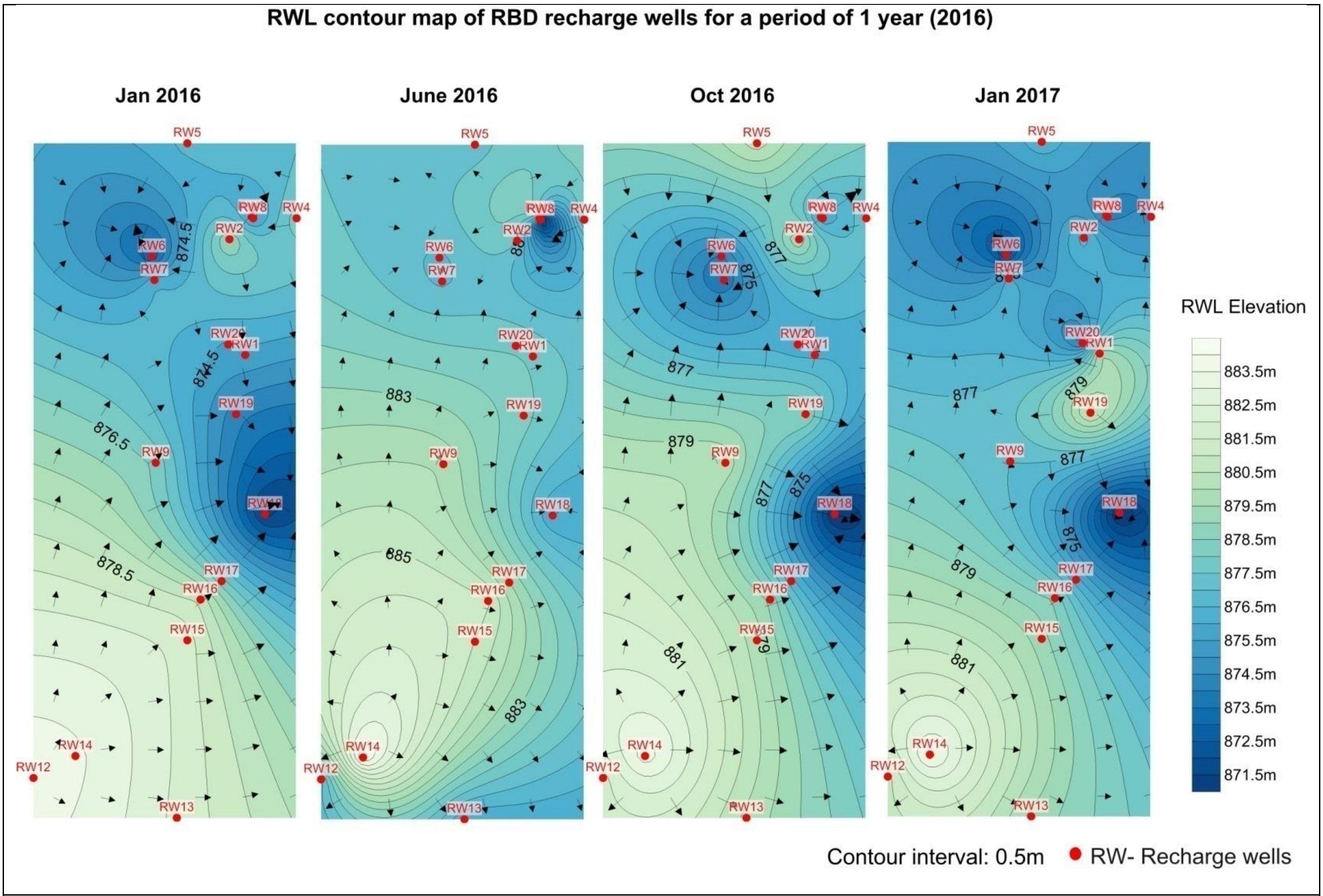
Static water level measurements were taken in all common recharge wells by Acwadam and Biome team in the year 2016 of the following common recharge wells.

Well no.	**Latitude**	**Longitude**	**Elevation (m)**	**Description of location** H = House
RBD-RW1	12.90705	77.68737	882	Near H-12
RBD-RW2	12.90793	77.68725	881.7	Opp H-134, next to H-99/2
RBD-RW3	12.90810	77.68742	881.9	Behind the clubhouse
RBD-RW4	12.90809	77.68776	882.4	Clubhouse play area
RBD-RW5	12.90866	77.68693	881.3	Near Old STP
RBD-RW6	12.90780	77.68666	881	Near H-102
RBD-RW7	12.90762	77.68668	881	Near H-21/35
RBD-RW8	12.90809	77.68743	881.9	Near H-133
RBD-RW9	12.90623	77.68669	884	Opp H-171

Well no.	Latitude	Longitude	Elevation (m)	Description of location H = House
RBD-RW10	12.90515	77.68661	886.5	Opp. H-310
RBD-RW11	12.90510	77.68558	885.6	Near H-249
RBD-RW12	12.90383	77.68576	888.4	Opp H-272
RBD-RW13	12.90353	77.68685	888.5	12th cross, 3rd Main, opp H-325
RBD-RW14	12.90400	77.68608	888.2	Near H-370
RBD-RW15	12.90488	77.68693	886.8	Opp H-371
RBD-RW16	12.90519	77.68703	886	Opp H-397
RBD-RW17	12.90533	77.68719	885.3	H-428
RBD-RW18	12.90584	77.68752	883	Phytorid STP
RBD-RW19	12.90660	77.68730	882.3	Near H-9
RBD-RW20	12.90713	77.68724	882	Near H-5
RBD-RW21	12.90603	77.68668	884.5	Near H-135
RBD-RW22	12.90606	77.68684	884.1	Near H-172
RBD-RW23	12.90577	77.68692	884.6	Near H-425/426
RBD-RW24	12.9045	77.6865	887.4	Near H-285
RBD-RW25	12.90756	77.68626	882.8	Near H-57
RBD-RW26	12.90763	77.68678	881.1	Near H-18
RBD-RW27	12.90728	77.68757	882.2	Clubhouse
RBD-RW28	12.90642	77.68690	883.2	H-94/1

Common recharge wells in RBD

Based on the static water level data collected for 4 quarters in the year 2016, a RWL water contour map was made as given below.



Recharge wells RWL contour map based on 2016 data

Excluded wells:

RW11: false water levels due to addition of Sump water

RW10, 21, 22, 23, 24, 25, 26, 27 & 28 due to accessibility issue & inconsistent data.

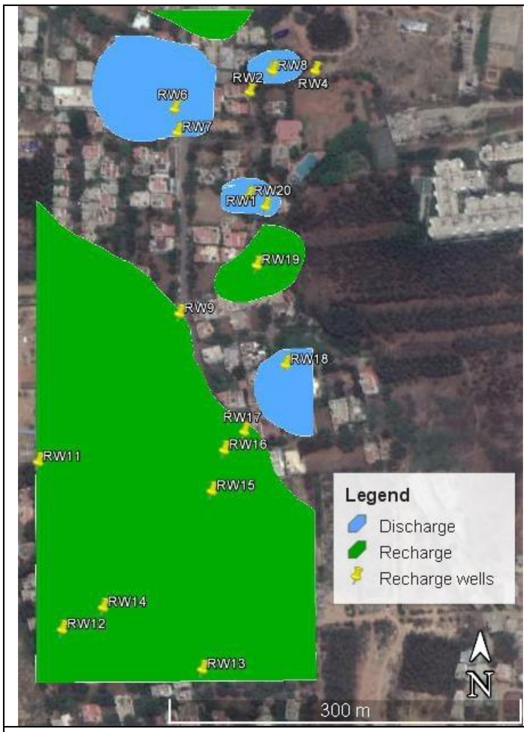
Observation:

- Groundwater movement is primarily from SW to N & NE indicating recharge areas in the SW and W.
- Wells RW 1,3,6,7,8,18 and 20 fall in discharge zone where groundwater flowlines are converging.
- Wells RW 2,4,5,9,11,12,13,14,15,16,17 & 19 prominently fall in recharge zone where groundwater flowlines are diverging.

Analysis:

- The difference between lowest and highest contour line value increases from 8m in Pre-monsoon (January-June) to 11m in Post-monsoon (July-Dec) indicating noteworthy recharge in the area.

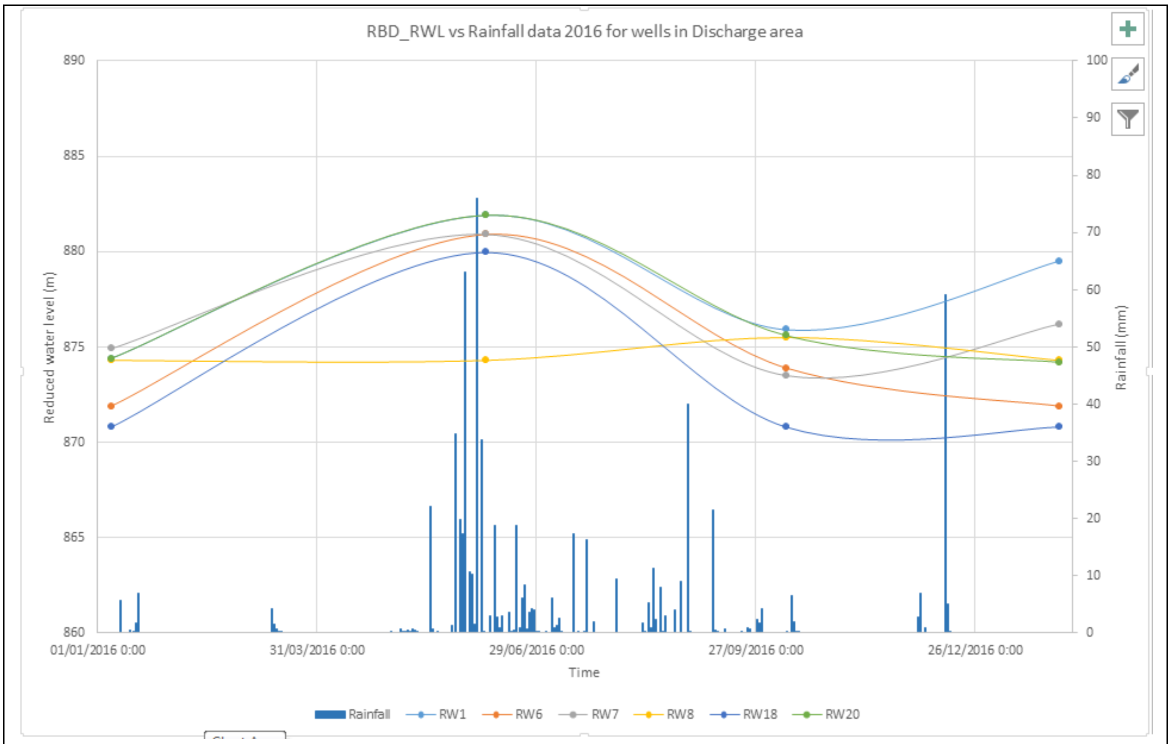
Based on this contour map, recharge and discharge areas were demarcated as shown in fig. Recharge wells falling in the natural discharge areas can be redefined as withdrawal wells and water can be potentially utilised for further consumption.



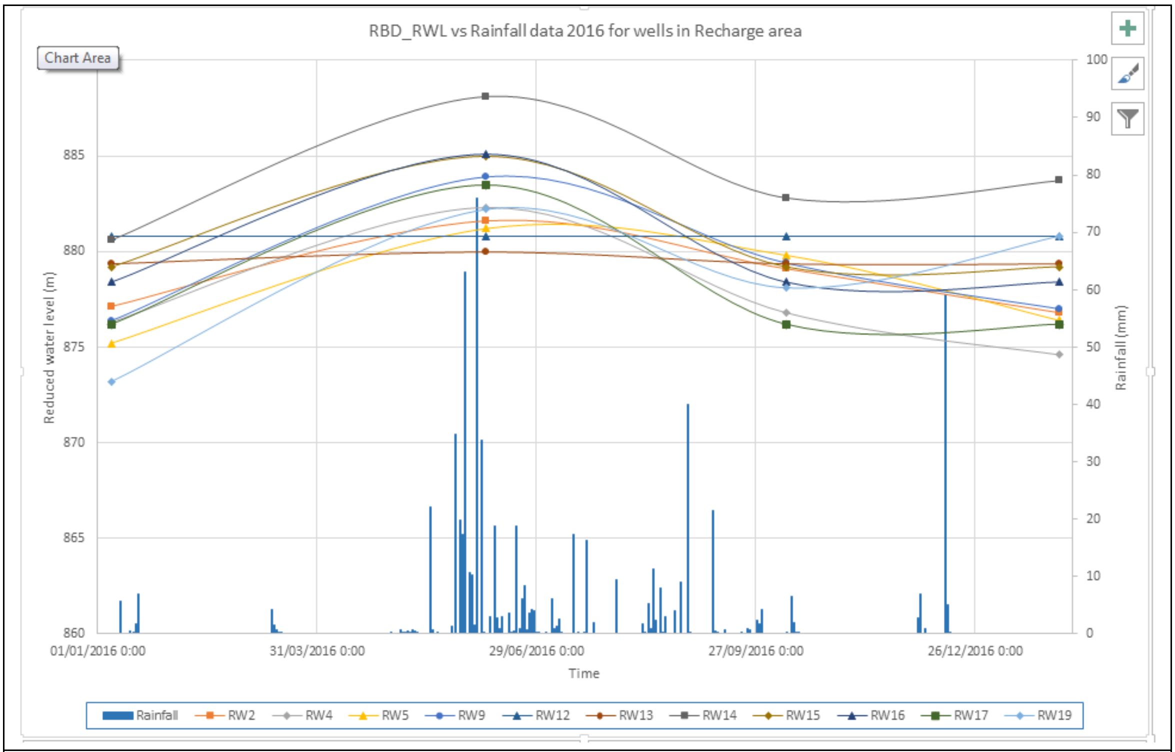
Recharge & Discharge areas

Comparison between wells in Discharge area & Recharge area:

Reduced water levels of wells in discharge and recharge areas were plotted against daily rainfall for the year 2016 and the plot shows the following indications.



Hydrograph of wells in Discharge area vs rainfall based on 2016 data



Hydrograph of wells in Recharge area vs rainfall based on 2016 data

Observation:

- In fig above wells in Discharge area, the changes in the water level are relatively gradual eventually attaining a relatively static state with average annual fluctuation of 7m in the year 2016.
- In fig above wells in Recharge area, the changes in the water level are relatively sudden and majority of the wells witness the continuation of decrease with average annual fluctuation of 5.7m in the year 2016.

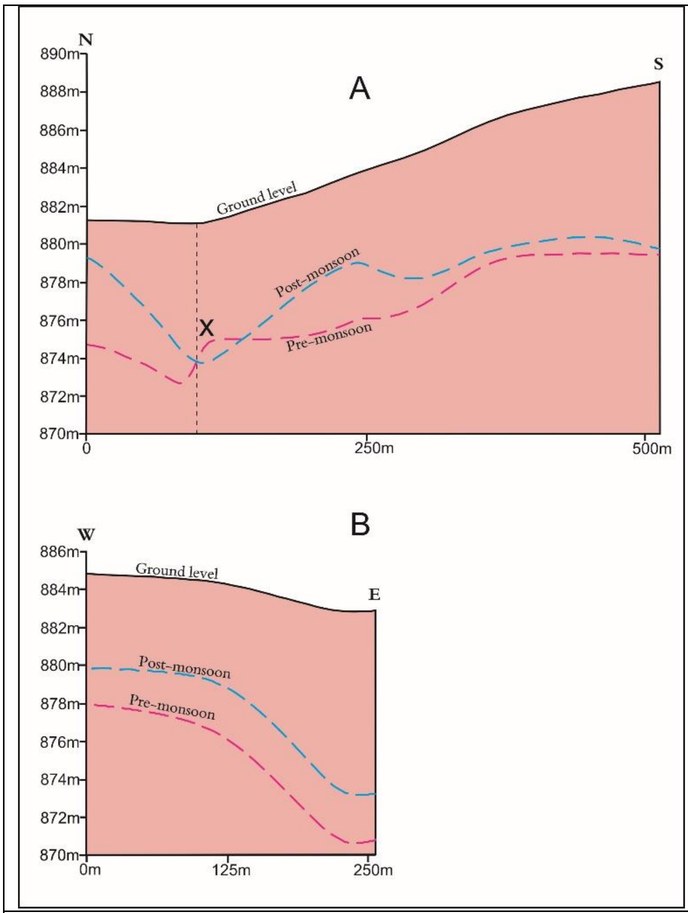
Analysis & Inference:

- The fairly gradual changes and eventual static state of water levels in Discharge area further confirms the discharging nature of the area.
- Whereas the sudden changes and continous decrease in the water levels in Recharge area confirms the recharging nature of the area.

Water table

RWL contour map made from water level data of recharge wells for pre & post monsoon seasons were used to draw the general water table of the layout.

Using SURFER software, cross sections were drawn along N-S and E-W direction of these contour map as shown in fig.



Pre & post monsoon 2016 fluctuation in water table along N-S (A) &E-W (B) direction of the layout

Observation:

- Both season water levels are relatively shallower in the north compared to the southern part of the layout (A). Similarly, shallower in the western compared to the eastern part of the layout (B).
- Inconsistent variation between pre and post monsoon water table along N-S direction of the layout, whereas a notably consistent variation along E-W direction.
- The intersection of pre & post monsoon water table in (B) denoted by "X" hints towards a discontinuation in the shallow aquifer and possibly a boundary between 2 different aquifers in the subsurface of the layout.

Analysis & Inference:

- The presence of the water table at relatively shallow depths in the north and western parts as compared to other parts of the layout **validates the occurrence of flooding** during monsoon season in the northern part of layout near entrance.
- The inconsistent variation in the water table of pre and post monsoon seasons along N-S direction could be probably due to one or several of reasons such as the existence of multiple aquifers in the recharge wells, interference between shallow and deeper aquifers and leakage from an exogenous source to the aquifer in some portions of the layout, particularly during the pre-monsoon period.
- The discontinuation "X" could be a consequence of one or more of the above mentioned factors and needs further exploration through testing of a few recharge wells in and around that location.

Borewells

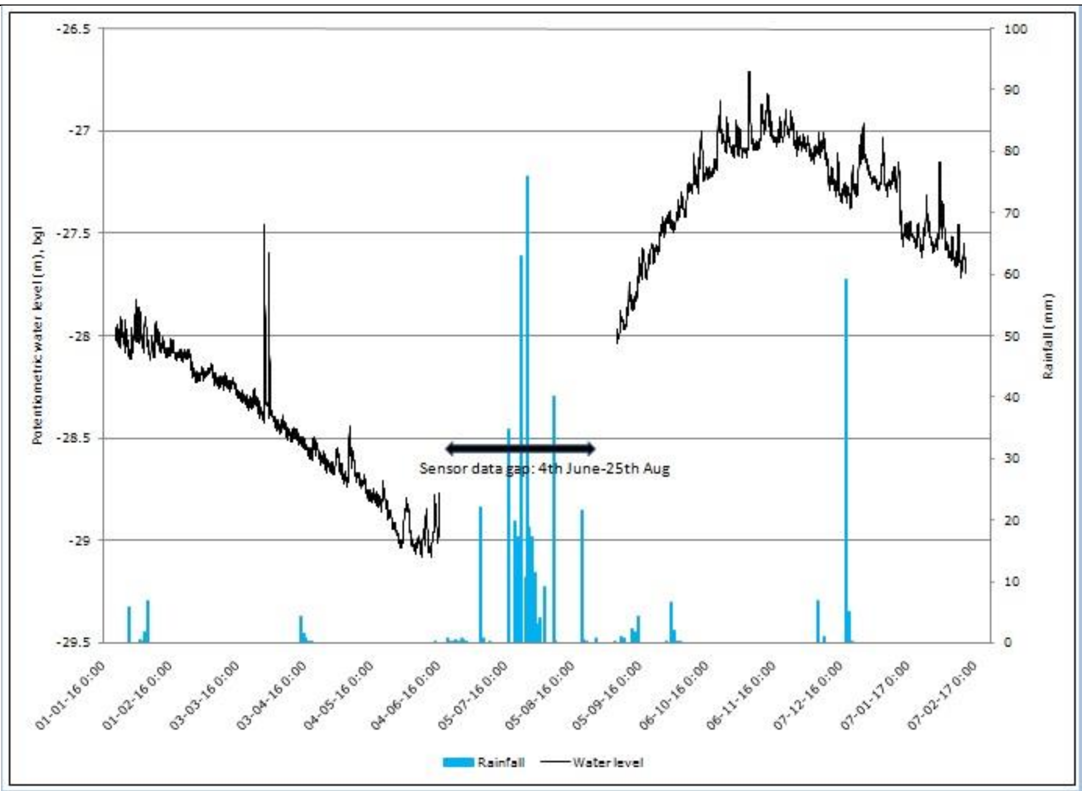
There are several borewells in RBD and some are yielding a good share for water demand. The narrative obtained from the POA regarding BW is tabulated in table below.

Potentiometric water level measurements were taken manually in borewells (only in wells with acessibility) in Oct 2016 and the plot is shown in fig.

Sr.no	Location	Total depth (m)	Depth of source (m)				October 2016
			1st	2nd	3rd	4th	Water level (m)
BW1	Clubhouse playground	244	219	238	-	-	127.4
BW2	Swimming pool filtration room	-	-	-	-	-	12.19
BW3	Opp H. No. 57-Apoorva	-	-	-	-	-	132
BW4	Opp H. No. 93	-	-	-	-	-	not accessible
BW5	Opp H. No. 137	81	-	-	-	-	36.26
BW6	Near H. No.172	-	-	-	-	-	not accessible
BW7	Near H. No. 246	195	-	-	-	-	57.9
BW8	Near H. No. 262	225	143	-	-	-	22.1
BW9	Near H. No. 347	144	73	83	103	107	27.2
BW10	Near H. No. 401	85	-	-	-	-	65.3
BW11	Near H. No. 416	328	141	-	321	-	122.4
BW12	Near STP-II (Opp H. No. 416)	190	29	-	131	169	105.15

Borewell dataof RBD with Oct 2016 water levels

HOBO sensor data analysis: In order to study the water level changes in a borewell tapping deep aquifer, HOBO water level sensor was installed in BW9 for long term monitoring and data is plotted below.



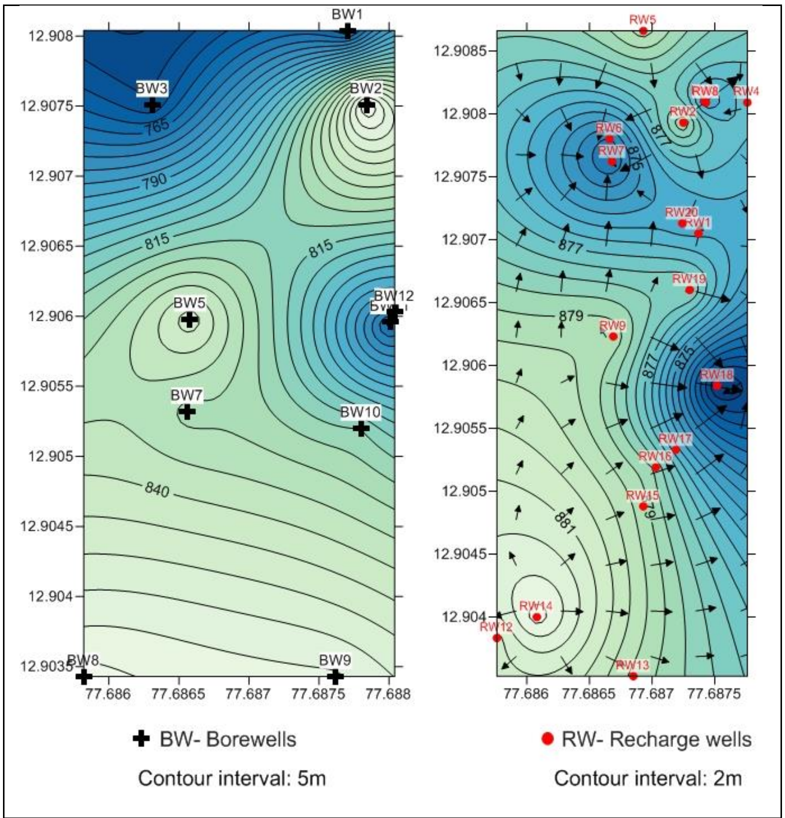
HOBO water level data from borewell BW9 vs. rainfall (mm) based on Jan 2016-Jan 2017 (1 year) data

Observation:

- There are several minor fluctuations in the water level readings and some major ones.
- There is a steady decrease in the potentiometric water level from Jan to June 2016 (pre-monsoon).
- There is substantial rise in water level starting June 2016 however there is data gap from 4-June-2016 to 25-Aug-2016 due to unforeseen malfunction in sensor.
- Starting Aug 2016, water level increase continues through monsoon till Oct 2016.
- Post monsoon, from Oct 2016 to end of Jan 2017 (end of observation period), the water level steadily decreases.

Analysis & Inference:

- Minor fluctuations throughout the monitoring period maybe the result of pumping in the vicinity and the major ones are most probably due to physical disturbance to sensor position.
- The steady decrease represents pumping in borewells in the vicinity.
- During pre-monsoon dry period, there is sharp increase in water level which may be probably due to delayed recharge effect from January rainfall.
- With start of monsoon (RWH recharge through recharge wells) and possibly lesser pumping in borewells in the vicinity, there is a significant rise in water level from June to Oct 2016 till end of monsoon period.
- During the missing data period, the trend (steady rise) between the two dates is still representative of part of the recharge process.
- The steady decrease during Oct 2016-Jan 2017 shows a very similar behavior like Jan-June 2016 data, concluding a repetitive cycle taking place Pre-monsoon to Post-monsoon.



Borewell-Recharge wells co-relation based on

Oct 2016 data

Co-relation between Borewells & Recharge wells based on Oct 2016 data:

Based on the potentiometric water level of the borewells, a RWL contour map was prepared as shown in fig above.

In the borewell contour map, there is a relatively large head difference of nearly 100m between northern and southern parts of the layout which is partly due to borewells tapping different confined aquifers.

Not much can be analyzed and concluded though,due to only one time borewell water level data and also most of the borewells are pumped regularly which gave dynamic potentiometric water levels instead of stable water levels.

An attempt is made to investigate any potential co-relation between the water levels of recharge wells and borewells.

Way forward

- The T & S of shallow and deeper aquifers need to be estimated by performing **Pump tests** in order to draw a more sustainable groundwater mangement plan in the layout.
- There is a need to perform **Slug tests** in the open wells and borewells tapping all the aquifers to estimate recharge rates.
- Based on preliminary findings of groundwater movement & recharge/discharge areas 1 open well each from delineated recharge and discharge areas were chosen for installation of HOBO sensor for long term monitoring.
- 1 HOBO sensor each was installed in:
  1) Recharge area - RW5
  2) Discharge area - RW7
- Laboratory Quality test of water samples from RW5 & BW7 and any probable co-relation between their results would possibly help postulate the inter-relationship between discharge and recharge areas and further our understanding about the subsurface of the area.
- Although, long term monitoring for 1 year was done on one of the borewells, there is further necessity to study water level changes in other borewells tapping intermediate/deep aquifer and find out possible groundwater recharge happening in these aquifers in tandem with recharge taking place in the shallow aquifer. These can be achieved possibly by co-relating the water level fluctuations in selected open wells and borewells over a longer time period.
- Under such premise, defunct borewells BW2 and BW11 were shortlisted and 1 HOBO sensor each was installed for long term monitoring.

Recommendations

- ***Withdrawal & Recharge wells:*** Once the quality of the groundwater from shallow aquifer is deemed fit and within desirable standard quality limits, systematic pumping needs to be performed concurrently with recharge efforts. Recharge wells falling in the discharge area should be designated as withdrawal wells.
- ***Water quality:*** Systematic pumping of water from withdrawal wells and introduction of fresh rainwater through recharge wells will eventually bring the essential quality parameters within desirable limits and improve the overall quality of groundwater in longer run.

Messages

- Communitizing existing borewells and banning of new borewell drilling complimented by metered water connection works best for sustainable usage of water. And judicious demand management and efficient waste water usage ultimately leads to cutback of high per capita urban consumption moving towards more community centric sustainable consumption.
- Water requirement for construction can be fulfilled by utilizing treated waste water with desirable quality instead of precious fossil groundwater. Banning borewell water for construction is a good way forward.
- Borewells are drying out and reviving them is relatively expensive than maintaining, conserving and reviving the shallow aquifer, associated wells & surface system.
- Mandatory Rainwater Harvesting along with construction of appropriately placed recharge structures are excellent measures by leveraging the vast area of the layout by artificial & natural rainwater recharge which will keep the shallow aquifer revived.

Kaikondrahalli (KKD) lake cluster –Lake & Shallow aquifer

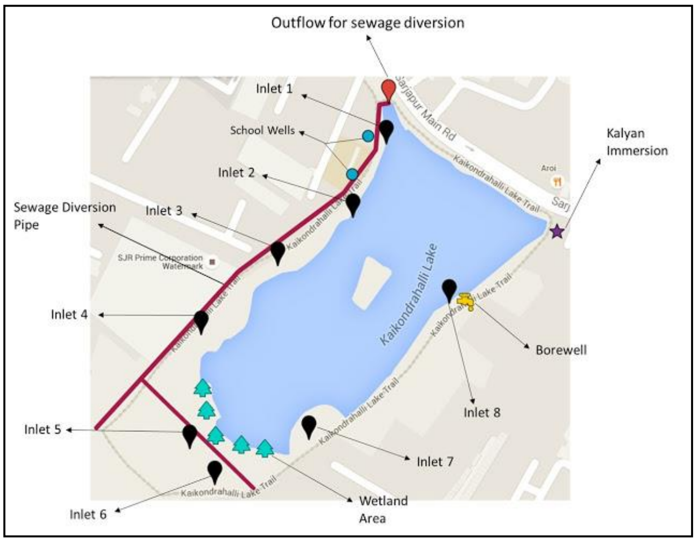
Introduction

Kaikondrahalli Lake is situated right off Sarjapur Road and can be considered as one of the more vibrant lakes that are existent in Bengaluru. It is one of the few lakes remaining from the original many lakes that survive today. The lake is predominantly taken care of by a citizen run organization known as MAPSAS. Although most of the lakes or rather tanks are man-made structures built in 16th century during the Kempegowda kingdom, anthropogenic interventions and alterations like rapid urbanization and non-governance of these water bodies has shrunk the number of lakes from 262 in 1960 to present day 81 of which only 34 are recognized as live lakes.

The whole idea of catching the runoff by constructing bunds ultimately transforming into tanks (artificial lakes) was to create a productive ecology, a reliable water source and recharging the subsurface water (groundwater). During this entire process, an interaction is inevitably bound to happen between the surface water (runoff and the accumulated lake water) and the subsurface water (groundwater).

An attempt is made here to understand this interaction between the surface water and groundwater and how any physical, chemical and biological changes in any of these components affects the other one. **However, this attempt is strictly from hydrogeological perspective**.

Surrounding this lake, there are many old and new dug wells which are main source of drinking and domestic water for many people and these dug wells serve good points of observation. Renuka school (a government school) is located next to the lake. The school has two recharge wells and rainwater harvesting has been implemented in this school. The recharge well diameter is 0.91m (3 ft) with 4.57m (15ft) depth. The well water is used by the school for non-consumptive purposes. The school is able to pump water twice everyday from this well. Further down from the lake and the school, is an independent house with an old open well. The open well called as “Priya’s well” is 6.09m (20ft) in diameter with 12.19m (40ft) depth approximately. The open well water is sometimes used by the house owners for gardening purpose.



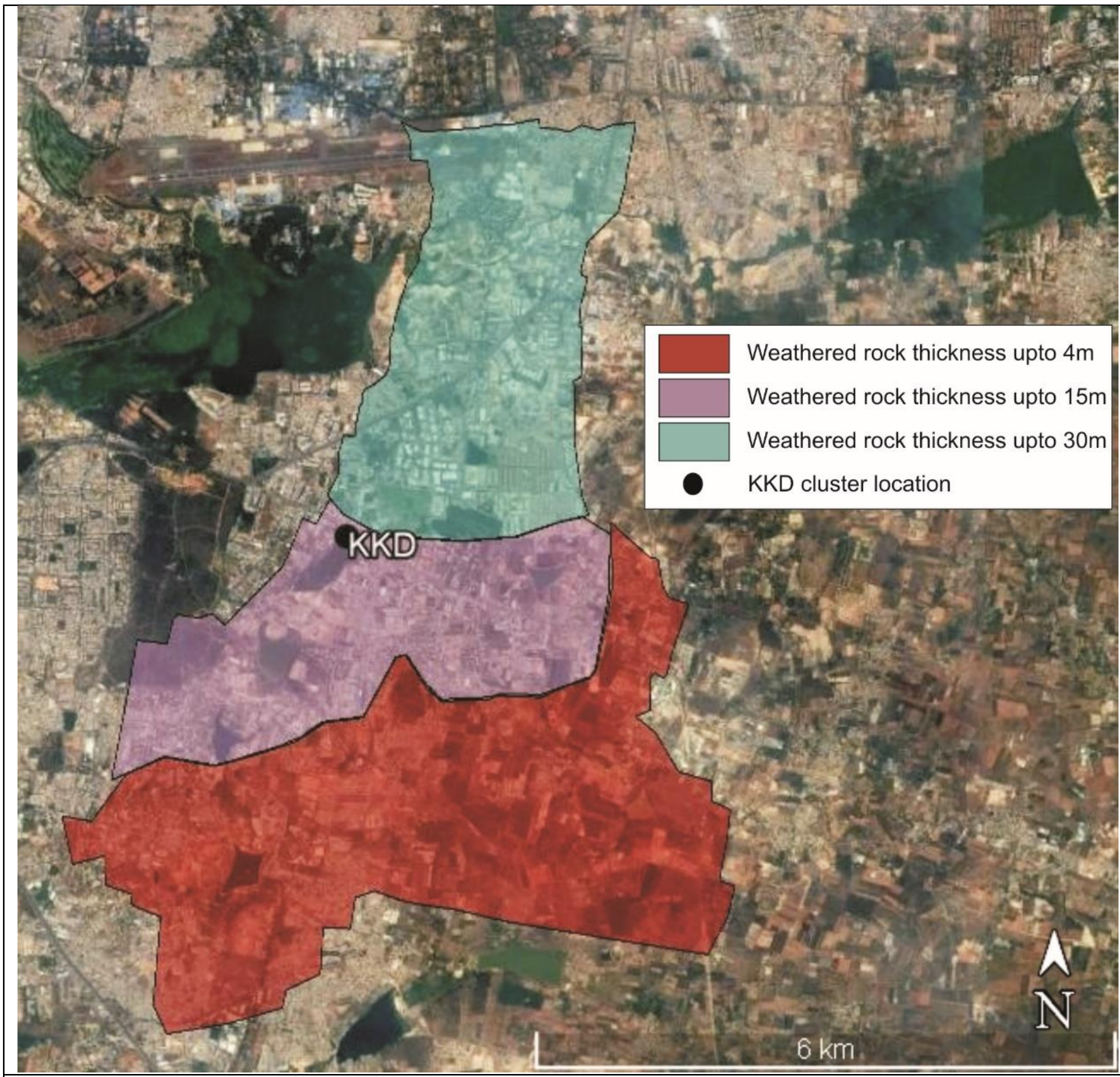
Google image of Kaikondrahalli lake & surroundings

The following text primarily describes the methodology, observations and analysis of recorded data on water level changes & quality in the lake and the surrounding dug wells. The text also details out the aquifer delineation, its thickness & characteristics, learning’s and way forward for lake and its vicinity in general.

Hydrogeology &Aquifer characteristics

Weathered rock thickness

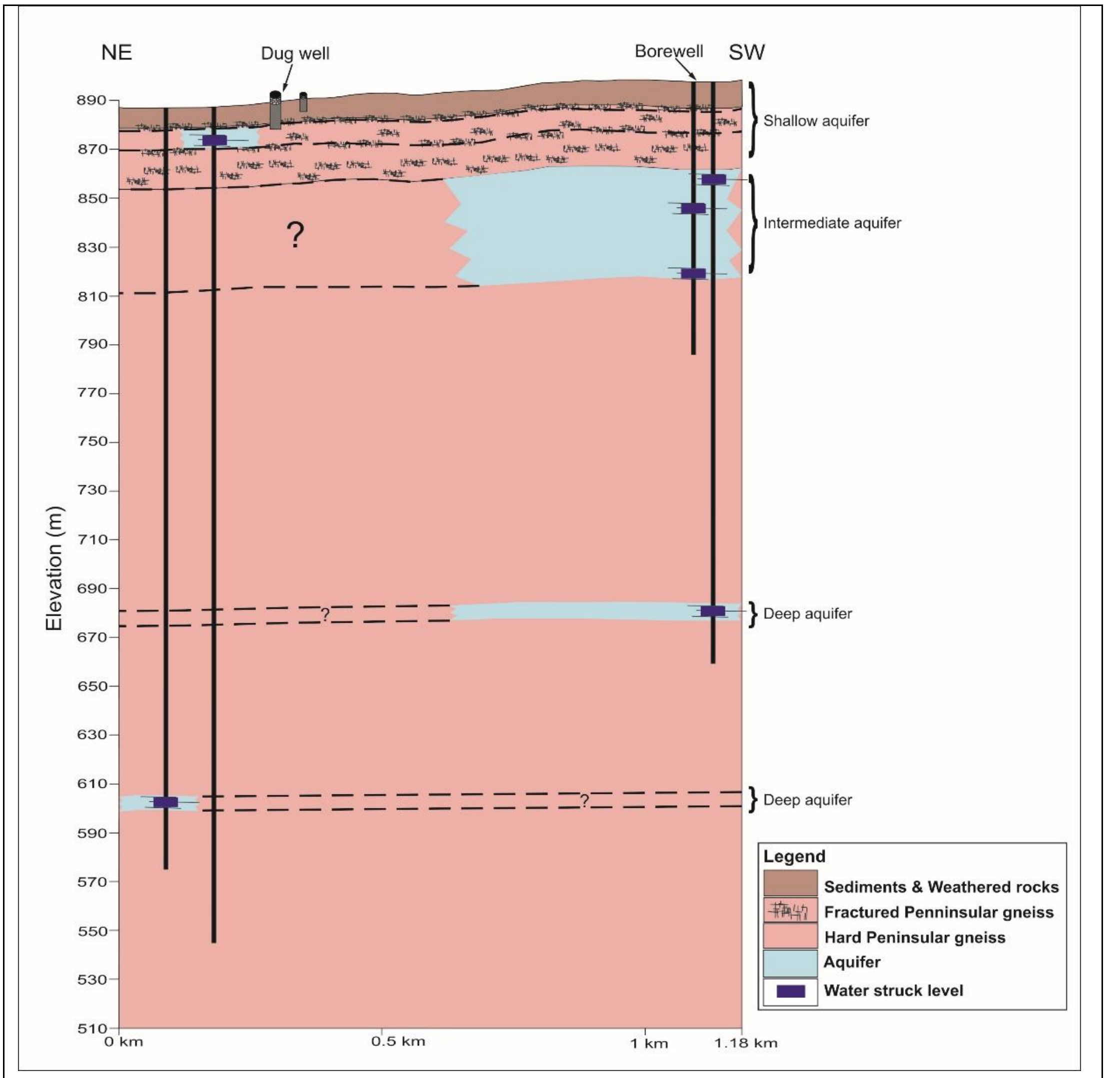
Kaikondrahalli cluster was plot on a Google image overlaid with varying weathered rock thickness in the watershed. It falls in the area which has relatively lesser thickness of weathered rock upto 15m compared to APR cluster. Nevertheless, the subsurface has considerable thickness of strata that makes the shallow aquifer.



Location of KKD cluster with respect to weathered rock thickness across the watershed

Aquifers

Based on borewell narratives a hydrogeological section along NE-SW direction was drawn shown in fig below. A thick zone of sediments and highly weathered and fractured rock is encountered upto 35 meters below the surface. Hard and fractured rocks extend from below 35 meters to greater depths.



Hydrogeological section along NE-SW direction

3 distinct groundwater-bearing zones, corresponding to different aquifers can be identified and delineated as shown in fig. Based on the water struck levels and major fractures and fissures, top and bottom of different aquifers were indicatively delineated but with uncertainty (?) regarding their lateral extent due to limited data.

These aquifers can be broadly categorized based on the depths at which they are encountered below ground level (bgl).

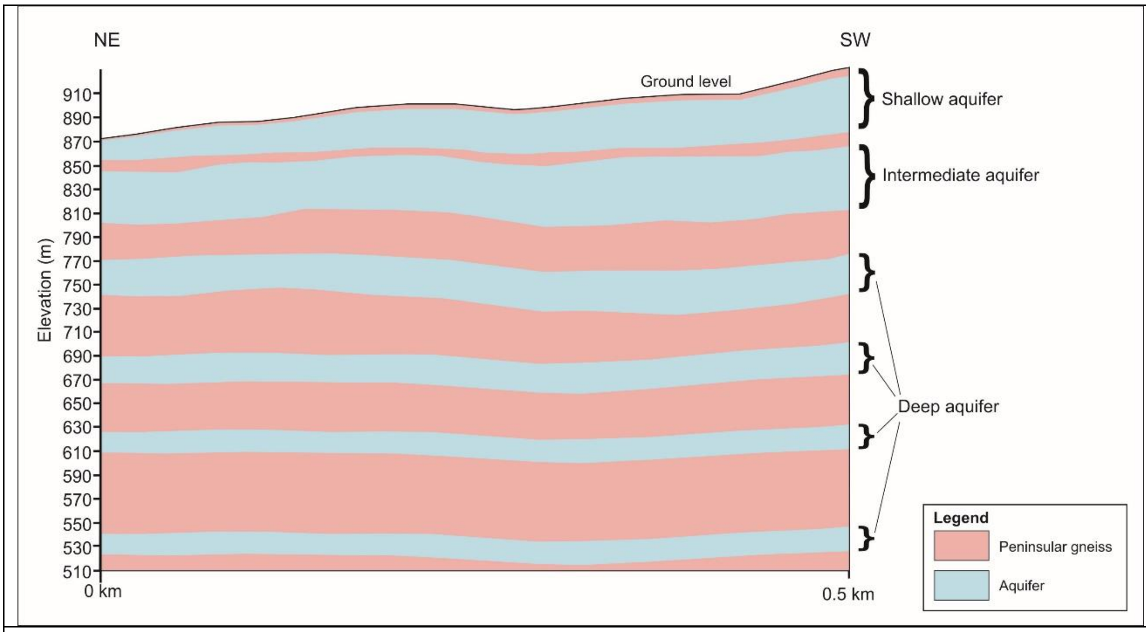
1) Shallow aquifer: 0-20m (approx. 20m thick)

2) Intermediate aquifer: 35-76m (approx. 41m)

3) Deep aquifers: 207-212m (approx. 5m) and 282-287m (approx. 5m)

Note: The intermediate aquifer is relatively thicker and most borewells near KKD lake are tapping it.

Geophysical method of Vertical Electrical Sounding (VES) survey was done by a third party in the Upper Ponnaiyar watershed and one such station 8 was located near the KKD lake. A section is drawn based on this plot and different aquifers were indicatively delineated as shown below.



VES section along NE-SW direction based on data from Station #8

Aquifer characteristics

Pumping tests

Once these different aquifers are identified and delineated, next step forward is estimating their characteristics -Transmissivity (T) and Storativity (S). Pumping tests were carried out to evaluate the response of the aquifer & well to pumping and the estimates are given below:

Aquifer system	**Transmissivity (m^2/day)**	**Storativity**	**Specific capacity of well (C)** lpm/meter drawdown
Shallow	5.94-6.44	0.001-0.002	18.91
Deep	8.8	0.030	18.52

T & S estimates of aquifers and C of observed wells in KKD

Groundwater and Surface water (GW-SW) interaction

Withdrawing water from shallow aquifers that are directly connected to surface-water bodies can have a significant effect on the movement of water between these two water bodies. The effects of pumping a single well or a small group of wells on the hydrologic regime are local in scale. However, the effects of many wells withdrawing water from an aquifer over large areas may be regional in scale (Winter, Thomas C. et al., 1998).

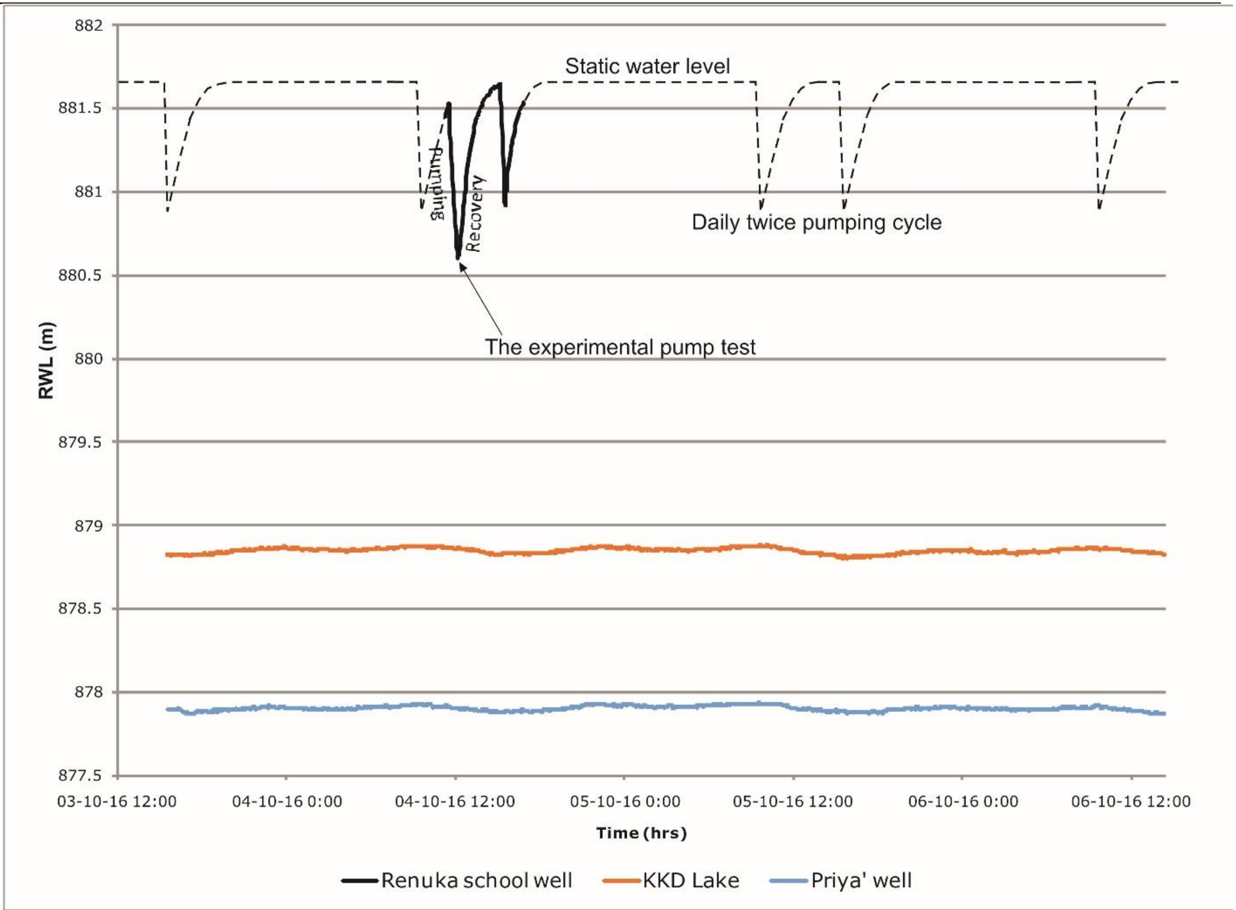
Groundwater and surface water are not isolated components of the hydrologic system, but instead interact in a variety of physiographic and climatic landscapes. Thus, development (or exploitation perhaps) or contamination of one commonly affects the other. Therefore, an understanding of the basic principles of interactions between groundwater and surface water (GW–SW) is needed for effective management of water resources (Sophocleous, Marios. 2002)

The Experiment

To study this interaction and to investigate relationship whatsoever between Lake and wells in its vicinity, induced changes in the water level of a dug well were executed by a pumping test. Under ideal conditions (no other pumping in the vicinity & test/observation wells prior/post to test until observation) pumping in a well normally induces change in water level (cone of depression/radii of influence) in the water bodies/wells in the vicinity.

Pumping test was carried out in a small dug well in Renuka school near Kaikondrahalli lake. HOBO sensors were installed in the pumping well, the lake and an adjacent well-Priya's well to record water level changes (if any) during and after the test. Pumping well could only be monitored during school operating hours due to school administrative reasons, however sensors in Lake and Priya's well were stay put as long as practically feasible.

Google image of the study area



RWL data of pumped well in Renuka school and observed Priya's well & KKD lake during the experiment in Oct 2016

Observation:

- Pumping test in the well in Renuka school gave a classic drawdown-recovery curve.
- During and post pumping test in Renuka school well, there are no observable abnormal changes in water levels of Lake and Priya's dug well.
- However, the non-derived water level fluctuations in Priya's well and KKD lake appear synchronous to each other.

Analysis & Inference:

- The classic drawdown-recovery curve indicates the typical unconfined nature of the shallow aquifer underlying Renuka School.
- The induced change in volume of water brought about by pumping in the school well appears too small to affect any change whatsoever in the comparatively large volume of water contained in Priya's well and the lake.

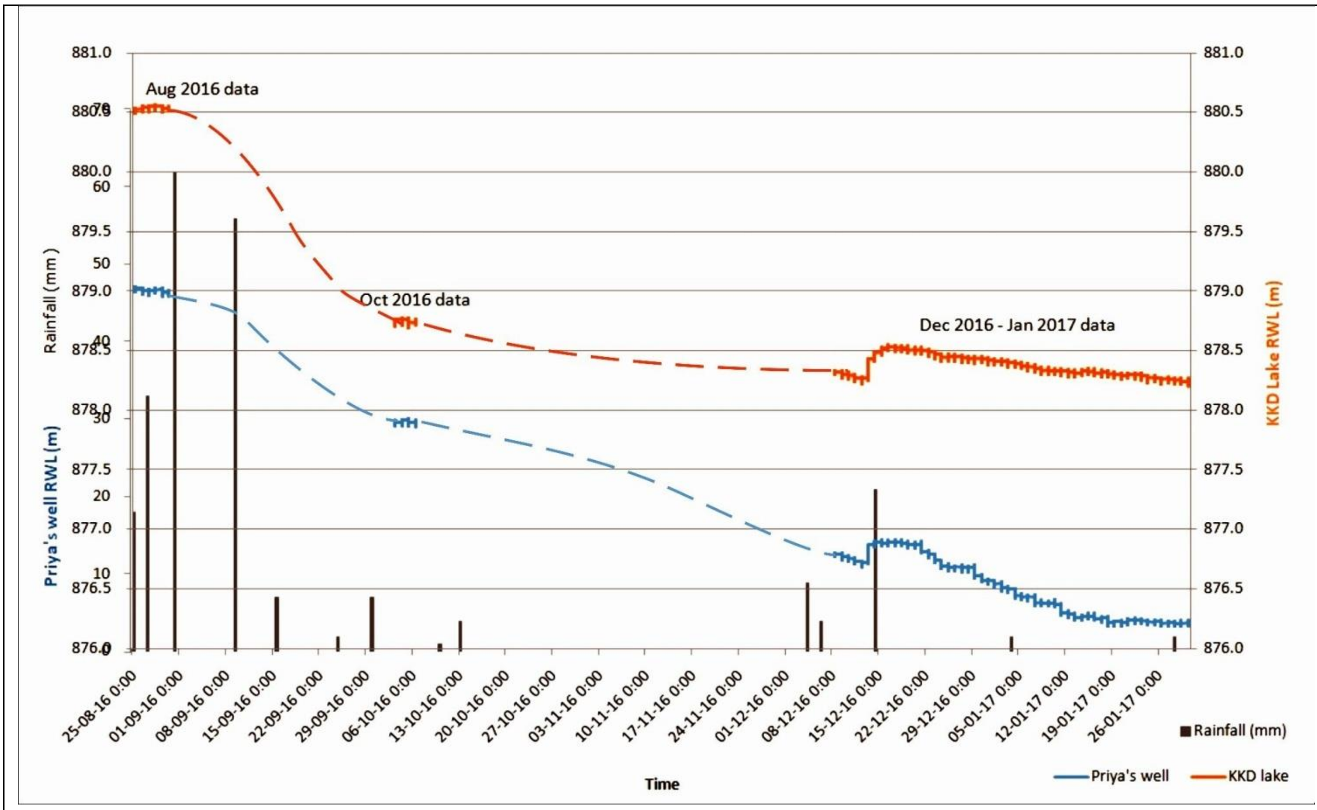
Way forward:

- The observation points (wells) need to be more in number and widely spread around the lake.
- No prior and post pumping in the pumping well and observation wells.

Static water level changes

As discussed in previous section, data on changes in static water level in open wells and/or lakes offer a great deal of information about any possible inter-relationship between groundwater and the surface water.

HOBO water level sensors were installed in Lake and Priya's dug well during the year 2016 for recording water level changes. The data gaps were interpolated based on general trend of the changes. The resulting plot is given in fig below:



RWL data from Priya's dug well and KKD lake for year 2016 with interpolation to periods of missing data, plotted against the rainfall (mm) for same period

Observation:

- There is a very obvious similarity in major water level changes between Priya's well and lake even without interpolation of data gaps.
- Post Aug monsoon, water level in Priya's well and lake starts decreasing sharply until reaching a steady decline in Oct closely following the retreating rainfall. However, a sharp increase can be noticed in the middle of Dec during which >20mm rainfall was also observed.
- Post Dec, there is a noticeable continuous drop in water level of Priya's well, while a steady decline in the lake water level.

Analysis & Inference:

- There seems to be an unambiguous inter-dependence and synchronous relationship between lake water and dug well water (shallow aquifer) which needs further understanding with more data.

Lake is Recharging or Discharging?

According to one of the original objectives of building tanks (lakes) in Bengaluru, the groundwater was to be recharged by catching the rainwater runoff and allowing it to percolate into subsurface classifying these lakes as man-made recharging structures. However, some observations that were made during our study in dug wells and Kaikondrahalli lake water levels offer an interesting insight to the role of lakes particularly in context to the shallow aquifers. The text that follows explains these further.

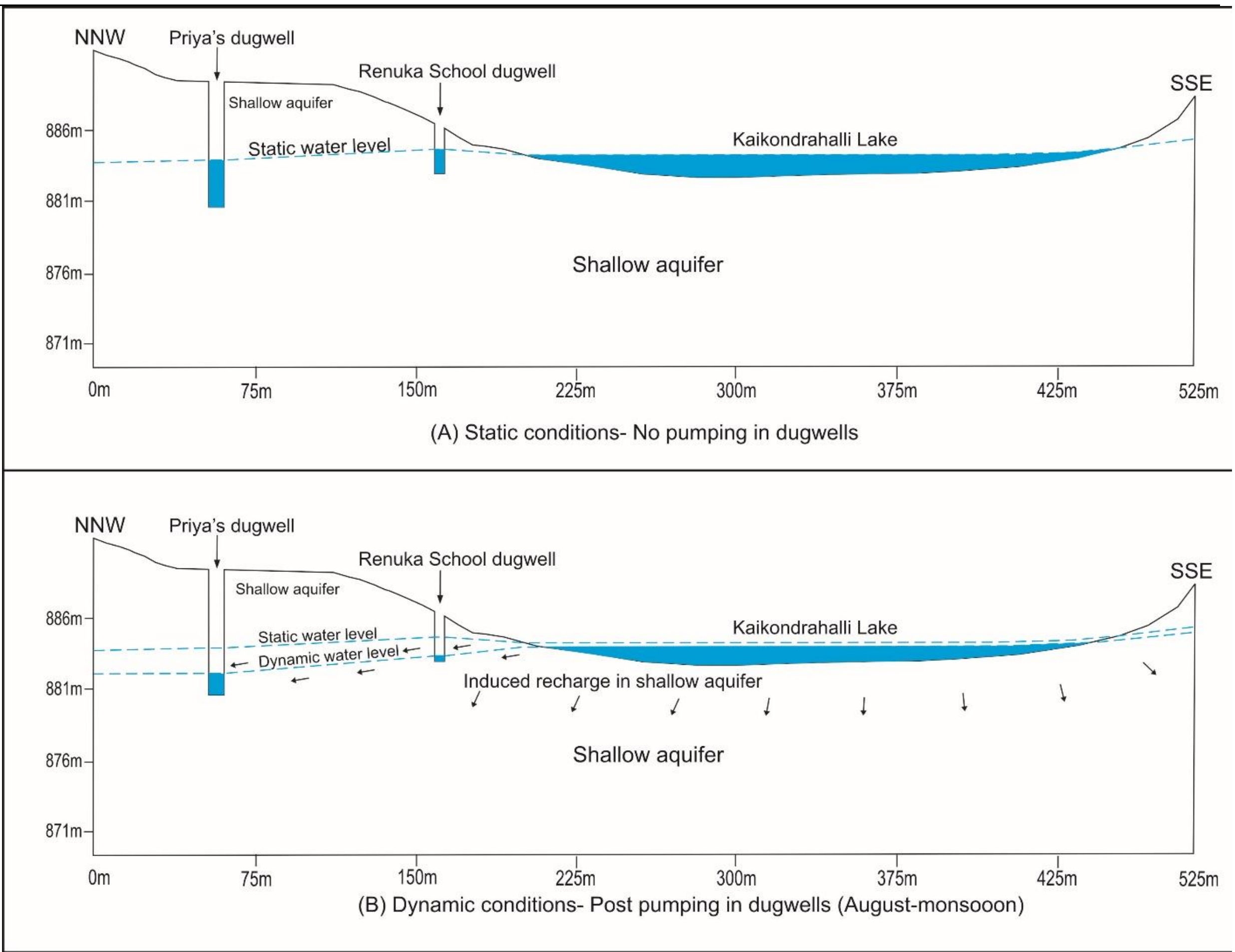
To get scientifically fair & broader understanding of the GW-SW interaction/inter-relationship, additional observation points were searched around KKD lake. However, due to urban encroachment many of the old dug wells have been filled up to ground level, some disappeared due to construction and a few silted up due to non-maintenance.

Consequently, this study and its inferences outlined in the following text are based on limited data points and the results therefore are exclusively for the northern part of the Kaikondrahalli lake. In future, a more extensive study covering most parts of the lake vicinity will give more detailed and broad scientific conclusions.

August 2016 data
Static water levels were recorded from this limited number of dug wells and Kaikondrahalli lake concurrently during the monsoon period in Aug 2016.
These static water levels were converted to reduced water levels (RWL) to draw a water contour map.
The obtained RWL contour map was overlaid on GOOGLE EARTH to give a more geographically sound understanding as shown in fig.

RWL contour map with water movement denoted by arrows overlaid on Google image based on Aug 2016 data

A section profile was drawn out of the RWL contour map with all observation points covered, to get a clear viewpoint.



Cross section showing inter-relationship between shallow aquifer and KKD lake during monsoon

Observation:

- During no pumping, water levels in all observation points remain in a static equilibrium state.
- However, during & post pumping in dug wells the general water movement is from the lake toward the dug wells evident from the contour map and section.

Analysis & Inference:

- The movement of water from hydraulically high point in lake toward the lower point in dug wells is the result of a Hydraulic gradient formed due to cone of depression during/post pumping in dugwells.
- Since the dugwells are tapping the shallow aquifer, the water moving down from lake is probably percolation and it can be inferred that the lake in this case is recharging the shallow aquifer and ultimately replenishing the dugwells.

December 2016 data

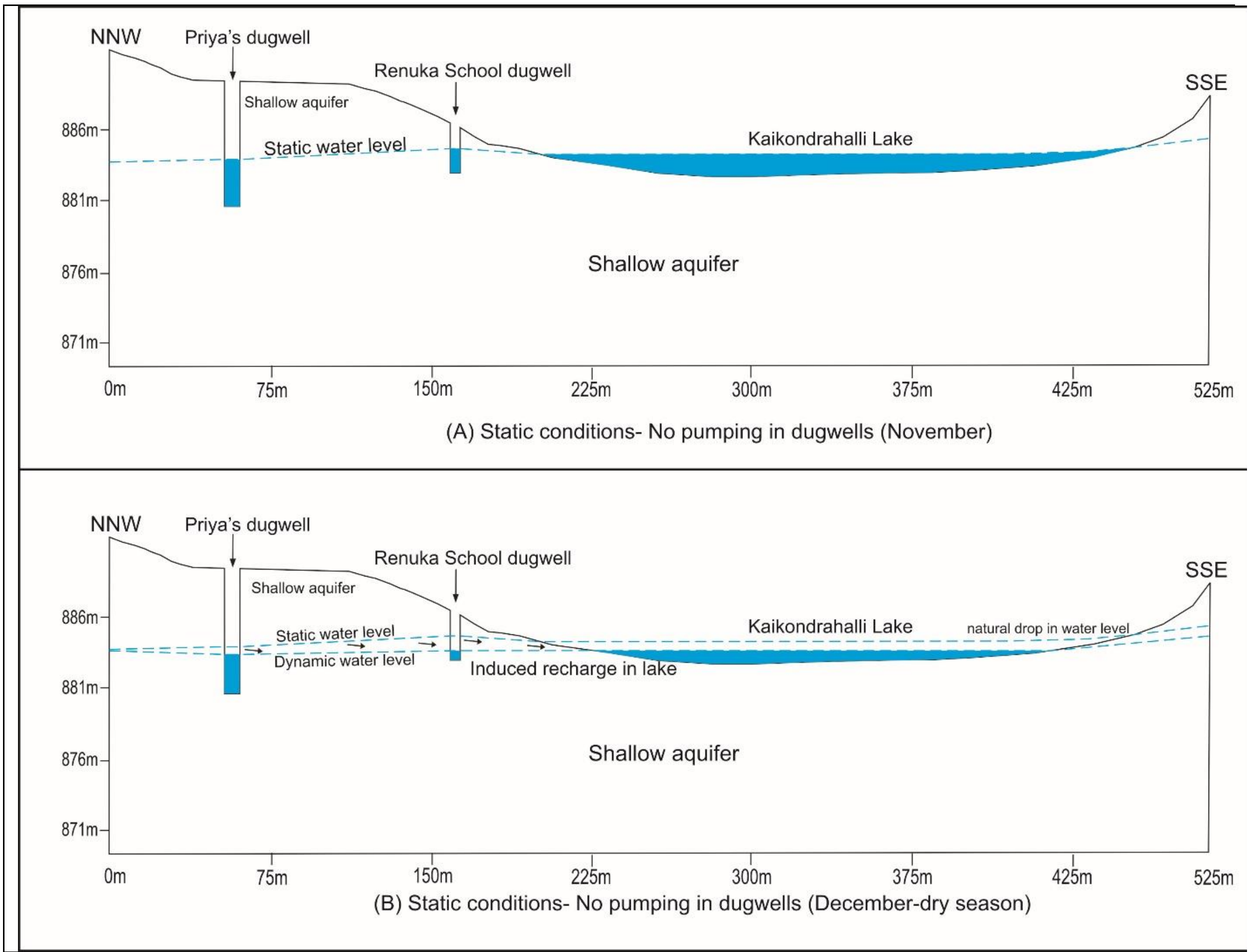
Static water levels were recorded from same dug wells and Kaikondrahalli lake concurrently during the dry season in Dec 2016.

These static water levels were converted to reduced water levels (RWL) for plotting in SURFER

software to draw a water contour map.
The obtained RWL contour map was overlaid on GOOGLE EARTH to give a more geographically sound understanding as shown in fig.

RWL contour map with water movement denoted by arrows overlaid on Google image based on Dec 2016 data

A section profile was drawn out of the RWL contour map with all observation points covered, to get a clear viewpoint.



Cross section showing inter-relationship between shallow aquifer and KKD lake during dry season

Observation:

- During dry season & high temperature even without pumping, there is a natural drop in water level of lake and dugwells.
- However, based on the contour map it is evident that general movement of groundwater is from dugwells toward the lake.

Analysis & Inference:

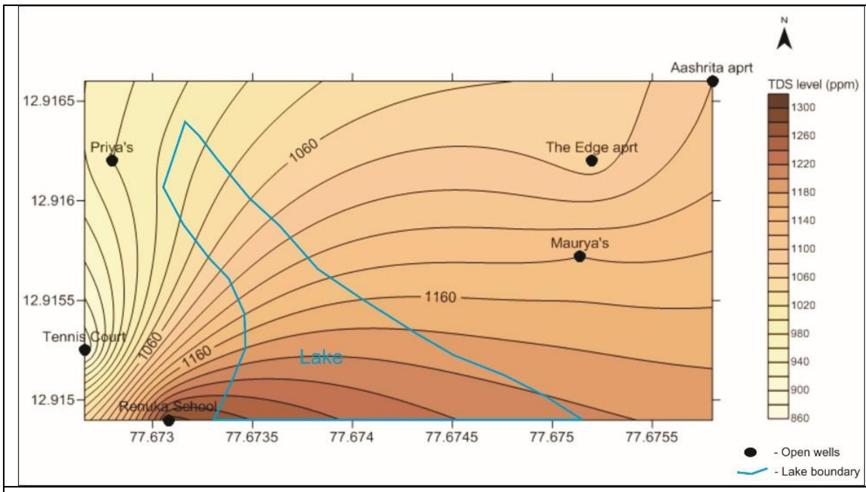
- The movement of groundwater from dugwells tapping shallow aquifer toward the lake is the result of an induced Hydraulic gradient formed during/post natural drop in lake water level.
- Since the dugwells are tapping the shallow aquifer, the water moving from dugwells toward the lake is probably subsurface recharging (movement) and it can be inferred that the shallow aquifer in this case is recharging the lake.

Water Quality

Simple measurements of basic water quality parameters were taken with the help of a portable instrument "TRACER" at dug wells around KKD lake during Feb 2017. These data was plotted in "SURFER" software to make contour maps of individual parameters showing their distribution and trend in the area as shown in below figures.

Total Dissolved solids (TDS in mg/l)*:*

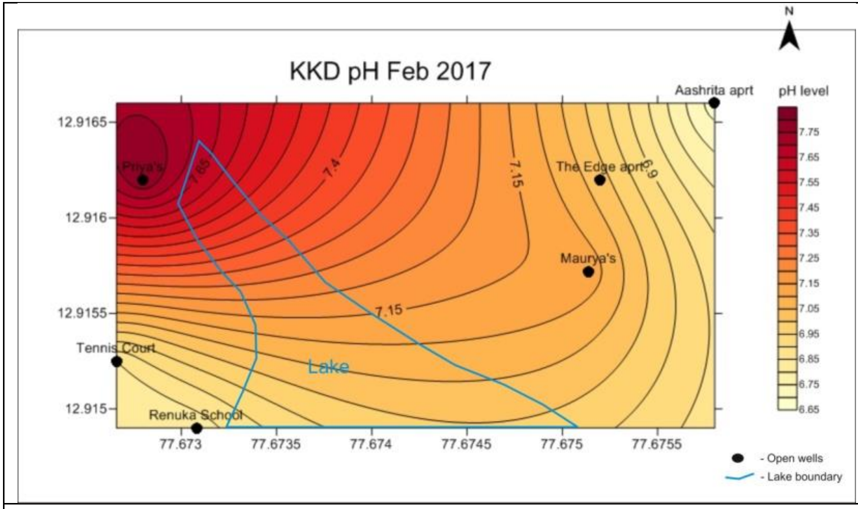
The total concentration of dissolved minerals in water is a general indication of its suitability for any particular use (Driscoll, Fletcher G., 1987). The map below clearly shows TDS levels increasing as one moves from Lake surroundings towards dug well in Renuka school and the center of the lake. A clear indication of settling of various solids in the lake and its immediate vicinity.



TDS map based on Feb 2017 data

pH:

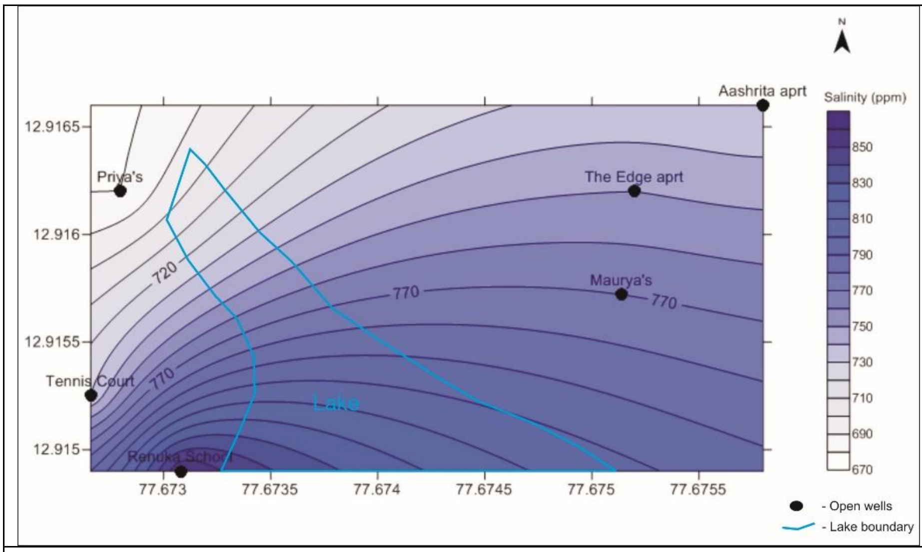
Water is said to be acidic or alkaline (basic) depending on the relative concentration of hydrogen ions. Water with <7 pH is generally acidic and >7 is generally alkaline. pH is highest in Priya's well and decreases from the surrounding toward the center of the lake.



pH map based on Feb 2017 data

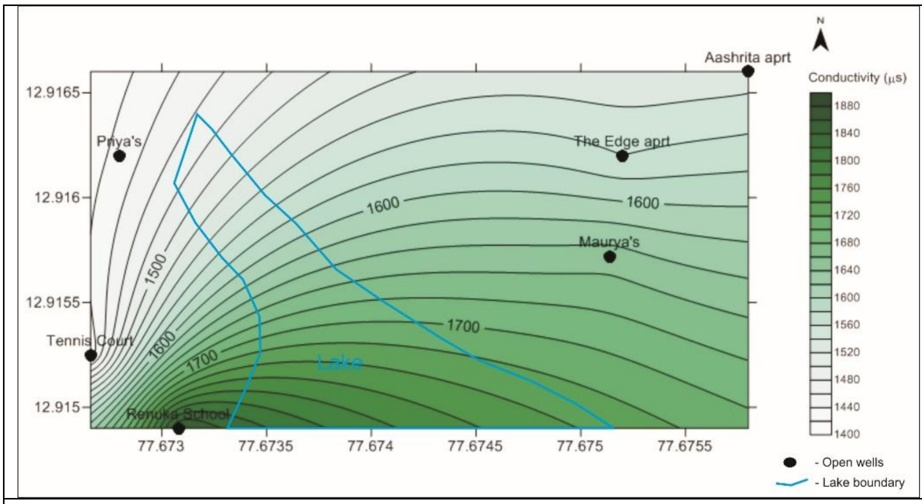
Salinity (ppm)*:*

Salinity is the measure of all the salts dissolved in water. It is relatively higher in Renuka school dug well and immediate vicinity of the lake as compared to observations points away from the lake.



Salinity map based on Feb 2017 data

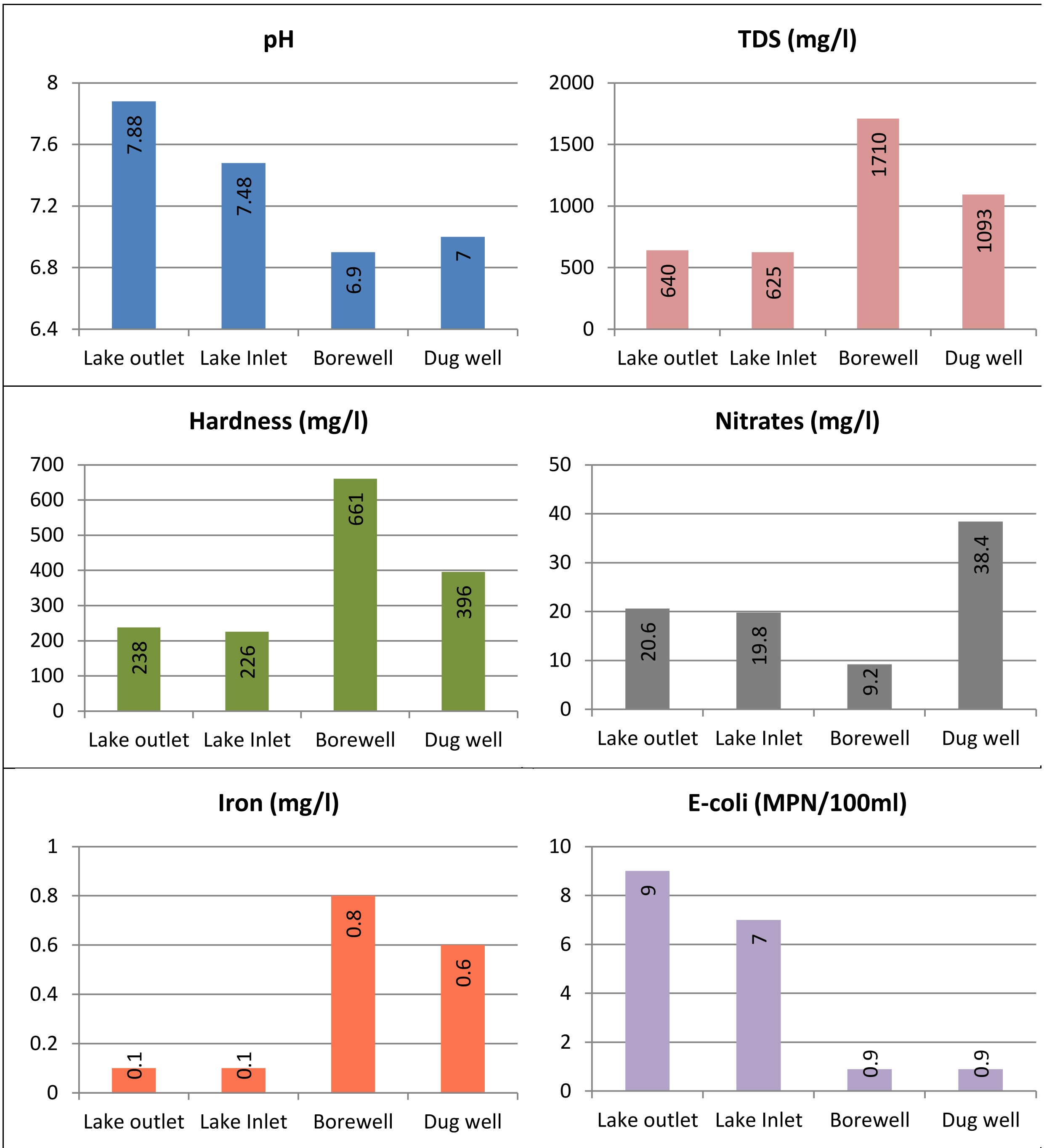
Conductivity (µs):
It is the ability of the water to conduct an electrical current and is a direct function of Salinity. It is relatively higher in Renuka school dug well and immediate vicinity of the lake as compared to observations points away from the lake.



Conductivity map based on Feb 2017 data

Water quality indicative comparison

Laboratory analysis was done on water samples collected in Sept 2016 from Lake outlet, inlet, a nearby Borewell and a dug well in Renuka school. The test parameters from lab results have been plotted individually in fig for different samples. The plot gives simple indicative comparison due to only 1 time data.



Indicative comparison of pH, TDS, Hardness, Nitrates, Iron and E-coli from lab test results of water samples in Sept 2016 from KKD Lake outlet & inlet, Borewell and Dugwell near KKD lake

Way forward

- For a more comprehensive understanding of the inter-relationship between shallow aquifer and the lake, more observation points need to be included.
- Periodic recording & study of water quality parameters need to be undertaken to see the movement & deposition of water constituents between shallow aquifer and lake. A better picture of the various parameters distribution can be obtained by getting measurements every quarter for entire year and more particularly pre & post-monsoon of all the wells and the lake.

Messages

- Based on the study of limited observation points in the northern vicinity of the lake, it is clear that most probably there is a mutual relationship between KKD Lake and the Shallow aquifer in its vicinity where both the entities are inter-dependent.
- Sustainable utilization of water from Shallow aquifer in tandem with wholesome conservation of the lake complimented with efficient Rainwater harvesting in the vicinity of the lake will ensure this mutual relationship persists for long time.