Final Report

AGRAR
Augmenting Groundwater Resources by Artificial Recharge

AGRAR Case Study
Kolwan valley site, Pune district, Maharashtra, India

Prepared by

Advanced Center for Water Resources Development and Management

ACWADAM

Funded by

DFID Department for International Development

Co-ordinated by

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

July 2005

AGRAR Project
Case Study Research Report

AUGMENTING GROUNDWATER RESOURCES BY ARTIFICIAL RECHARGE

Detailed case study of Kolwan valley, Mulshi taluka, Pune district, India

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Front Cover: Main monitoring site in Kolwan valley (check dam CD3) with a part of the stilling well and an observation borehole.

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The Kolwan case study site provided many challenges, right from the inception stage of the project. The authors were able to meet these challenges head-on only through a co-ordinated effort involving colleagues from ACWADAM and GOMUKH. We would particularly like to thank the trustees of ACWADAM, Prof. Deolankar (who is currently a senior professor at the University of Pune carefully reviewed this report and made useful suggestions towards its improvement), Dr. Anil Lalwani, Dr. V. V. Peshwa, Dr. V. G. Phansalkar, Dr. Vivek Kale, Mr. Suhas Joshee and Dr. (Mrs.) S. K. Joshi, all of whom took active interest in the project and provided helpful suggestions from time to time. Dr. Peshwa and Dr. Phansalkar also gave useful inputs during fieldwork, for which we specially thank them. We also acknowledge the inputs rendered by Ms. Sangeeta Bhuia *nee* Sharma during the initial phases of this project, especially during the inception phase fieldwork and during the geophysical surveys leading to the drilling of observation boreholes. Mr. Suhas Jamkhandi has single-handedly managed our accounts and also provided enormous support in the day-to-day administration. We thank him for his patience and support at all stages of the AGRAR project.

GOMUKH was an active partner on this project. GOMUKH made important contribution to this study and their staff from Pune and Chale helped immensely in the project study. We would particularly like to thank Mr. Suneel Waman, Mr. Raosaheb Badhe (who subsequently left GOMUKH), Mr. Datta Shelke, Mr. Balasaheb Jaigude, Mr. Jalinder Dhamale, Mr. Aalam Tamboli and Ms. Chikoo ….for their immense contributions to activities on this project. We would also like to thank Mr. Pramod Sadolikar (consultant to GOMUKH) for his analytical inputs to the socio-economic survey. Mr. Vijay Paranjape, GOMUKH's principal trustee, also facilitated some of the discussions between ACWADAM and GOMUKH, that went a long way in improving the whole effort. We sincerely acknowledge GOMUKH's inputs to this project.

Many government departments provided us secondary data. These include rainfall data for Hadashi and Walen Minor Irrigation Tanks and weather station data from Karmoli. These recording stations are operated by the Irrigation Deparment and Water Resources Division respectively, both under the aegis of Government of Maharashtra. We are also grateful to the Central Ground Water Board (CGWB) regional office in Pune for sharing their observation well data for the dug well in Kolwan. It would have been difficult to access the latest census data without the help of the Statistics Division, Department of Economics and Statistics, Government of Maharashtra.

Mr. Harshavardhan Dhawan effectively integrated his environmental sciences project work (a summary of which is presented in the report) with the AGRAR study. We thank him, not only for his exhaustive work on irrigated agriculture in Chikhalgaon but his continued support during all other monitoring activities, especially during the period when pumping tests were conducted on the observation bore holes in Chikhalgaon. We would also like to thank Mr. Manoj Gholap and Mr. Dnyaneshwar Borge, who not only drove us to the field for every field visit (sometimes in very adverse conditions and through difficult terrain) but provided helping hands during the monitoring of bore holes, pumping tests and collection of samples for analyzing water quality.

A two-day seminar in October 2004 (Artificial Recharge of Groundwater), in Pune, helped us not only in sharing AGRAR experiences from the three main case study sites, but also in listening to various perspectives on artificial recharge, which in turn, directly or indirectly helped broaden our understanding on the subject. Representatives from Government organizations, NGOs and some private consultants actively participated in the seminar through presentations and discussions. We are highly indebted to them for providing new insights on artificial recharge, especially in India.

A special mention needs to be made about Late Mr. Rakshe of Dynalabs, who not only helped install the weather station network but also made useful inputs to other partners during the workshop held in Pune in March 2004.

And finally, it would have been impossible to conduct the research project without the support and help of communities from the Kolwan valley. We would specially like to single out the temperamental *Phale guruji* (teacher) of Chikhalgaon whose constant encouragement and proactive critique helped improve our interface with the villagers of Chikhalgaon. The deputy sarpanch of Chikhalgaon, Mr. Lahu Phale and his family needs a special mention for his zeal and enthusiastic support during fieldwork. There were common people from villages in Kolwan valley, who helped us in so many ways, often interrupting their daily chores to lend a helping hand to our tasks. We express our sincere gratitude to them.

It is quite likely that in a project like this, some names tend to be inadvertently left out. If at all this has happened, we sincerely apologise for the lapse and express our thanks to these individuals or organsations here.

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Summary

This report is the final output describing results of the research conducted under the DFID funded AGRAR project in one of the three detailed case study sites, i.e. at the Kolwan valley site in Pune district of Maharashtra state in India. Research activities at the site began in mid-2003, although work, in the form of collecting background information, selecting areas for detailed surveys and setting up some of the research activities actually began in late 2002. The detailed background to the project was provided in the form of an 'inception report' (Kulkarni et al, 2003).

The AGRAR research in Kolwan valley was undertaken by Advanced Center for Water Resources Development and Management (ACWADAM), a Pune based research NGO, in collaboration with GOMUKH, again based in Pune but *implementing* watershed development projects in and around Pune. The research essentially focused on studying artificial recharge to augment the groundwater resources through watershed development. It included the study of small check dams constructed across streams to create water impoundments, from which infiltration occurs over a period of time and which, in turn, is supposed to result in recharge to underlying aquifers. The study, therefore, involved meteorology, hydrology, hydrogeology, social and economic aspects of groundwater resources in Kolwan valley. An important criterion of the study was to understand if and how artificial recharge impacts on already changing livelihoods in such areas, where watershed development is being conducted progressively on a large scale, encompassing villages within a small river basin, called the Walki river basin (popularly known as the Kolwan valley).

The AGRAR study focused on two basic aspects:

1. The physical dynamics of how recharge occurs.
2. The effects (if any) of artificial recharge on the livelihoods of communities living in the valley.

The physical aspects of artificial recharge were studied using a comprehensive methodology that involved detailed monitoring of various aspects like rainfall, evaporation, stream flows, water levels in wells and observation boreholes around the main structures (check dams), aquifer properties (through pumping tests) etc. The socio-economic and livelihoods angle was studied using a combination of formal household surveys as well as informal discussions with various stakeholders. The methodology of monitoring was based on a standard process presented in detail as a set of guidelines for the project (Gale et al, 2003).

Kolwan valley is located in Mulshi taluka (tehsil) of Pune district in Maharashtra and forms a part of the Deccan Volcanic Province of central-west India. Rugged, undulating landscape, with a variable soil cover and a high but variable rainfall characterise the area on the scale of the river basin. Constituted of different sub-horizontal basalt units that make up 8 lava flows, the Kolwan valley is dominantly

constituted of ‘compound’ type of basalt units alternating with ‘compact’ basalt units. The degree of weathering and the nature and intensity of fracturing in these two units largely control groundwater resources within this area, with the compound basalt units showing sheet joints the density and frequency of which changes from place to place. The compact basalts, on the other hand are more sub-vertically jointed. A compound basalt unit and the underlying compact basalt unit are often in hydraulic continuity with each other, forming a well bounded shallow, unconfined aquifer over which check dams for facilitating artificial recharge are constructed.

GOMUKH undertook watershed development in Chikhalgaon watershed in 1997-98; this watershed formed the major focus of the AGRAR study. Amongst a variety of watershed development measures, three check dams were constructed in a sequence to impound runoff through the mainstream and recharge groundwater in this watershed. The AGRAR study revealed that rainfall, runoff and recharge events around check dams are complexly interlinked, in an area where groundwater abstraction is limited. Natural recharge often masks effects of artificial recharge from such small structures, which occurs as a sequence of events from an individual structure.

The quantity of recharged water (both natural and artificial recharge) is quite small in proportion to rainfall and surface runoff. Natural infiltration is to the extent of 100 mm, whereas infiltration from the artificial recharge structure is 33 mm. However, only some 12 mm of water is actually recharged to the underlying aquifer. As compared to this value, runoff estimates in watersheds from the Kolwan valley are in the range of 800 to 900 mm. Moreover, artificial recharge is more likely to occur through structures that are located on or within natural recharge areas (like the check dam CD3 in Chikhalgaon). Structures like CD1 and CD2 in Chikhalgaon actually gain water from groundwater discharges and have little to do with addition of water to the underlying aquifer(s). Nevertheless, the small quantities of water added to the aquifer as artificial recharge are large enough, when compared with the drinking water demand of different villages in the valley. On slightly larger scales, at the watershed or river basin levels, check dams have induced infiltration in such a way that baseflows to streams and river lag more than before, creating a positive impact on ‘environmental’ flows. At the same time, it is difficult to separate baseflow from the water releases from surface water tanks, especially in upstream areas of the main Walki river channel.

Most villages in the Kolwan valley depend on surface water from the Walki River and some irrigation reservoirs as source of irrigation. Agriculture is still the major occupation of most of the people. Even though the river basin receives a high amount of rainfall, the region used to face severe scarcity of water during summers. However, with interventions like village drinking water supply schemes and watershed development activities under various Government and NGO programmes, water scarcity has reduced considerably. However, the impacts of such activities in different villages are quite variable because of natural and socio-economic conditions. Irrigation is growing, and although it still is surface water dominated, groundwater irrigation is also growing slowly in different villages. This trend is felt more strongly in ‘project’ villages where artificial recharge measures were implemented.

Irrigated cropping has changed considerably from the time before implementation of watershed development projects of which artificial recharge is an important component. Even though paddy is still the dominant kharif (rainfed) crop, wheat and vegetables are now grown as regular irrigated, rabi season crops. Significantly, sugarcane is also grown as an annual crop, mainly on river water. Domestic needs including drinking water are met entirely from groundwater, usually tapped through dug wells in the shallow unconfined aquifers. Artificial recharge, as mentioned earlier, forms a significant component when compared to this demand.

The actual impact of the check dam on the livelihoods of the people may be quite small as compared to other 'push and pull' factors, but it is something that cannot be neglected, at least not on the scale of four or five watersheds from where GOMUKH is scaling up this activity to the river basin level. Groundwater abstraction for irrigation is still quite limited but there are signs of increasing abstraction, after the watershed development projects were implemented. This increase can be attributed to a perceivable improvement in groundwater conditions, artificial recharge being one of the drivers to this effect. People report an increase in baseflows as well as rise in the water levels. Most of the wells in the five villages have water throughout the year, but this may also be due to the fact that partially penetrating wells have been deepened now.

After the intervention of GOMUKH in the valley i.e. after 1996, there is a clear-cut increase in vegetation cover, mostly benefiting livestock. This increase can be attributed to the various watershed development activities undertaken by GOMUKH, artificial recharge being one of them. Moreover, there is an improvement in the overall standard of living, drinking water supply, ownership of assets and most significantly in the economic condition of households in project as well as non-project villages. The improvement in annual income of many households can be attributed to the introduction of multiple cropping in the valley, although other factors have also played an important role in this improvement.

Finally, it is quite clear that groundwater use in the Kolwan valley is bound to increase, if current trends are to be followed. Groundwater use is certainly bound to increase in areas of watershed development where lands are away from rivers and farmers look to local sources of irrigating such lands. It is envisaged that increased groundwater abstraction, especially from the shallow aquifers in the Kolwan valley will induce a larger magnitude of water level fluctuation, creating more space in the aquifer for recharge. Both natural and artificial recharge will increase in response to increased abstraction. Having said that, it also indicates the dangers of groundwater abstraction developing into problems of groundwater resources overexploitation. Therefore, under these project scenarios, artificial recharge ought to be placed in context to a more specific groundwater management strategy that considers both the supply and demand sides of groundwater resources so as to maintain a 'sustainable' balance between recharge and discharge of groundwater from the aquifers in Kolwan valley. ACWADAM is hoping to continue research even after the formal completion of the AGRAR case study and thereby advising organisations like GOMUKH in developing strategies for systematic, community-based groundwater management.

Notwithstanding any of the two scenarios above, the sustainability of groundwater resources in the area will depend upon the magnitude of groundwater abstraction because the groundwater storage in basalt aquifers in the Kolwan valley is quite limited and will not exceed more than 100 mm of equivalent rainfall. It is during the period of increased groundwater utilisation, that the issue of sustainability will need to be considered while managing water resources in Kolwan valley. During such foreseen periods one clearly sees the importance of not only managing the supply side of the water management using AR, also a felt need to manage demand for limited groundwater supplies. Striking a balance between the supply and demand sides, based on continued monitoring and improved knowledge will hold the key to sustainability of the groundwater resources in Kolwan valley.

1 Purpose

The purpose of this study was to investigate the effectiveness of artificial recharge structures at three different locations in India. These three locations not only represent diverse physical regimes but also form different cultural and socio-economic settings. This report covers findings at the Kolwan valley site in Maharashtra, investigated for the effectiveness of artificial recharge structures in the Deccan basalt setting. The effectiveness of artificial recharge was investigated with respect to impacts on water resources, including groundwater but also highlighted the complexity of the relationship between artificial recharge and changing livelihoods of rural communities in the region.

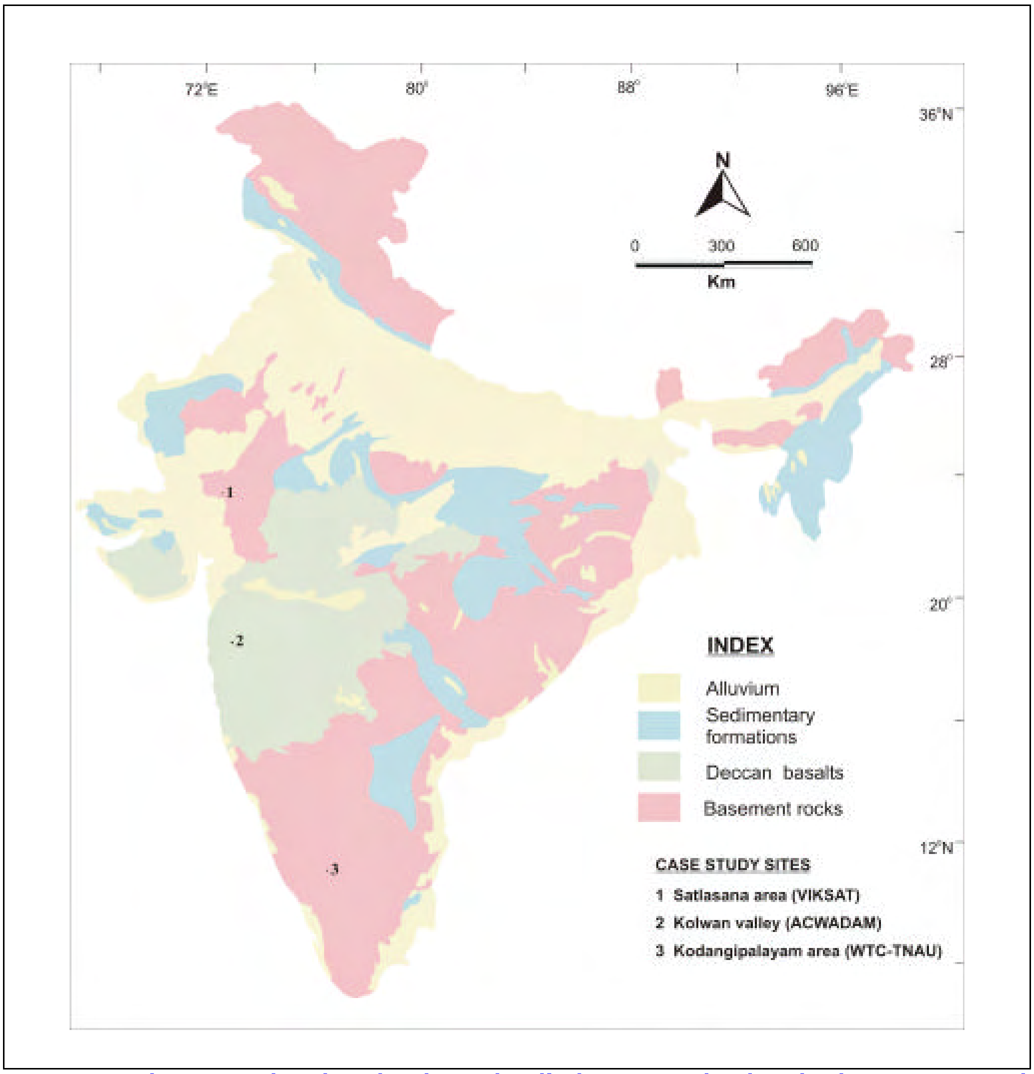


Figure 1: Location map showing the three detailed case study sites in the AGRAR project.
Location 2 is the Kolwan valley site, located on Deccan basaltic rocks.

1.1 ORGANISATIONS AND STAFF

Advanced Center for Water Resources Development and Management (ACWADAM) is a non-profit organization working in earth sciences applications, particularly in groundwater resources management. Consisting of a team of geologists with diverse backgrounds in earth science applications and established in 1998, ACWADAM was started by a group of University of Pune researchers with an experience of more than 25 years in geological sciences research and education. ACWADAM works in the areas of training and applied research, with one of its focus areas being groundwater management. ACWADAM's website www.acwadam.org provides detailed information on its activities and completed projects.

Heading the AGRAR site investigations on the ACWADAM team, was Dr. Himanshu Kulkarni, Founder Secretary and Executive Director of ACWADAM. He holds a doctorate in Hydrogeology from the University of Pune and also supervises Ph.D research in groundwater at the same University. He was instrumental in establishing ACWADAM, having served as a CSIR Research Scientist at University of Pune for over ten years. Dr. Kulkarni has experience in a wide range of hydrogeological applications with his principal area of expertise being groundwater systems from various geological settings, including hard-rock areas of west-central India, with most of his publications being related to the hydrogeology of Deccan basalts. During the last six years, Dr. Kulkarni has been co-ordinating ACWADAM's extensive hydrogeological work in a various regions of India. This work essentially deals with research aimed at developing community based groundwater management systems and systematic planning of groundwater recharge through watershed development programmes. Dr. Kulkarni has also been co-ordinating ACWADAM's inputs on the other DFID (UK) project called Community Management of Groundwater Resources in Rural India (ComMan).

ACWADAM's AGRAR research team consisted of Ms. Uma Badarayani, Mr. Vinit Phadnis and Ms. Sangeeta Sharma, the latter leaving in early 2004, making way for Mr. Phadnis. Ms. Badarayani is a geographer with a post-graduate degree in geography from University of Pune. She has a research background, having completed her post-graduate dissertation on the hydraulic geometry of Koyna river basin, an important area in western Maharashtra. She was specially recruited for the AGRAR project, after she completed an assignment with the National Commission for scheduled castes and scheduled tribes, Government of India. Her experience there helped in the livelihoods study on the AGRAR project. Ms. Sharma is a post-graduate in applied geology from Dibrugarh University in Assam. Having studied subjects like Hydrogeology, Geophysics, Petroleum geology and Mining, she completed her studies with a dissertation in Geomorphology of a river basin in Assam that also included a short study on soils. Ms. Sharma also worked as a researcher on the DFID-ComMan project. Both, Ms. Sharma and Ms. Badarayani are formally trained in GIS and are conversant with GIS tools and applications in the field of hydrology and hydrogeology. Mr. Vinit Phadnis worked with ACWADAM before he embarked to Germany to pursue a post-graduation in Tropical Hydrogeology. Mr. Phadnis is a geologist by qualification and has worked in the field of Deccan basalt geology, remote sensing and GIS applications and groundwater management, the last through ACWADAM projects. He is also pursuing his Ph.D. in hydrogeology at the University of Pune.

GOMUKH Trust (connoting the origin of the river Ganga, and referred to henceforth in this report as GOMUKH) is an established NGO working on government-funded watershed rehabilitation projects in Maharashtra, in addition to diversification into activities like urban environmental sciences and rooftop rainwater harvesting. GOMUKH is an interdisciplinary organisation, employing economists, social development specialists and engineers to design and implement watershed development activities. These include the building of check dams and field bunds, spring protection, support for organic farming and marketing, and support for various non-farm activities. GOMUKH has been working in the AGRAR research study for nearly ten years now and have been interested in understanding groundwater resources better, especially from the angle of artificial recharge.

The GOMUKH team consisted of Mr. Suneel Waman, Executive Director, Mr. Raosaheb Badhe, Project co-ordinator, who has since left, and field assistants, Mr. Balasaheb Jaigude, Mr. Datta Shelke and Mr. Jalinder Dhamale. Mr. Waman is an M.Tech. in water resources from IIT with a graduation in civil engineering from University of Pune. He has been working in the water resources sector for over ten years now. His experience is mainly in the field of rural water resources engineering including co-ordinating and implementing various watershed development schemes for GOMUKH as well as for other associate NGOs. He is actively involved in training programmes that include capacity building of NGO leaders, staff and farmers. Mr. Raosaheb Badhe co-ordinated the social sciences work for GOMUKH in addition to shouldering the responsibility of project co-ordination in Kolwan valley.

Mr. Jaigude, Mr. Shelke and Mr. Dhamale are residents of Kolwan valley. They have been working with GOMUKH for the last 6-7 years. They form an effective link between the institution and the community, catalysing the smooth execution of GOMUKH’s participatory programmes in Kolwan valley, including work on the AGRAR project. Mr. Shelke is studying for his graduation in commerce while Mr. Jaigude has completed his tenth grade (secondary school). Both of them have obtained a diploma in watershed development. In addition to organising village meetings (*gram sabhas*) and conducting participatory rural appraisals (PRAs) for various projects, these two village youth have some experience in measuring water levels, collecting rainfall data from established stations in the region and also gathering related agricultural, social and economic information.

1.2 ROLE PLAYED BY LOCAL COMMUNITIES

The entire community from Kolwan valley played a significant role in the AGRAR project. Even though project activities were restricted to 5 villages (5 watersheds), people from the remaining villages also attended a couple of *Pani Parishads* (Water Conferences), organised by GOMUKH, where preliminary AGRAR findings were presented. More specifically, the communities of Chikhalgaon, Nandgaon, Bhalgudi, Hadashi and Nanegaon were involved in the monitoring process. Rain gauges in Kashig, Kolwan and Nanegaon were maintained and monitored by the local youth, mostly by high school students from these villages. These will continue to be maintained and monitored even after the project is formally completed.

Chikhalgaon village, where the Automatic Weather Station is installed, continues to play a very active role in the monitoring process. From donating community land for setting up the weather station and helping install, maintain and monitor equipment, the people of Chikhalgaon played a major role in the smooth functioning of the project. None of the boreholes drilled in the open fields around the check dam CD3, have locks on them. What better testimony to the awareness created in the area by the people of Chikhalgaon!

Building community rapport through informal meetings with people. The people in Chikhalgaon actively participated in the project during all stages including during the laying down of the foundation for the automatic weather station.

1.3 STRUCTURE OF THE REPORT

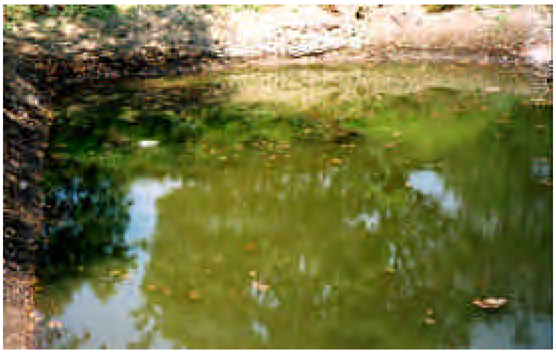
The report has seven chapters, including this one. Chapters 2 and 3 describe the setting of the case study area and explain the methodology of the study respectively. Chapters 4 and 5 present case study results, separating them into physical and socio-economic aspects respectively. Chapter 6 discusses the significance of the results and attempts to synthesize results from chapters 4 and 5 in order to explain the effectiveness of artificial recharge interventions on groundwater resources and the livelihoods of the village communities. The final chapter lists out the conclusions and recommendations.

2 Case Study Setting

2.1 INTRODUCTION

Artificial recharge refers to the augmentation of groundwater resources usually involving transfer of surface water to aquifers through human intervention (Gale et al, 2002; Athavale, 2003). Artificial recharge in rural India has primarily piggybacked on watershed development projects. Generally, watershed development projects include the component of recharging underlying aquifers mainly through spreading methods, considered 'traditional' as far as the history of water conservation and watershed development in India is concerned. However, more specific methods like direct recharge through farm-ponds, open wells, boreholes as well as roof-top rainwater harvesting are gaining in popularity as an integral component of watershed development as well as separate, specific, 'groundwater recharging' initiatives. A comprehensive review of artificial recharge methodologies, including the ones mentioned above, can be found in Gale et al (2002).

K.T. Weir



Farm pond

Spring tank

Check dam

Common water conservation measures practiced in India. Farm ponds and check dams are commonly used as artificial recharge structures.

Watershed development projects are still quite broad-based, limiting the extent of the understanding of natural and artificial recharge processes occurring in different areas. The hydrogeological nuances resulting from highly variable rainfall and geological factors are seldom considered while assessing recharge to groundwater, especially in areas of watershed development. The hydrogeology of hard-rock regimes poses enough complexities to fully understand recharge processes under current investigative approaches. The impact of artificial recharge on such regimes is therefore still a grey area, both in terms of hydrogeological perspectives as well as in context to larger impacts that include livelihood changes that occur as a consequence of watershed projects, and therefore, as a consequence of artificial recharge.

The Deccan Volcanic Province in central-west India offers a unique hydrogeological setting for the study of artificial recharge. The type of basalt, its degree of weathering, and the nature and intensity of fracturing control the occurrence and movement of groundwater resources in the Deccan basalt (Adyalkar and Mani, 1971; Deolankar, 1980; Kulkarni et al, 2000). Hydrogeologically, the Deccan basalts are quite inhomogeneous in nature with highly variable conditions controlling groundwater occurrence and movement. The Deccan basalts cover a vast expanse of central-west India. A large portion of the basalt outcrops in the state of Maharashtra, although it also extends into the adjoining states of Gujarat, Madhya Pradesh, Karnataka and Andhra Pradesh (Figure 2). Thus, a systematic study of artificial recharge gains great importance in the Deccan basalt region.

The Kolwan valley in Pune district of Maharashtra state is a typical river basin located in the Deccan basalt setting and offers a unique opportunity to study groundwater in its various dynamics: physical, social, institutional and economic. Understanding these dynamics is the key to describing how the livelihood aspects in typical Deccan basalt settings are linked to groundwater resources, and consequently to recharge, both natural and artificial. Understanding the heterogeneity of Deccan basalts is important in hydrogeological investigation of basalt aquifers (Kulkarni, 1993).

The Kolwan valley case study is set on three different scales, namely, the river basin scale, the watershed scale and the recharge structure scale. The purpose of this chapter, therefore, is to provide a logical introduction to the case study, explaining the geographical, geological and hydrological location of the study area, at the same time attempting to explain the background information on various scales. In order to present the information in a simple format, this chapter is divided into three main parts:

1. *the regional setting, wherein the location of the case study area within the district is explained;*
2. *river basin and watershed scale setting of the study area are explained;*
3. *location and description of a single recharge structure, which formed the focus of the research in Kolwan valley, are explained.*

The Kolwan valley site in Mulshi taluka was selected primarily as it is largely representative of hydrogeological conditions within the Deccan basalt as well as because it represents various other typical dimensions common to many other regional as well as local settings such as recharge initiatives, dominantly through watershed based interventions at the scale of a village. In order to maximize the output from a study that attempts to understand the 'microwatershed development model' as a common mechanism for implementing 'artificial recharge' to groundwater resources, the research methodology included studies on various scales, described in detail later in the report.

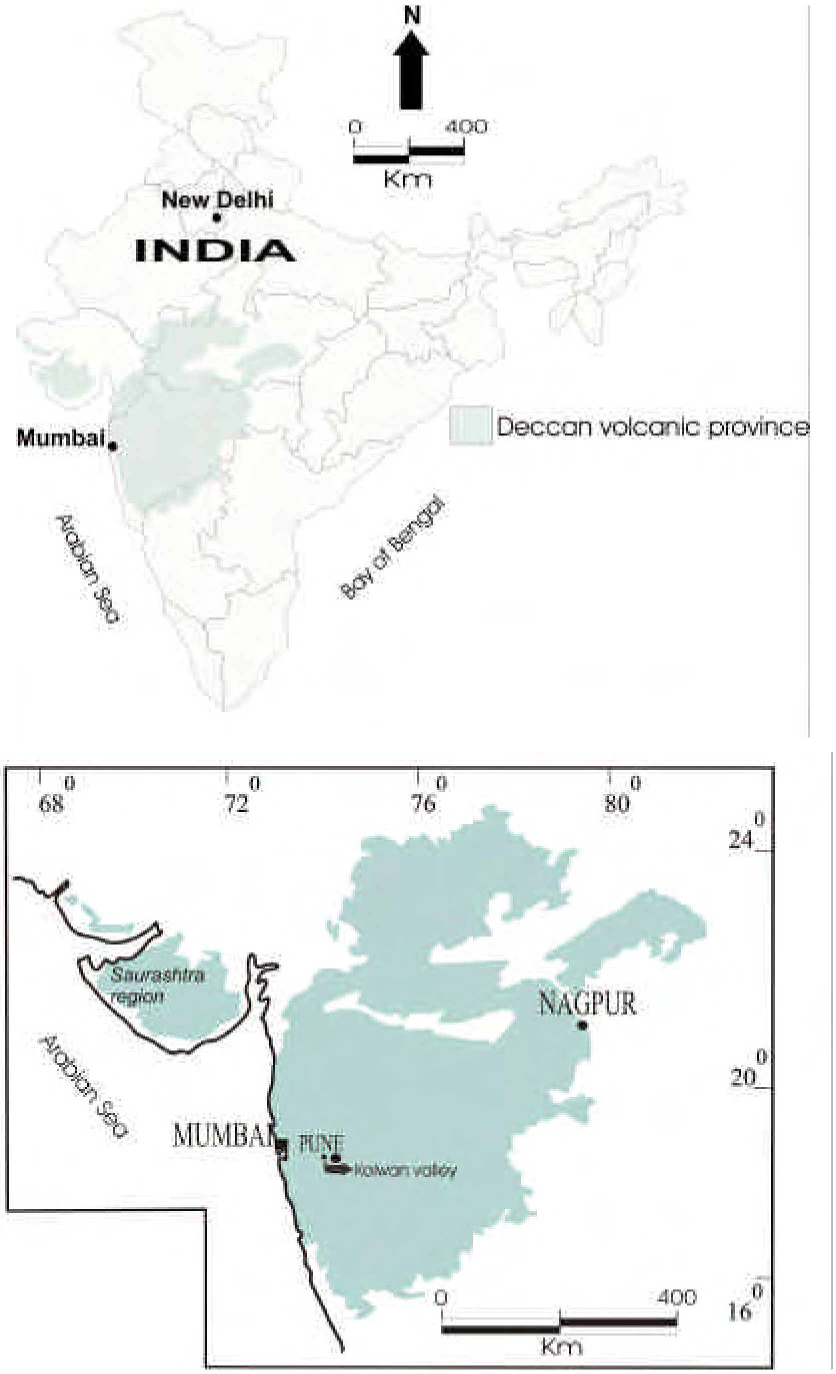


Figure 2: Deccan volcanic Province in India

(State outlines indicated in the map of India)

Before attempting to investigate the scientific and socio-economic aspects of artificial recharge to groundwater, it was thought necessary to understand the physical and contextual settings in which the study would be undertaken. It was useful to describe the background to the study site with respect to various aspects, both physical and socio-economic. The present chapter describes this background at the three different scales specified above. The district scale setting includes relevant information (mainly using secondary sources of data) of physical and socio-economic type, including some background demographic information for Pune district. The watershed scale information is more specific to the AGRAR project area. It is broadly subdivided into the physical setting, socio-economic setting and the status of watershed development activities in the area.

2.2 DISTRICT-SCALE SETTING

Kolwan valley is located in the Mulshi taluka (tehsil) of Pune district in Maharashtra state (Figure 3). Maharashtra occupies an important place in the country's social, cultural and economic progress. Considered to be one of the more progressive states in the country, it hosts Mumbai as the state capital, also considered to be the financial capital of the country. The *Economic Survey of Maharashtra for 2002*-03 gives some basic statistics for the state. Spread over an area of 308000 km^2, Maharashtra consists of 6 revenue divisions that include 35 districts. The districts are further classified into 353 talukas with 43722 villages. There are 378 towns in the state. Maharashtra has a total population of 9,67,52,000, of which nearly 58% lives in rural areas. The population density in the state has risen from 129 per km^2 to 314 per km^2 over a decade. The state has a literacy of 77.3%. The proportion of gross irrigated land to gross cropped land is only 16.4% despite a large number of large, medium and minor irrigation reservoirs. *Table 1* shows some statistics for the state of Maharashtra, including broad figures for the rural setting in the state. The table also gives some idea regarding the status of public water supply facilities.

The state of Maharashtra is divided into two major physiographic divisions, the upland areas occupied by what is called the plateau region and the western coastal strip, commonly referred to as the Konkan region. The Western Ghats ranges mark this division, dominantly running almost north-south, parallel to the western coast and separating the two regions. This ridge forms an important climatic divide, causing a rain shadow effect on its eastern side from the predominant west to east monsoon winds. The central and eastern parts of the state are undulating or flat plains making up the plateau region, dissected by the two main river valleys, the Godavari and Bhima.

Maharashtra state is considered a semi-arid ecological region. The state has a unimodal monsoon rainfall pattern and about 85% of rainfall is normally received during the period June-September. Average annual rainfall across most of the area, which lies within the rain-shadow of the Western Ghats, is between 500 and 800 mm. However, towards the west, annual rainfall is much greater, and is often as much as 4000 mm. The state is divided into nine rainfall zones, indicating the variability of rainfall across the state (*YASHADA, 2000*). More than 30% of Maharashtra's 34 districts, including Pune district fall within the scarcity zone where the average rainfall is less than 700 mm.

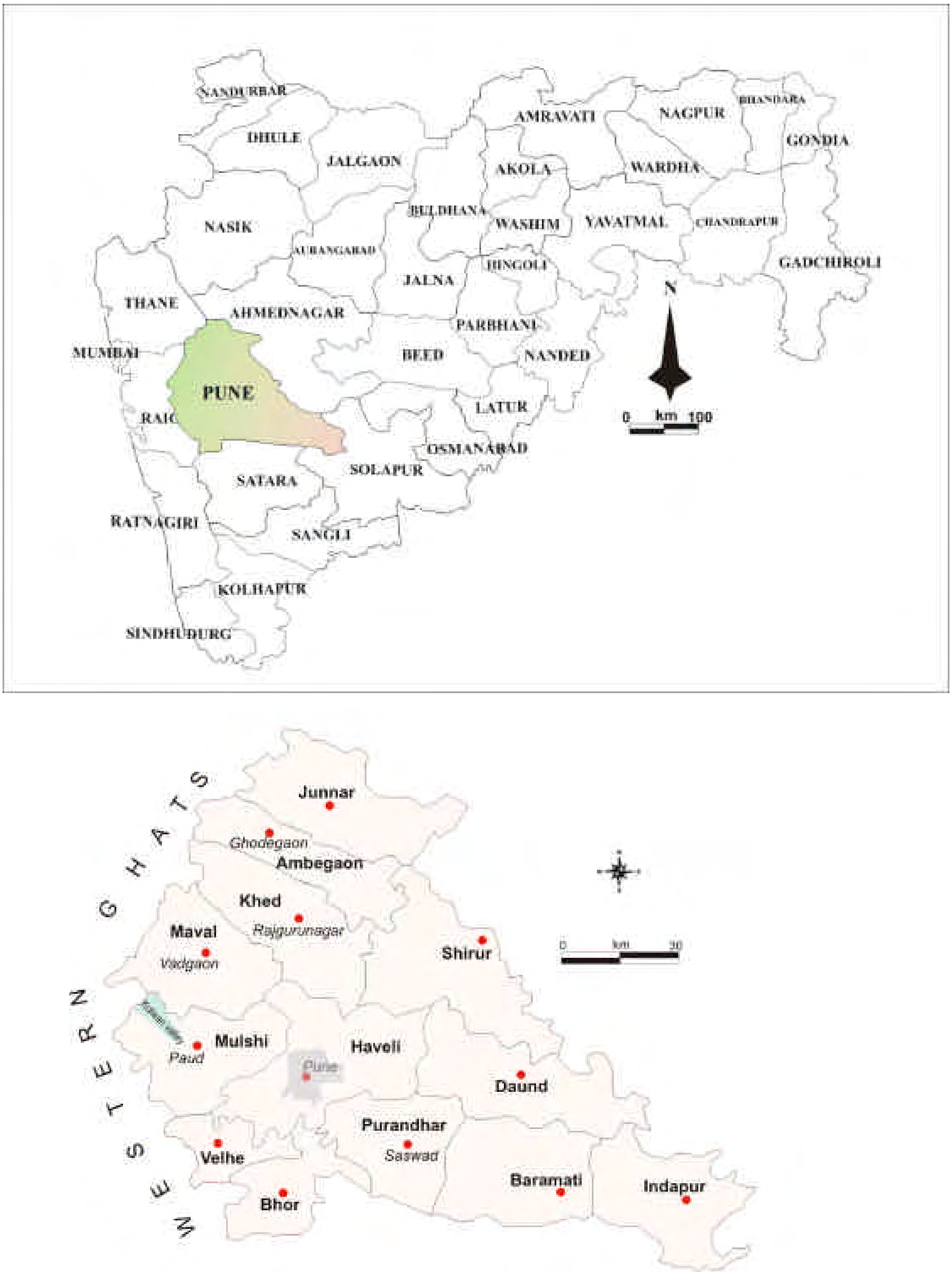


Figure 3: The setting of Kolwan valley within the administrative framework of Pune district of Maharashtra state. ***(Taluka headquarters indicated in italics, where different from taluka names. Shaded gray indicates approximate limits of Pune city.)***

Table 1: Maharashtra State rural statistics *(after Scott Wilson, 2002)*

1	Area	307713 km^2
2	Rural Districts	33
3	Zilla Parishads (District Rural Panchayati Raj Institutions (PRIs))	33
4	Panchayat Samitis (Middle Level Rural PRIs)	321
5	Gram Panchayats (Local Level Rural PRIs)	26600
6	Rural Families	11 million
7	Rural Population	52.5 million
8	Rural habitations to be reached with water supply and sanitation	86681
9	Existing public water supply facilities:	
	(a) Dug Wells	90000
	(b) Boreholes with hand pumps	210000
	(c) Mini piped water supply schemes	14000
	(d) Piped water supply schemes	
	(i) Multi-village	487
	(ii) Single village	9500
10	Average number of tanker fed habitations	5500
11	Habitations receiving less than 40 lpcd	25750
	Schemes are in progress	11375
	Habitations left to be tackled	14375
12	Proportion of water supply schemes depending on ground water	90%

Figure 4 shows the high degree of rainfall variability within a narrow zone encompassing the Konkan coastal plain, the Western Ghats within which the Kolwan valley is located and the flatter central-west plateau region of the state. The Konkan coastal area shows a mean annual rainfall of 2380 mm whereas the upland central-west Maharashtra region receives only about 580 mm as the annual average. Paud, the headquarters of Mulshi taluka, wherein the Kolwan valley is situated, receives an average annual rainfall of 1707 mm. The figure also shows that the western ghats rise to an elevation of about 1200 m above mean sea level (MSL), from the Konkan coastal plains where elevations are barely within 400 m above MSL. The plateau to the east of the Western Ghats levels off to elevations between 400 to 600 m above MSL.

Maharashtra state occupies such a position within the Indian geographical setting that a majority of the state is underlain by hard-rock geology (Figure 5). Hard rocks, including both igneous and metamorphic rocks, cover almost 90% of the state. Deccan basalts occur in all the districts of the State excepting Bhandara and Gadhchiroli, indicating the clear dominance of basaltic geology in the state. The other geological formations, older and younger than Deccan basalt, occur to a lesser extent in the districts of Bhandara, Wardha, Chandrapur, Gadhchiroli, Nagpur, Yavatmal, Buldhana, Akola, Amravati, Dhule, Jalgaon, Nanded, Kolhapur, Sindhudurg and Ratnagiri. In the remaining 14 districts, Deccan basalt is the only geological formation. The Deccan basalts are occasionally capped by laterites mostly in the coastal districts but also at some locations in a few of the inland districts. Figure 5 indicates that Pune district is entirely constituted of Deccan basalts.

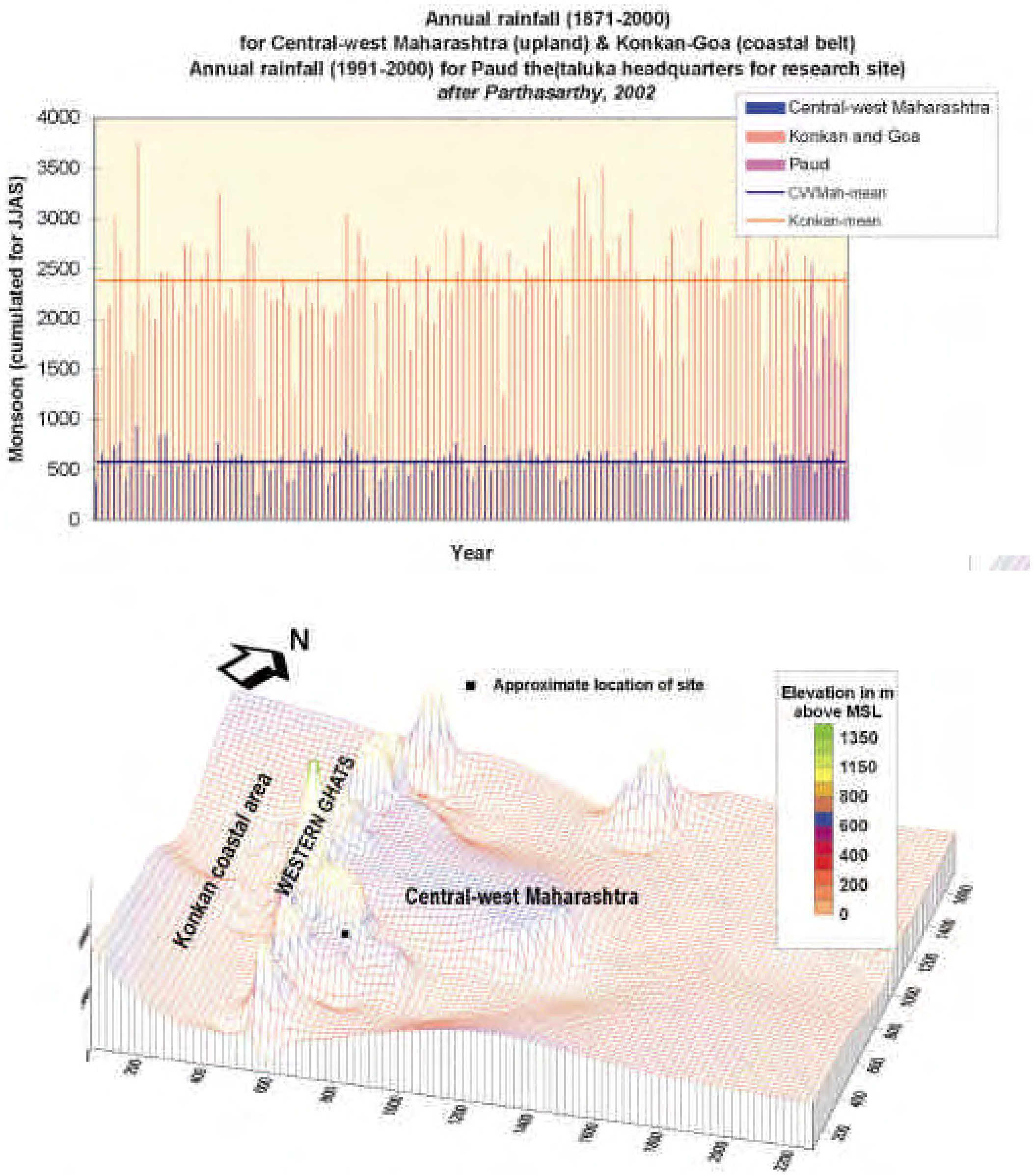


Figure 4: Rainfall and physiographic variability in western Maharashtra

Nearly 65% of the state's area is under cultivation, of which only 23% is irrigated and more than 50% of the irrigated area can safely be considered to be reliant exclusively on groundwater (Phatak et al, 1999). Considering the importance of groundwater, especially in the rural sector, artificial recharge is quite popular in the state, watershed programmes providing the major avenue for implementing artificial recharge measures.

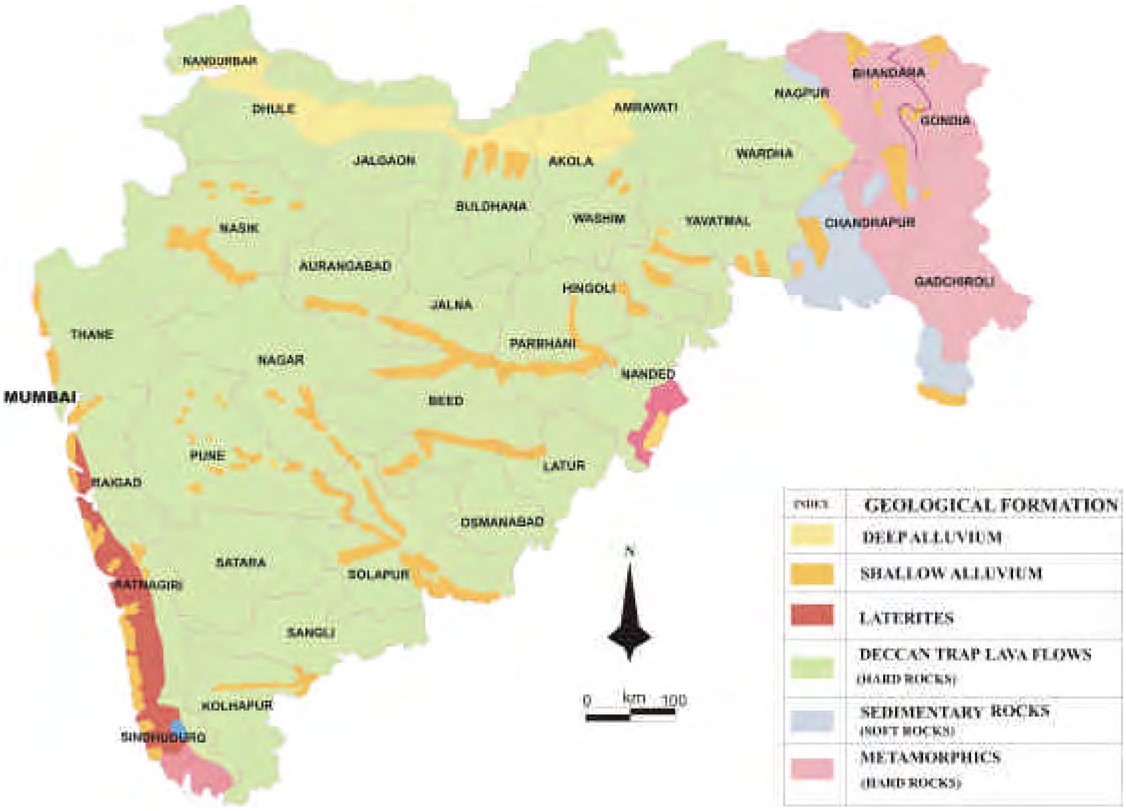


Figure 5: Geological map of Maharashtra ***(after Geological Survey of India, 1997)***

2.2.1 Pune district

Pune district occupies a strategic position within western Maharashtra. The district headquarters is Pune city, which along with its twin city of Pimpri-Chinchwad, forms the largest urban agglomeration in the district, and arguably is the largest city in Maharashtra, apart from Mumbai. Pune city is located on the main arterial road and rail lines that connect northern and peninsular regions of India. Its proximity to Mumbai is also critical in terms of trade commerce, social and economic status. In fact, with excellent road and rail network connections, it is increasingly becoming a sister city to Mumbai. Moreover, Pune has been a historically significant place right from the reign of Shivaji, through the period of the Peshwas, and later on, under the British rule. Social service institutions and educational institutions have flourished in Pune over the last one and a half century. The presence of old educational institutions as well as research institutes providing value education in various fields, have contributed to the development of the city's rich social, cultural and economic ethos. At the same time, these very factors have 'pulled' hordes of students, professionals and labourers to the city, not only from rural areas in Maharashtra and India, but also from other cities in India.

The strategic location of Pune district, in general and Pune city in particular has contributed to the development of the region through time. Pune district almost entirely falls within the Bhima river basin, a sub-basin of the larger Krishna river, which is one of the main rivers in peninsular India. Pune district occupies a large portion of what is know as the 'Upper Bhima Basin'.

Pune district is constituted of 13 talukas (Figure 3). The Bhima basin in Pune district includes sub-basins of the Nira, Indrayani, Mula, Mutha, Vel, Ghod, Meena, Pushpavati and Pavna rivers, all of which originate in the western Ghats and traverse the western talukas of Pune district (Figure 6). Several large and small dams have been constructed on these rivers, catering to various needs including water supply for urban and rural needs (domestic water and irrigation and industry) and hydro-electricity. The major water projects include Varasgaon, Panshet, Khadakvasla, Mulshi, Veer, Ghod, Kukadi and Bhima, to name a few. The western portion of the basin falls within Pune district.

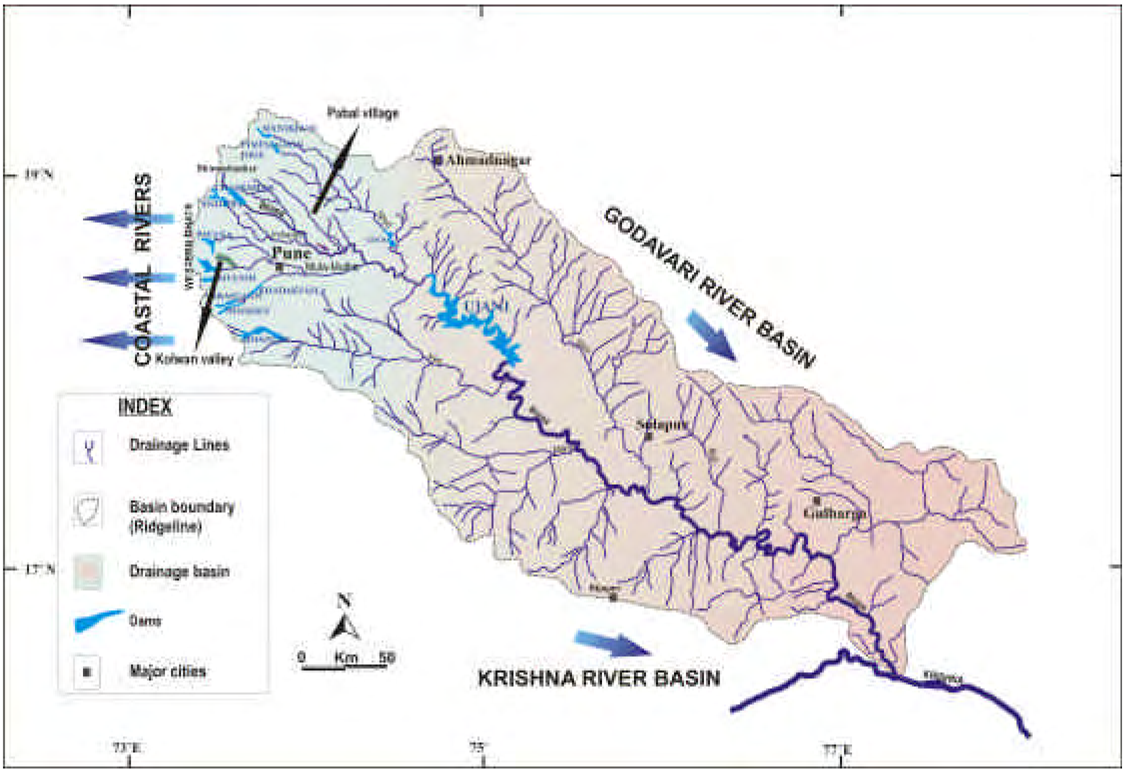


Figure 6: The hydrological setting of Kolwan valley, as a sub-basin of Bhima river basin (*after Global Water Partnership, 2002*)

The western ghats traverse the western talukas of Pune district, especially Maval, Mulshi and Velhe talukas (Figure 3) and hence rainfall in the western portions of these three districts is quite high, exceeding 2000 mm. Rainfall progressively declines to the east with the eastern talukas, like Purandar, Daund, Indapur and Shirur typically falling within a 'rain-shadow' zone with an annual mean rainfall below 500 mm. However, high rainfall talukas are characterised by hilly terrain, imposing restrictions on water storages, both at the surface and underground, because most of the rainfall is lost through surface runoff. This is perhaps the logic behind the presence of numerous large and small dams in this region.

It was estimated on the basis of the last census (2001) that Pune district has a population of over 7 million (Table 2). Of this, more than half the population is constituted by the population within Pune's urban setting, including the twin cities of Pune and Pimpri-Chinchwad. The urbanisation of Pune city has been quite rapid with the population rising exponentially from less than 0.2 million in 1902 to over 4 million in 2001 (Figure 7). The urban sprawl can be estimated from the fact that the city area was only about 40 km^2 in 1978 whereas it expanded to an area of about 150 km^2 in 1997 (Kulkarni et al, 1997). The city's limits extend far beyond this area today and it is estimated that the city area is nearly 400 km^2, whereas the urban area limits set for Pune city including several new villages encompass an area of some 700 km^2 (Nalavade, 2000).

Table 2 : Pune district population figures for 2001

(Census of India, 2001, provisional data)

	Rural	Urban	TOTAL
Male	1,557,463	2,211,665	3,769,128
Female	1,474,255	1,989,172	3,463,427
TOTAL	3,031,718	4,200,837	7,232,555

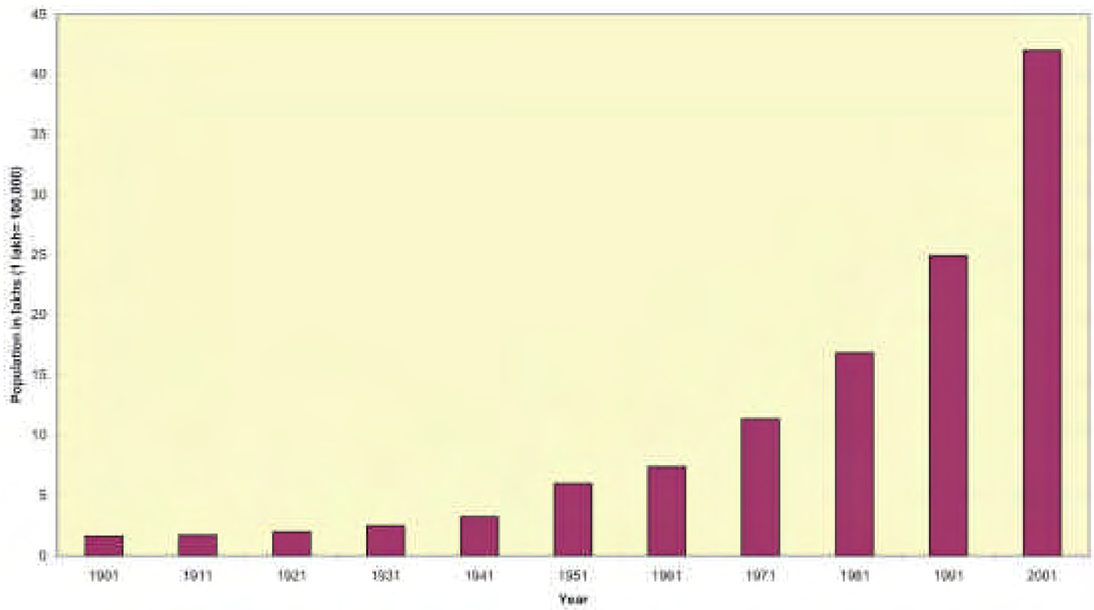


Figure 7: Population growth of Pune city over the last decade

2.2.2 Mulshi taluka

Kolwan valley is a part of the Mulshi taluka of Pune district. Figure 3 illustrates the location of Kolwan valley within the Mulshi taluka, including the main villages in the taluka. Paud, located 30 km from Pune city, is the taluka headquarters. The total area covered by Mulshi taluka is 1040 km^2. The Census data for 1991 and 2001 makes an interesting comparison (summarised in *Table 3)*, indicating some trends in the statistics for the taluka (*Maharashtra Census Directorate, 1995 and 2005*). Some 11 new villages have been added to the taluka records between 1981 and 1991, with a 13% decadal increase in the population of the taluka, over the earlier decade (*Maharashtra Census Directorate, 1995)*. The entire population of Mulshi taluka has been classified as 'rural population'. One significant change over the last decade is indicated through an improvement in literacy rates. The male literacy rate has increased by 10.45%, female literacy rate has increased by 14.58% and the overall literacy rate has increased by 12.58% from 1991 to 2001.

Table 3: Mulshi taluka statistics for 1991 and 2001

(after Maharashtra Census Directorate, 1995 and 2004)

Parameter	1991	2001
Area	1040 km^2	1039 km^2
Villages	150	144
Inhabited villages	147	141
Occupied residential houses	22691	23000
Households	23197	*Not available*
Total population	123326	127305
Male population	62532	66250
Female population	60794	61055
Population density	119 per km2	123 per km2
Scheduled castes	7%	8%
Scheduled tribes	4%	4%
Literacy (overall)	55.32%	67.90%
Male literacy	69.25%	79.70%
Female literacy	40.52%	67.90%

Agriculture and related activities formed the bulk of the occupation of people in Mulshi taluka and continue to do so, even presently. Figure 8 illustrates how changes have occurred in the major occupations of people from Mulshi taluka. Various other economic activities also feature in the occupation profile for the taluka, mainly service and support activities in the urban areas. However, the bulk of the rural population is engaged in the three occupations shown in Figure 8. Crop cultivation has decreased slightly over the last decade and agricultural labour has gone up. However, the complexity of occupations goes slightly beyond compartmentalised figures (as shown in the graph) because people are often engaged in a variety of activities ranging from agricultural labour to part-time services, considering the potentially strong rural-urban links where Mulshi is concerned.

Of the 147 villages under the 1991 census, the proportion of villages serviced by different basic amenities is highly variable (*Table 3*). Education, drinking water, communication and power supply is available in most villages in the taluka but medical facilities, post & telegraph facility, market centres and approach by proper roads are not fully developed across villages. And although concrete data for 2004 was not available on the taluka scale, the changes in facilities that lagged behind considerably are not significant from those provided in the census data for 2001, at least visually. However, statistics can be misleading as is evident from some random drinking water surveys conducted by GOMUKH in Kolwan valley. Despite the fact that drinking water facilities are developed in all villages in the taluka, the quality of water remains questionable. *Table 4* indicates the proportion of the taluka population served by different amenities.

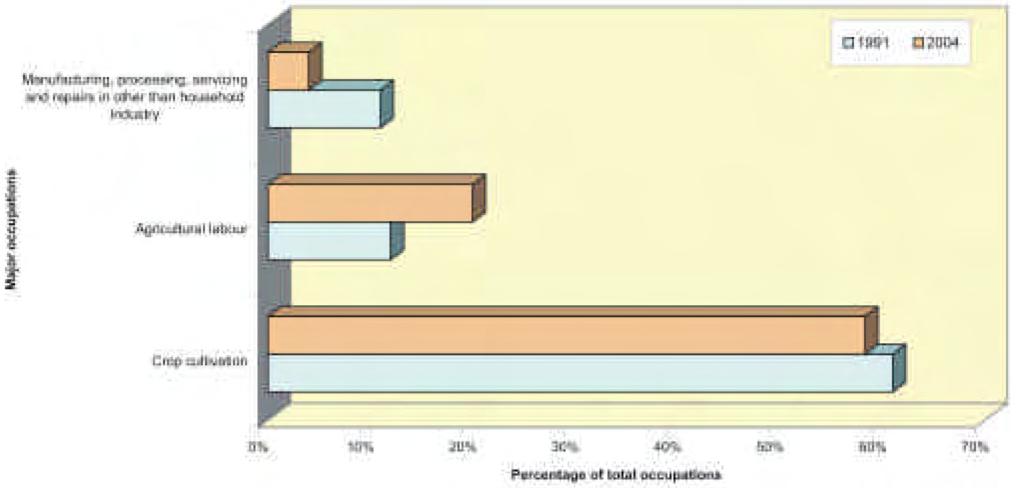


Figure 8: Comparison of occupations in 1991 and 2004 for Mulshi taluka, a dominantly rural setting near Pune

Table 4: Facilities available to the rural population of Mulshi taluka in 1991

Upper row indicates number of villages while lower one gives percentage of villages serviced

(*after Maharashtra Census Directorate, 1995)*

Education	**Medical facility**	**Drinking water**	**Post & telegraph**	**Market / Bazar**	**Communications**	**Roads**	**Power supply**
136	36	147	40	1	125	68	130
93%	24%	100%	11%	1.65%	86.81%	21.43%	97.80%

Only 17 villages out of the total 147 in the 1991 census had no power supply. The other villages had either domestic or agriculture related supply. *Prima facie*, one would expect Mulshi taluka to be covered by a large proportion of irrigated land. In reality, however, Mulshi taluka includes only about 56% of its total area as cultivable land. This could be due to a combination of factors including its physiography, forest cover and the large Mulshi reservoir, that is perhaps the most significant physical feature on any map or satellite imagery of the area. Moreover, only 2.7% of the cultivable area is irrigated even though a variety of irrigation facilities are employed for irrigating this land. *Table 5* shows the areas irrigated by different sources in the taluka. The total area irrigated was only 1564 hectares in 1991. The AGRAR project hoped to look into changes since this data because it was expected that a some change in irrigation facilities and irrigated area had occurred over the last decade, as a response to implementation of irrigation facilities as well as due to watershed development programmes. However, lack of official figures for the year 2001 could not make a comparison possible.

Table 5: Area irrigated by source (in hectares) in Mulshi taluka

(*after Maharashtra Census Directorate, 1995)*

Government canal	**Private canal**	**Well**	**Well (with electricity)**	**Bore well**	**Tank**	**River**	**Lake**	**Others**
19.36	-	9.00	378.00	-	0.77	1103.53	-	34.00

The physiography of Mulshi taluka can be described as 'dominantly rugged'. Most of the taluka is characterised by undulating, often rugged terrain, forming a part of the western ghats that outcrop within 100 km of, and run nearly parallel to, the west coast of peninsular India. The eastern boundary of the taluka grades into a less rugged, flatter landscape as one travels into the adjoining Haveli taluka, wherein Pune city is located.

Some 67569 ha land in Mulshi taluka is agricultural land, out of which 98.6% is uncultivated land and 10.40% is irrigated land. There are 398 irrigation wells in use in the taluka (*District social and economic bulletin, 2001-2002*). There are 27 Diesel pumps and 212 electric pumps on these irrigated wells. Pune district has 89902 irrigation wells with 2483 of these wells not in use (*District social and economic bulletin, 2001-2002*). Of these, 9656 wells are powered by diesel engines while 53170 wells are pumped using electric motors. Some 223 wells are used for purposes other than irrigation. In Mulshi taluka, there are 421 successful boreholes. Out of these, 366 and 23 boreholes had hand pumps and electric pumps respectively, installed on them (*District social and economic bulletin, 2001-2002*).

The climate of Mulshi taluka is generally pleasant, although summers and winters can be somewhat extreme with summer temparatures approaching 40° C and winter temparatures falling to below 10° C. The summer season is spread over March, April and May whereas winters are spread over the period from November to February. The average rainfall, mainly through the southwest monsoon, in the district is about 1600 mm. and occurs over the period from June to October. The maximum humidity at 70 to 80 % is recorded during the rainy season, whereas in summers it is as low as 30%. The area is characterised by light to moderate winds during most of the dry season. The monsoon season is characterised by strong winds blowing from the west and southwest. Without major industrial influence and traffic congestion, the climate of Mulshi can be described as invigorating, inviting weekend visitors to the increasing number of tourists and health spots, especially around the Mulshi reservoir.

Most rivers of peninsular India originate in the Western Ghats. The Mula river also originates in the western extremity of Mulshi taluka in the ghats, and then flows into the Mulshi reservoir from which water is released into the river from time to time. The river downstream of Mulshi reservoir also receives water from other tributaries like the Walki (Kolwan valley). Mula river flows further east to join with the Mutha river in Pune city. The drainage in Mulshi taluka is entirely part of the Bhima river basin. The water resources of Mulshi taluka are controlled by the high precipitation in the region. The Mulshi reservoir is a large dam constructed on the Mula river for generating hydroelectricity. Most villages depend upon surface water from rivers and some irrigation reservoirs in addition to groundwater resources, for irrigation. Agriculture is still the major occupation of people living in Mulshi, although, small industrial and agro-industrial units are increasingly being established in the taluka. However, water use by such units would still be meagre in comparison to water used in agriculture.

Mulshi taluka is well connected to the city of Pune by a metalled road network. In fact, a road now links Pune to the coastal district of Raigad in the Konkan and passes through Paud and other villages in Mulshi taluka, making it possible to access the Mumbai-Goa national highway (NH8). Moreover, a road joining this major arterial road at Paud passes through the Kolwan valley, connecting to the Mumbai-Bangalore national highway NH4. Roads are the only means of transport in the taluka with Government State Transport buses that connect villages mainly to Pune. Some transport buses that come off the Mumbai-Goa highway and Pune-Mumbai highway also pass through the taluka. There is also private transportation by jeeps, carrying passengers locally from Paud to various villages and back. Minitrucks, lorries and tractors constitute the major mode of transportation of goods and agricultural produce.

2.3 KOLWAN VALLEY

Kolwan valley is the common synonym for the Walki river basin. The largest village in the river basin is Kolwan, and hence, the name. The Walki River is not such a well-known river even in western Maharashtra. It is a tributary of the Mula river that flows into the Bhima river. The Mula and Bhima are well-known river systems in Maharashtra. The Walki is however, quite typical of many small-sized rivers in western India, with lengths of a few tens of km. It originates in the Western ghats and is the ‘backbone’ of Kolwan Valley, the focus of the current research project. Spread over an area of about 80 km^2, the Kolwan valley has a population of about 15000.

Kolwan valley consists of 16 villages and 48 hamlets with the length of around 15 km and the average width of about 5.5 km. Kolwan valley is bounded by longitudes 73°30’0”-73°37’37.5” and by latitudes 18°32’05”-18°37’40”. The basin trends roughly NW-SE. The Walki River originates in the western ghats and flows in a southeasterly direction, ultimately joining the Mula River to the north-east of Karmoli village, just over 1 km north of Paud, the taluka headquarters (Figures 9). The highest point within the watershed is 1100m above mean sea level and the lowest point is 570m above mean sea level. The area defined by the Walki river basin is included within the Survey of India toposheet number 47F/10. The main villages in Kolwan valley are shown on the map (Figure 9), along with the main road that leads to Pune to the ESE and to Lonavala (towards Mumbai) to the NW.

View of Kolwan valley during the monsoon season

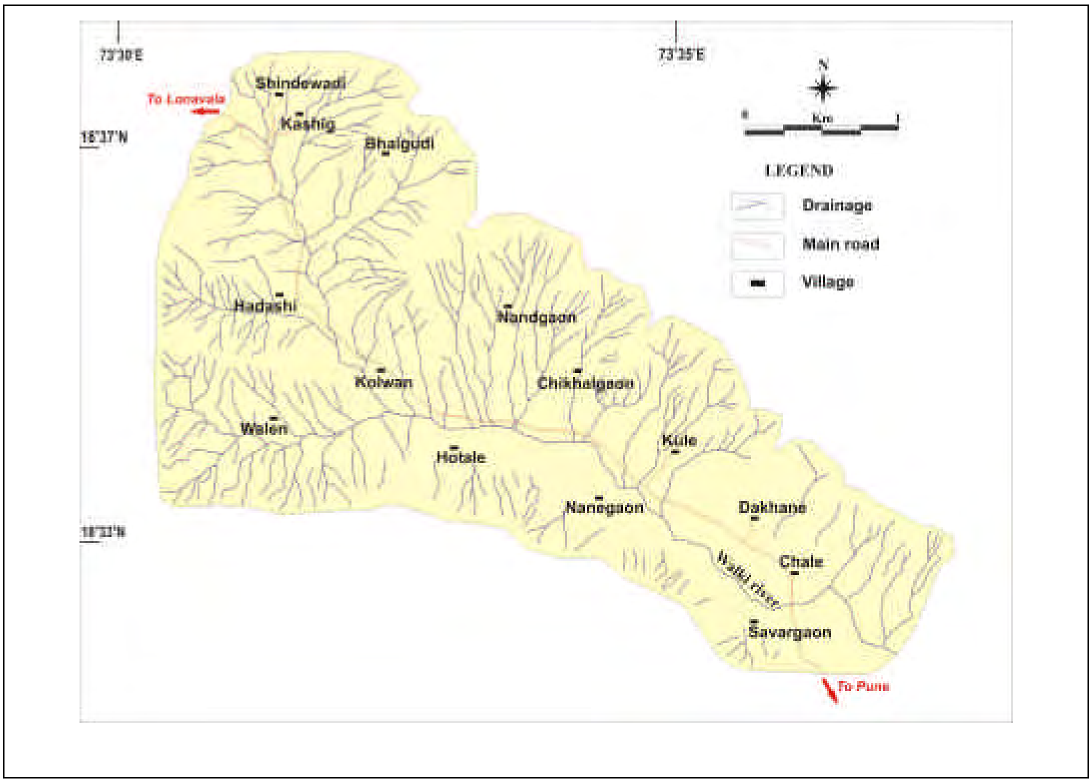


Figure 9: Base map of Kolwan Valley Watershed along with its drainage pattern

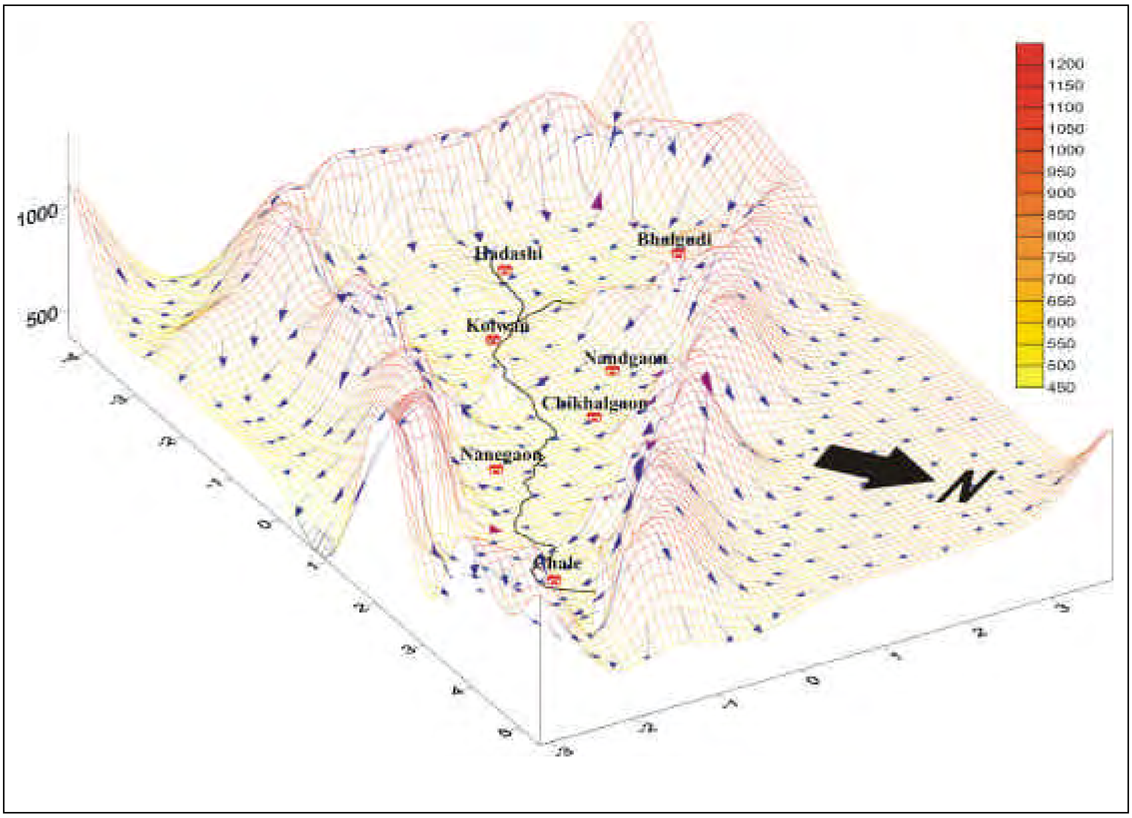


Figure 10: Topography of Kolwan valley, depicted in wireframe 3D, looking westwards

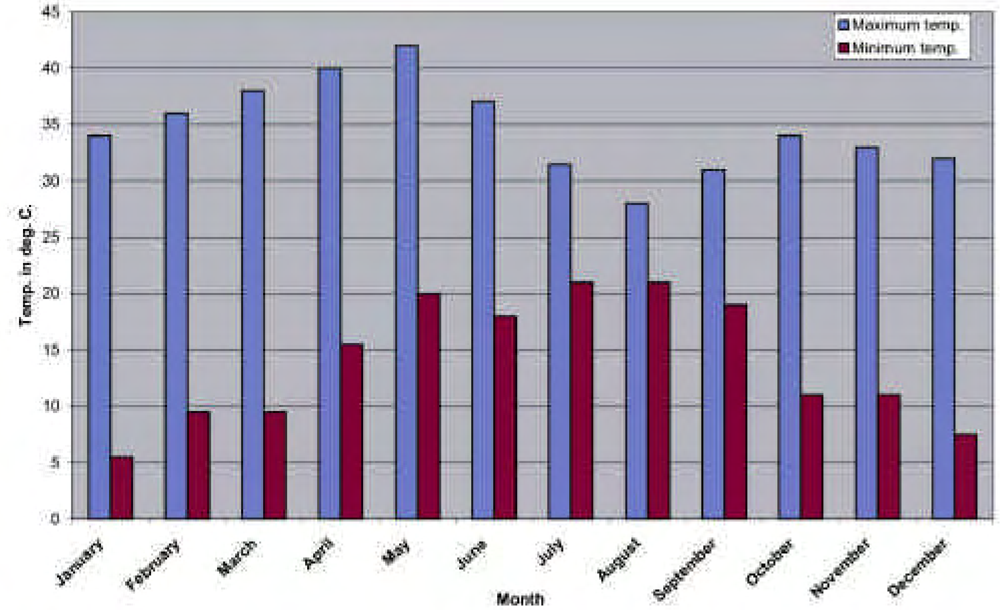
The AGRAR project commenced with gathering information on various aspects of the Kolwan valley, although the focus of the main research was in some of its microwatersheds and the recharge structures in one such microwatershed. However, during the initial survey, information regarding the Walki river basin was gathered in the form of direct observations and information based on secondary sources. A brief profile of the major observations made as a background to the AGRAR project, in the Kolwan valley, is presented below.

2.3.1 Topography and drainage

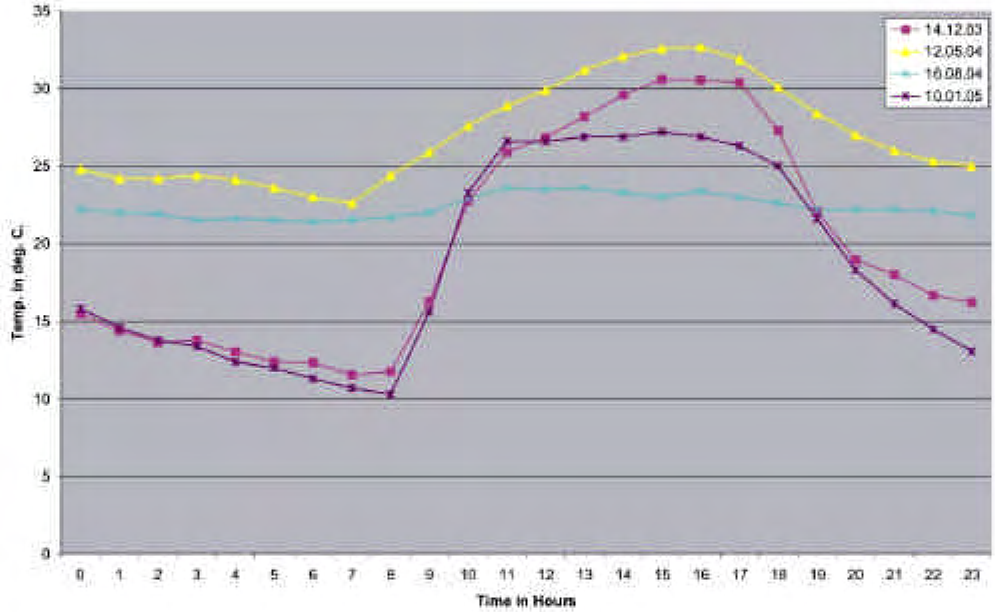
The region is mainly hilly with expansive plateaux to the west and small plateaux to the north and south. The valley itself is quite narrow and elongate, with steep ridge slopes that grade into a portion of terraces that, in turn, gently slope towards the main river channel. The slope of the land varies between 1% and 50%. Basaltic ridges on three sides surround the Walki River basin. The drainage pattern in the Kolwan valley is mostly dendritic to sub-dendritic. At places, however, fracture controlled linear drainage is apparent (Figures 10). Many streams originate in the northern basaltic ridges and drain south into the Walki River. There are relatively fewer streams originating along the southern slopes. Rapid and large quantities of surface runoff are experienced in all portions of the valley.

2.3.2 Climate

The watershed lies in the western part of Maharashtra, which experiences a tropical to sub-tropical climate. Kolwan valley experiences summers from March to June and winters from November to the following February. The nights during the summers are quite warm, with an average temperature of about 24°C, while the average temperature during the day is about 40°C. During winters, the mean daily temperature is around 30°C and the average night temperature is about 12°C, December being the coldest month. Humidity is very high during the summers with an average of about 70-80%. Climate is reported to change as one travels from the upper reaches of the valley to the lower reaches. Consequently, there is a difference in the land-use pattern and soil type in the entire valley, possibly on account of variable climatic conditions. Figure 11 shows the annual temperature variation in the Kolwan valley using data from the Karmoli and Chikhalgaon weather station.



A



B

Figure 11: Monthly temperatures for Karmoli during the year 2003 (A) and hourly temperature from the Chikhalgaon weather station for four days, showing seasonal variation (B).

2.3.3 Rainfall

The Walki River basin is located in a high rainfall zone (YASHADA, 2000). The region receives heavy rainfall over the period June to October, from the southwest monsoon. The average annual rainfall was stated to be in the range of 1500 to 2000 mm during the preliminary investigations on the AGRAR project. Even though the river basin receives a high amount of rainfall, the region used to face severe scarcity of water during summers. However, with interventions like village drinking water supply schemes and watershed development activities under various Government and NGO programmes, water scarcity has reduced considerably (*pers. comm. and informal discussions with communities in Kolwan valley).*

There was only one weather station at Karmoli, installed by the State Irrigation Department, at the beginning of the AGRAR project. The Irrigation Department also had rain gauges at the Walen and Hadashi Minor Irrigation Tanks. Rainfall data from these three stations was obtained, along with the data from the rain gauge station at Paud, the taluka headquarters. Subsequently, five rain gauges were installed at Kashig (near Bhalgudi), Kolwan, Nanegaon, and Chale, in addition to the Automatic Weather Station set up at Chikhalgaon. This was done to obtain an idea about the spatial rainfall variability in river basin. Hence, the Walki river basin included eight sets of rainfall data used in the AGRAR project.

Rainfall data from the Karmoli rain gauge station was available for a period of 12 years. The annual rainfall data for these 12 years has been converted into sets of one hydrological-hydrogeological cycle/year, which begins in June of each year (with the commencement of the monsoon) and ends in May the following year (peak summer). This was done to reconcile operations such as water level fluctuations in aquifer, agriculture, irrigation seasons and other responses to annual seasonality such as labour and temporary migration, all of which is governed by this hydrological 'year' rather than the calendar year.

Hence, each cycle consists of the entire monsoon, the following winter season and the summer season. This is in agreement with the river flow discharges (wet and dry-season) and saturation and desaturation trends in aquifers (especially shallow aquifers). The data for Karmoli is plotted using hydrological/hydrogeological years instead of calendar years. The highest annual rainfall was experienced in the year 1993-1994 and the lowest rainfall was experienced in the year 2000-2001 (Figure 12). In other words, the highest rainfall was during the period June-September 1993, while the lowest rainfall was recorded during the period June-September 2001.

The graph indicates that the highest rainfall was experienced on 19th June 1993. The plot of the annual rainfall (using a hydrological/hydrogeological cycle) for the Paud station, illustrates that the area experienced maximum rainfall in the year 1994-1995 and the minimum rainfall in the year 2000-2001 (Figure13).

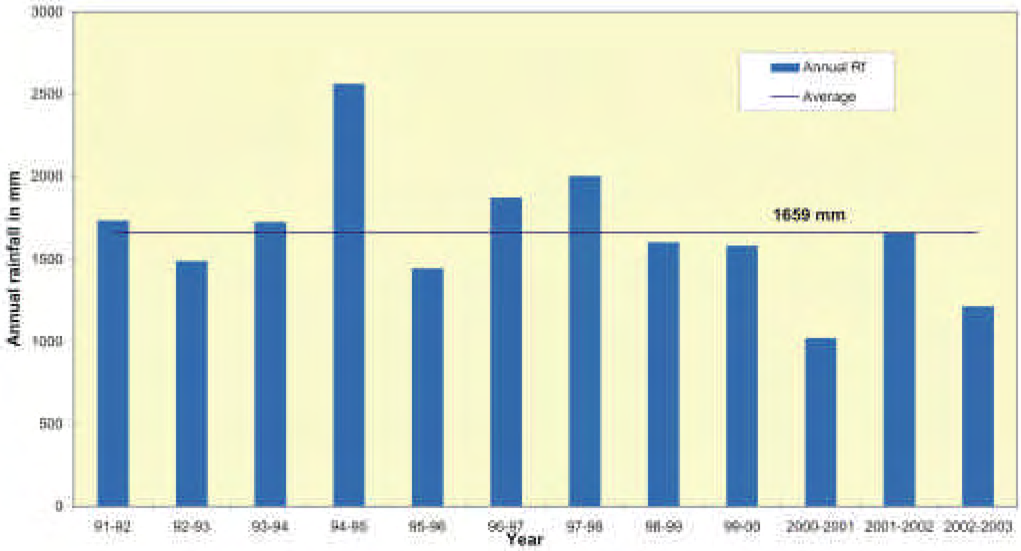


Figure 12: Rainfall data for Karmoli station for 12 years
(*one hydrological cycle, from the month of June to the following month of May***)**

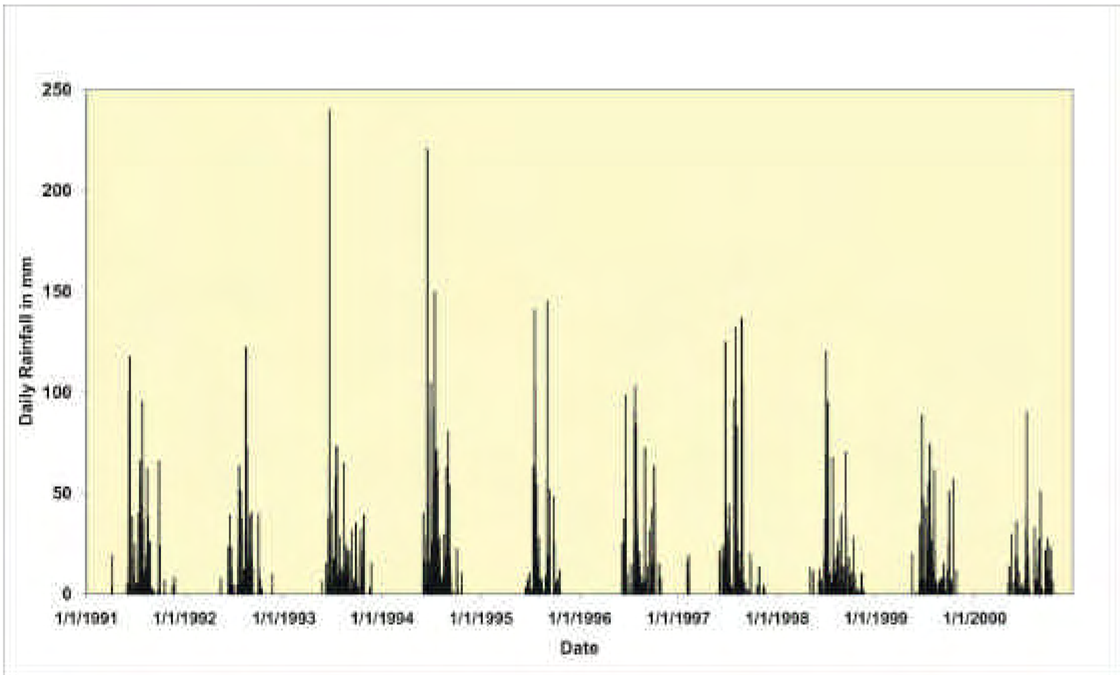


Figure 13: Annual cumulated rainfall and daily rainfall data for a period of 10 years is plotted for the Paud station

Daily monsoon data in the month of June and July has been used from Hadashi, Walen and Karmoli stations and is plotted to make a comparative study of rainfall at three sites within the valley, for the year 2003-04 **(**Figure14). It was observed that, from the onset of monsoon till 8th August, 2003, Hadashi, Walen and Karmoli have received rainfall measuring 2141 mm, 1899 mm. and 1055 mm. respectively. Hadashi recorded the highest rainfall. Both Hadashi and Walen villages experienced a high amount of rainfall of 153 mm. and 146 mm. respectively on the 28th July 2003. As compared to these villages, Karmoli, which is located in the lower reaches of the valley, received only 84 mm. of rainfall on the same date. This clearly implies the high degree of rainfall variability in the Kolwan valley.

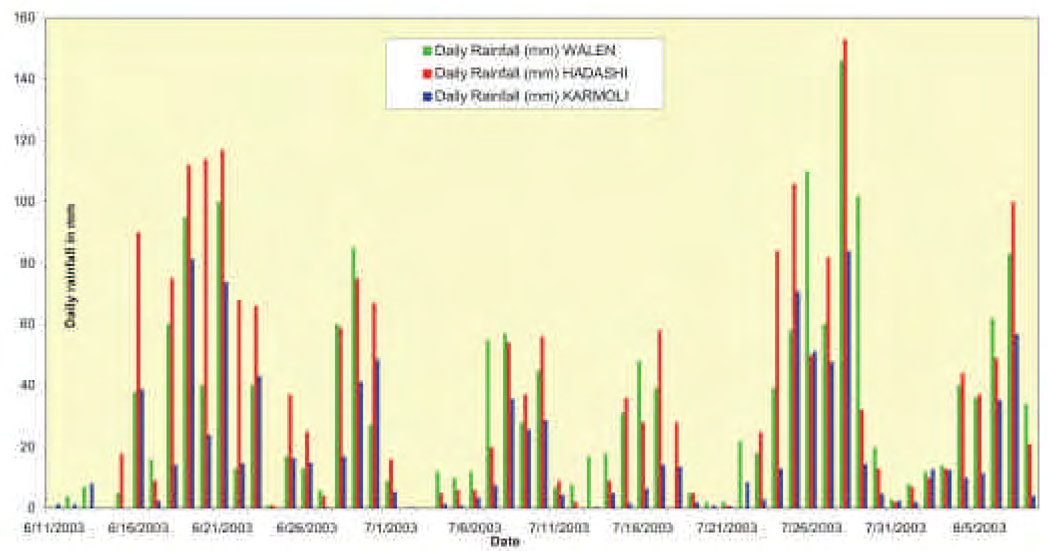


Figure 14: Comparison between data for three rain gauge stations for June and July *(unpublished records, Minor Irrigation Department, Paud, Mulshi headquarters)*

2.3.4 Soil type

Soil type usually depends on the type of bedrock, climate and weathering patterns (*Schroeder*, *1984*). Two types of soils are found in the Kolwan valley: red to reddish brown, silty soils (alfisols) and black, clayey soils (vertisols). The basalt forms the bedrock to both types of soils. The alfisols may represent high alumina and iron content. In fact, an almost clear division can be made between the northern and southern flanks of the watershed on the basis of soil cover alone. The northern ridges are covered by vertisols while most of the southern ridges are covered by alfisols. The valley receives most of the rainfall from the southwest monsoon, with the northern slopes bearing the direct brunt of the rainfall (they are exposed directly to the winds and the rains during the monsoon). The inner slopes of the southern ridges, which remain on the leeward side with respect to the direction from where the southwest monsoon precipitates rain, do not experience the direct impact of heavy downpours that characterise the rain in the region.

For instance, the rain gauges in Kashig, Walen and Hadashi recorded rainfall events of about 200 mm or more during one day this year (2004-05). The southern ridges are also thickly vegetated, while, vegetation found on the northern ridges is mainly in the form of small shrubs and bushes (Figure 15).

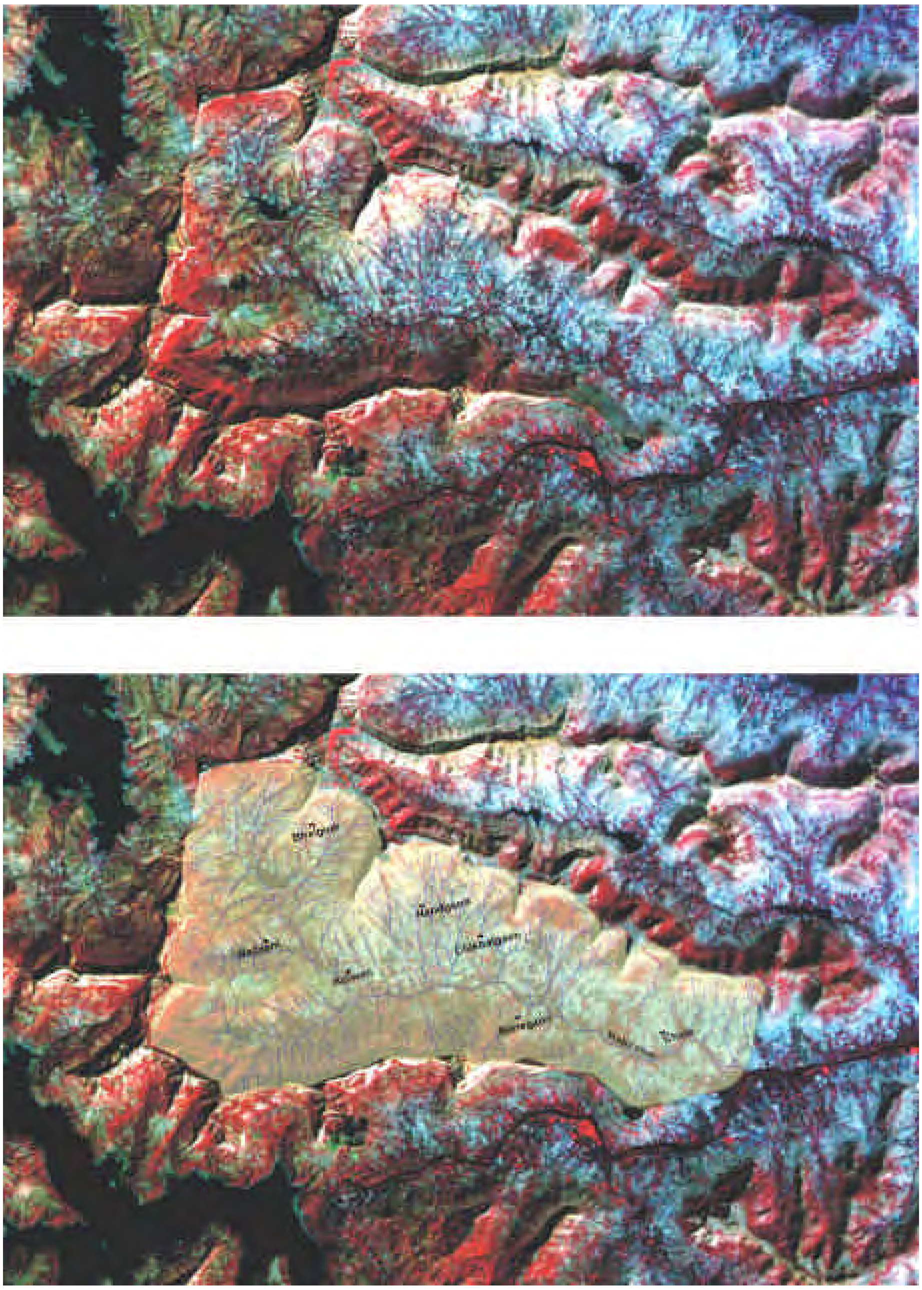


Figure 15: IRS-P6 data showing the contrast between northern and southern-western slopes of the Walki river basin with respect to soils and vegetation

Soils in the valley are typically clayey soils. Basaltic ridges generally show very thin soil cover, with the exception of some parts on southern slopes where soil cover is quite thick (at some places it is almost to 5-10m in thickness). In the plains the soil cover is quite consistent and varies in thickness from 2 to 4m. Heavy rains in the valley induce soil erosion, especially in parts where vegetation has been removed from slopes.

(a)

(b)

Northern slopes in Kolwan valley have thin soil cover and sparse vegetation (a). Western and southern slopes, on the other hand, have thicker soils and denser vegetation (b)

2.3.5 Geology

The Walki river basin is constituted entirely of the Deccan Basalt (Deccan basalts). These basalts (also referred to as Deccan Trap or Traps) were formed from the eruption of lavas some 65 million years ago. These lava 'flows' vary in thickness from a few meters up to 10s or even 100s of meters. Each lava flow can further be divided into sub-units. In general, the Deccan basalts can be grouped into two categories, 'simple' or 'compound' depending on the viscosity of the primary lava (Deshmukh, 1988; Kale and Kulkarni, 1992). The simple flows equate to classic flood basalts formed by quite effusive eruption of very large quantities of low viscosity lava from open fissures. The compound flows are either the product of an explosive activity from more viscous lavas or can be formed at the distal portion of simple flows where there is an increased viscosity from cooling and de-gassing. Both types of basalt flows tend to weathered variably across the entire Deccan volcanic province. Basalt lavas from Kolwan valley have been depicted dominantly as 'aa' and compound 'pahoehoe' lava flows belonging to the Karla formation (Geological Survey of India, 2001), but field observations during this study revealed that compound flows dominate in the Kolwan valley.

The compound flow basalts result from lavas, which lose much of their volatile gases prior to extrusion and hence are more viscous. This greater viscosity causes the remaining volatile gases to be trapped within the rapidly solidifying lava. The lava is characterized by rubbly upper and lower surfaces. Fragmentation of the upper surface results from the disruption of the viscous crust by the movement of the flow beneath it. Some compound flows may be devoid of a compact middle layer. Although distinction is made between the two flow types, gradations between simple and compound flows are not uncommon since the effects of the loss of volatiles and cooling will increase the viscosity of the lava and cause a change in physical characteristics (Macdonald et al, 1995).

Mapping basalt lavas can be a labourious exercise, especially in an area where both simple and compound types of flows overlap. In order to overcome this difficulty, the Kolwan valley has been divided into seven basaltic units that are essentially mappable portions of the lava sequence with a geometry that takes into consideration the weathering and fracture patterns in units, which avoids the semantics debate and ensures a more complete description of factors controlling groundwater accumulation and movement in these basalts. This distinction is based on research conducted over the last twenty years on the hydrogeological characterisation of Deccan basalts, summarised in Kulkarni et al, 2000. Figure 16 is a geological map of Kolwan valley showing the disposition of horizontal lavas in the Walki river basin. Further, regional linear features in the form of fracture zones and dykes often transect a sequence of basalt lavas. These lineaments in the Kolwan valley, were identified, using remote sensing data and field checks. The geological map also shows such lineaments, most of which are in the form of fracture zones. One dyke lineament traverses the eastern parts of the Kolwan valley, as shown in the Figure 16.

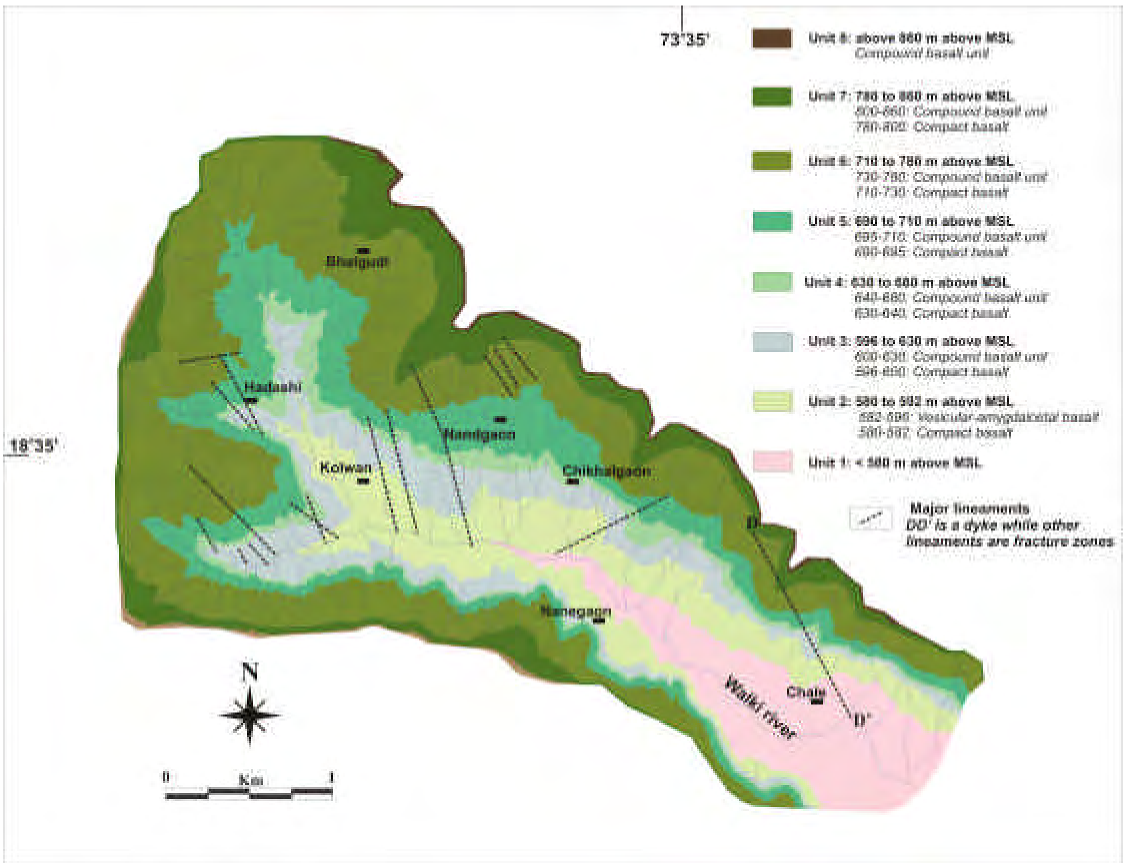


Figure 16: Geological map of Kolwan valley, prepared using remote sensing data, extensive fieldwork and dug well lithologs

Basalt lavas in Kolwan valley, disposed as near-horizontal units with tabular geometry.

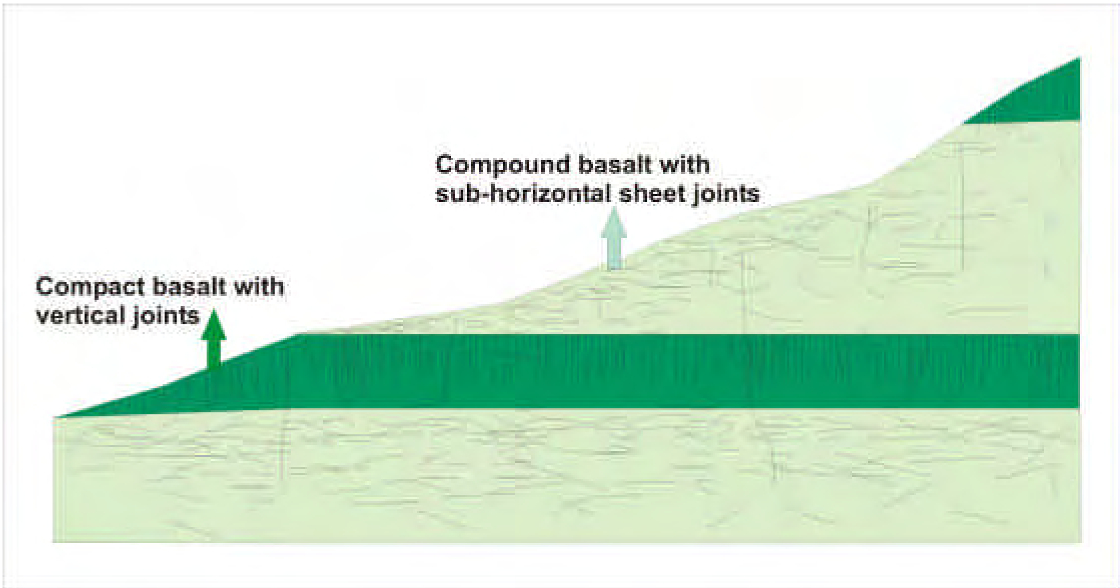


Figure 17: Conceptual diagram showing cross-section of basalts in Kolwan valley. Joint and fracture patterns determine the hydrogeological characteristics of the basalt units, thereby controlling the accumulation and movement of groundwater.

The interconnectivity between units and the fracture openings within each unit control the storage and transmission of groundwater in these basalts. Compact basalts have very little storage and transmission capability, except when jointed or fractured. Even then, the permeability of the fractured portion of compact basalts is quite limited as compared to that of weathered vesicular-amygdaloidal basalts / compound basalts (Kale and Kulkarni, 1992). Hence, due to the horizontal sheet jointing (related to the degree of weathering) and greater lateral interconnectivity, the vesicular-amygdaloidal portions of compound units usually form good locales for storage and transmission of groundwater.

2.3.6 Socio-economic profile and interventions through the watershed development programme

Agriculture is the main occupation of people living in the Kolwan valley. Villages here are largely dependent on rainfed agriculture. Only a few farmers use irrigation facilities and grow irrigated crops, although this trend is noticeably increasing during the last couple of years. In addition to agriculture, the villagers are involved in other small scale activities like livestock-rearing, forestry, fishing, hunting, plantations, orchards, mining activities, manufacturing, processing, servicing and repairs in household as well as in non-household industry, constructions, trade and commerce, transport, storage and communications and in some other allied activities. It was generally observed that most workers involved in these activities are males. Women are more involved in agricultural activities as compared to their involvement in the other activities mentioned above. Even though the ratio of males to females in agricultural labour is high, it is seen that in some villages the ratio of women involvement is more than their male counterparts (District Census Handbook, 1995).

Jowar (Sorghum) and Paddy are reported to be the most common crops cultivated during the Kharif (rainy season). Again, during this study, paddy seemed to overrides Jowar significantly. Wheat is the main crop grown during the Rabi season (irrigated cropping). During the two-year study in Kolwan valley, an increase in the variety of crops grown, especially during the irrigated season, was clearly noticed. Vegetable cultivation has visibly increased and so has sugarcane. Other important crops grown are ragi (red millets), chana (horse gram), tuar (Bengal gram) and some other pulses. The higher slopes in Kolwan valley are mostly forested or barren. The middle slopes comprises dominantly of cultivated area, with paddy cultivation being the most dominant cultivation while the plain portions adjoining the river is undergoing a transition from traditional paddy-wheat cropping to cash crops, mainly sugarcane as well as agro and non-agro based industry. Most of the villages are located in the middle, gently sloping portions, perhaps because the river floods the plain portions adjoining its channel during the monsoon.

Drinking water availability is not a major problem because most of the 18 villages have at least one water supply scheme. Villages are essentially constituted of more than one habitation and virtually all villages, in addition to a public water supply scheme, also depend upon other sources like springs and wells to meet domestic demand of water. Irrigation water is largely lifted from the Walki river and from the minor irrigation tank of Hadashi. There are some 100 'lift irrigation' schemes from the Walki river (including 8 from the Hadashi minor irrigation tank). Of these 40 schemes lift water using diesel engines, while the remaining 60 are powered by electricity. Well irrigation is limited, although it is perceived to be increasing to cater to an increased demand of irrigated crops.

Although agriculture and farm labour are the major occupations of people from Kolwan valley, migration (short and long-term) to Pune, Mumbai and other cities in Maharashtra is common for people from Kolwan valley. Our surveys and discussions in villages revealed that virtually all households in the valley have one or more members working in cities and industries close by. Migration to work is for service and labour.

Many institutions are working in Kolwan valley. Most of these institutions are involved in various types of development work. Watershed development work in the valley has been carried out by a number of NGOs such as GOMUKH, Gramshakti and Gangotree, in addition to Government run programmes taken up through the local self government, i.e. gram panchayats. Water resources development, either through a watershed development programme or otherwise, continues to be undertaken by various 'Programme Implementing Agencies (PIAs)'. Such work broadly includes development of natural springs into 'spring-wells' (or spring-tanks as they are commonly known). These springs have been broadened and stabilised for tapping the natural flow of spring water and storing it 'in-situ' for drinking & domestic use, irrigating lands, construction of inland fish farms and construction of storage/recharge weirs with big trees and saplings in the vicinity. The watershed programme in Kolwan valley covered a population of about 15,000 people in ten villages. Under this programme, cement bunds, earthen bunds, farm ponds, water-impounding structures, forestation and contour trenches have been constructed. Additionally, institutions like 'Sadhana village' are involved in other social work activities like running a home for mentally challenged adults. Such organisations have also put a few water harvesting structures on the main Walki river channel.

There are 28 check dams / weirs constructed in the Kolwan valley. Out of these 28 structures, 12 are masonry check dams, 14 are 'Kolhapur' type weirs (gated weirs) and 2 are earthen check dams. Out of these 14 Kolhapur type weirs, the Government constructed 10 weirs. GOMUKH has constructed all the rest of the structures. The last structure (downstream) on the Walki River is a check dam built by the irrigation department for Savargaon village, just upstream of its confluence with the Mula River. GOMUKH is planning watershed development activities in five more villages this year. Work began in 2004 and will intensify during the summer of 2005. Details of the current watershed activities by GOMUKH in Kolwan valley are presented in the table given below.

Table 6: GOMUKH's watershed related work in five villages of Kolwan valley, for 2004-05

(after, GOMUKH, 2000)

Structure/activity	**Kule**	**Nanegaon**	**Nandgaon**	**Sathesai**	**Dongargaon**
Loose boulder structures	100	70	50	75	70
Earthen stream bund	2	3	2	1	2
Gabions (as cumulated length)	50 m	60 m	30 m	40 m	80 m
KT-weirs	1	1	1	1	1
Farm ponds (dug outs)	8	8	4	4	8
Cement stream bund	Nil	Nil	1	1	1
Vegetated field bunds	45 ha	20.5 ha	28 ha	25 ha	33 ha
Continuous contour trenches	14.5 ha	22 ha	17 ha	30 ha	6.25 ha

KT= Kolhapur type weirs (either gated or with overflow spillway); ha= hectares

The watershed project implemented in Kolwan valley by GOMUKH was an integrated programme of improving the natural resources base, thereby targeting improvement in the livelihoods of communities living in the villages. Hence, measures have been implemented with multifaceted purposes. However, the basis for the measures was broadly in the form of soil conservation, water harvesting and augmenting recharge to groundwater.

The watershed programme in Kolwan valley emphasized the conservation of water wherein techniques to harvest rainwater and measures to improve groundwater recharge were given topmost priority (*pers. comm.. GOMUKH)* Four major water harvesting techniques have been employed in the project villages by GOMUKH:

1. Cement bunds
2. Earthen bunds
3. Farm ponds
4. Storage weirs

GOMUKH began its watershed development programme in the year 1997-98. The total population from the 10 project villages at this time was about 12,000 (*GOMUKH, 2000*). At the beginning of the project implementation, i.e. in 1998, some critical social and economic issues were observed in these villages. These are listed below.

1. Despite migration, the number of families increased from 1261 in 1991 to 1344 in 1998.
2. Some 700 hectares of land was sold to non-resident purchasers. The total land holding in these ten villages is 3216 hectares.
3. Agriculture was the main activity in the villages, accounting for occupation of 75% families. Only 5% depend upon business and service as sources of income.
4. Social and political participation was low. However, this picked up significantly during the project implementation.
5. Cattle-rearing was done more as a lifestyle than as a source of income, as the ownership of milch and non-milch cattle was the same. This was attributed directly to the scarcity of groundwater, due to which, there were limitations on the growing of pastures.
6. Alternative livelihoods in villages are limited and hence migration to nearby cities like Pune, Mumbai and Lonavala is high.
7. Sanitation was poorly developed, with most of the population practicing open-access defecation. 42% of the 1261 households had a bathroom while only 2% had WCs. There were 11 septic tanks.
8. Drinking water was the topmost priority problem while interior villages also have improper access roads.

9. Tribal groups, although not in significant numbers, exist in the area and occupy the bottom of the social hierarchy.

At the onset of the watershed development project, GOMUKH, the implementing agency felt that the real critical issues were:

- Scarcity of water, despite an annual normal precipitation of 1580 mm, resulting in lack of irrigation and cultivation of only a single crop.
- Since most people depend upon agriculture (single crop) as the only source of income, there was hardly any surplus income.
- Migration was common and a direct result of saturation and limited per capita income through agriculture.
- Heavy rainfall caused soil erosion and high surface runoff, degrading lands and allowing water less resident time within the microwatersheds. This also implied individual investments in land-development at the start of the next Kharif season…

Kolwan valley project development began in November 1998 and continues as newer villages are included. Several positive impacts are emerging as a consequence of the watershed development programme in Kolwan valley. Cultivated land area has increased, even during the rabi season and farmers are now cultivating crops like irrigated (Rabi) wheat using surface water and some groundwater. A direct impact of the interventions by GOMUKH has been in the form of increased sustenance of several natural springs from the Kolwan valley. This is apparently a result of the recharge-enhancing measures in the catchments of some of these springs, although spring studies were not part of the AGRAR project. However, these springs occupy positions in the upper slopes in the basin, whereas aquifers tapped by wells are in the gently sloping middle and the flatter lower slopes.

In Kolwan valley, impacts such as increase in irrigated cropping are quite complex, in the sense that they can be attributed to any one or more of the following factors:

- Increase in the lifting of water from Walki river.
- Increased lifting of water from the minor irrigation tank at Hadashi.
- Impact of watershed development, on groundwater and surface water (increased base flows in streams and the river).
- Simply the effects of improved economy of communities, inducing investments in irrigation infrastructure, which was not possible some years ago.
- Improved awareness on irrigation schemes, agriculture and cropping.
- Improved market demand for a variety of crops, inducing irrigated cropping.

Some of these factors were examined during investigations pertaining to the AGRAR project, especially on the scale of sub-watersheds of the Walki river basin.

2.4 WATERSHED SCALE SETTING

As mentioned earlier, watershed development activities, including measures of artificial recharge have been implemented in Kolwan valley by organisations like GOMUKH. GOMUKH's Kolwan valley project development began in November 1998 and was handed over to the community in May 2000. GOMUKH had worked in some 10 villages, and therefore in whole or parts of 10 watersheds, implementing watershed development measures. Three of these watersheds were selected for studies under the AGRAR project. Two watersheds where watershed development was not undertaken were also selected for comparison with watersheds with watershed development activities.

Chikhalgaon watershed was selected as the major focus of this study. However, other sites (watersheds) were also studied to compare results with the main site, although the degree of detail at these other sites was quite limited when compared to the Chikalgaon watershed. The main recharge structure studied under the AGRAR project is located in Chikhalgaon watershed. The other study sites, where GOMUKH implemented watershed development, were Hadashi and Bhalgudi. Nanegaon and Nandgaon watersheds were the two sites without watershed development. A summary of physical details of each of the five watersheds is given below.

2.4.1 Physical setting

The physical setting of each of the five watersheds is summarised in this section, briefly describing the topography, geology and the hydrogeological monitoring framework.

2.4.1.1 Chikhalgaon watershed

Chikhalgaon watershed is the area within which the main site selected for the AGRAR project is located. Further, the main site in the Chikalgaon watershed includes a well-defined shallow aquifer that is superimposed by typical recharge structures constructed as a part of the watershed development programme undertaken by GOMUKH in Kolwan valley. Chikalgaon watershed is located between 18°34'18"N - 18°36'6"N and 73°33'24"E - 73°34'12"E The area of the Chikhalgaon watershed is 1.98 km^2. The village is located to the east of Chikhalgaon watershed (Figure 18). The village is located at 18°34'4"N & 73°34'46"E. It lies at a distance of 7 km. from Paud, on the way to Javan village through Kolwan.

The mean average elevation of the watershed is 750 m above msl. The highest elevation in the watershed is 1080 m above msl, while the lowest elevation is 587 m above msl. The hill range that forms the northern divide for the Walki river basin prominently marks the ridgeline of the watershed. The watershed is marked by steep slopes along this ridgeline that give way to gently undulating landscape, terraced at places for paddy cultivation. The lower portions of the watershed, near its confluence with the Walki river are relatively plain, or with gentle slopes. The average slope of the land is 6% and the slope of the area underlain by the Chikhalgaon aquifer (gently undulating and flat, valley portions) is 1.40%.

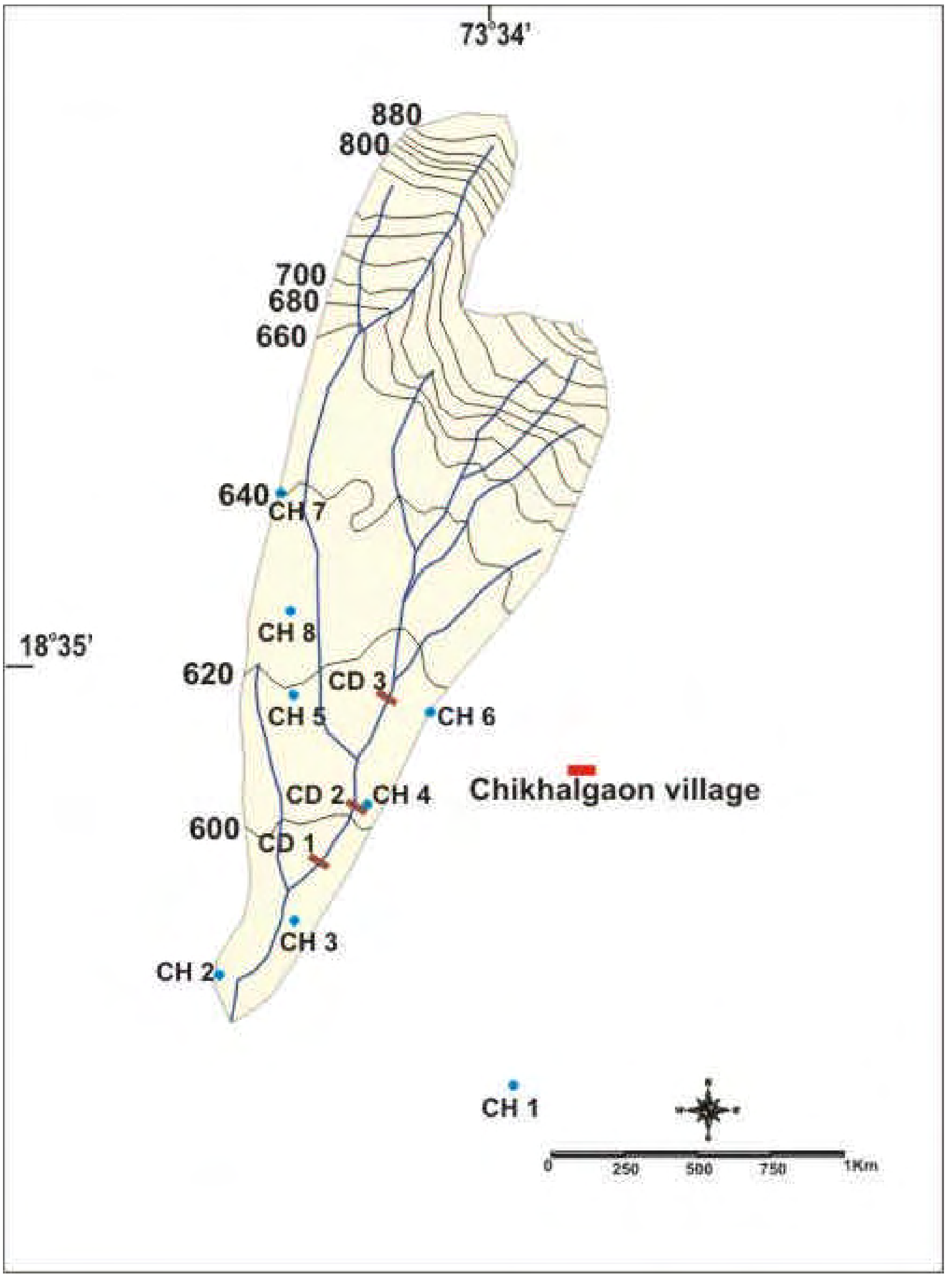


Figure 18: Topographic map of Chikhalgaon watershed (*contours in m above msl*)

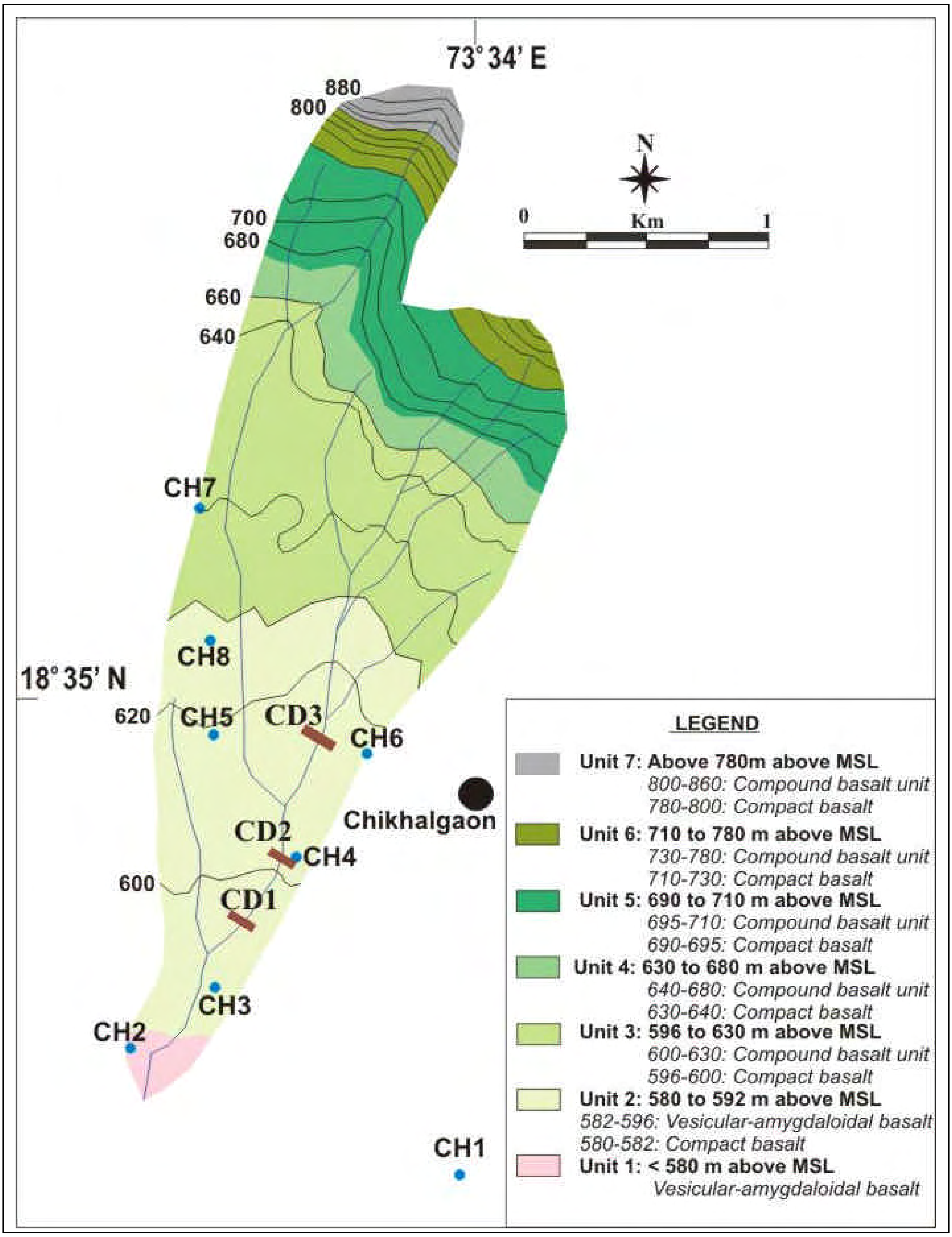


Figure 19: Hydrogeological map of Chikhalgaon watershed *(location of wells and check dams also shown on map)*

Six of the eight basalt units in the Kolwan valley, are exposed in the Chikhalgaon watershed, on the basis of the foregoing discussion on the hydrogeology of the Walki river basin (Figure 19). Compound, basalt units that are dominantly amygdaloidal in nature are prevalent in large portions of the watershed, often overlying columnar jointed basalts (compact basalts). Compound basalt units are made up of several 'bun' shaped members. Each 'bun' has a basal section of pipe amygdales, a central dense portion and an upper vesicular portion, often with a reddened glassy crust (as explained by Thorat and Sabale, 1990 and Bondre et al, 2000).

The Chikhalgaon stream, like most tributary streams of the Walki river, is seasonal. It flows during and just after the wet season, progressively drying up over the dry season. Flows in this stream were reported to last until the month of December, before the watershed project was implemented. Now flows in parts of Chikhalgaon stream can be noticed almost until the month of February. During the summer months, there is no flow in the stream since the check dams are dry and the water table drops below the streambed level.

The total stream length of the (main) stream is approximately 1.9 km. The Chikalgaon watershed represents a third order drainage basin, based on Strahler's (1952) method of stream ordering. The watershed drainage is made up dominantly of either first or second order streams. The bifurcation ratio of the first to second order streams is 4 and for the second to third order streams, it is 2. The drainage density of the watershed is 2.4 per km^2.

There are 8 wells in the watershed. All these wells are large diameter dug wells, tapping the shallow weathered/fractured basalt aquifer. Wells are typically 3 to 5 m in diameter and 3 to 10 m in depth. The well that supplies drinking water to Chikhalgaon village is not a part of the Chikhalgaon watershed but was included in the set of monitoring wells. With a depth of 15 m, this well is deeper than most private wells in Kolwan valley. It also has a larger diameter, at about 10 m. The design, depth and diameter of this well is similar to all the wells that supply drinking water to villages in Kolwan valley. All dug wells in Chikhalgaon watershed represented a part of the monitoring network in the Walki river basin, under the AGRAR project. There are no boreholes in Chikhalgaon watershed, although there are some private boreholes around Chikhalgaon village.

Table 7 presents a summary of the watersheds studied during the AGRAR project. The table brings out similarities and differences in these watersheds, all of which, except Nanegaon watershed, are third order basins {based on the classification by Strahler, 1952, for stream ordering}. Drainage in the Nanegaon area has been superimposed in many parts by agricultural fields. Hence, streams seem to disappear on the map. Looking at older maps (like the toposheet, for instance), the Nanegaon watershed represents a second order drainage basin.

Table 7: Profile of AGRAR watersheds from Kolwan valley

Watershed	Area in km^2	Elevation range (with mean elevation in parenthesis) in m above msl	Average gradient in percentage	Estimated mainstream length in km	Drainage density (km/km^2)	Dug wells (dws) and bore wells (bws)	Check dams
Chikhalgaon	1.98	587–1080 (750)	6.00%	1.90	2.4	8 dws	3
Nandgaon	2.59	583-840 (700	4.3%	2.00	4	8 dws	-
Bhalgudi	3.129	618-1200 (760)	8.48%	3.61	8.0	13 dws	4
Hadashi	3.58	595-860 (730)	4.5%	3.00	3.5	4 dws & 1 bw	2
Nanegaon	1.59	575-940 (750)	9.00%	-	-	7 dws & 1 bw	-

2.4.1.2 Other watersheds monitored in the AGRAR study

The Nandgaon and Hadashi watersheds include five basaltic units exposed in their respective areas. Chikhalgaon watershed includes six of the eight basalt units exposed in Kolwan valley. Bhalgudi watershed includes only four of these basaltic units whereas Nanegaon includes eight of these units.

The mainstreams in all these watersheds are seasonal and dry up by the month of February, although the streams in Nandgaon and Nanegaon dry up much earlier than the streams in the other three watersheds. The Hadashi stream has intermittent flows of water throughout the year as it receives releases from the minor irrigation tank (north of Hadashi village) every now and then. These geometry, including the basalt units exposed in these watersheds is shown in Figure 201.

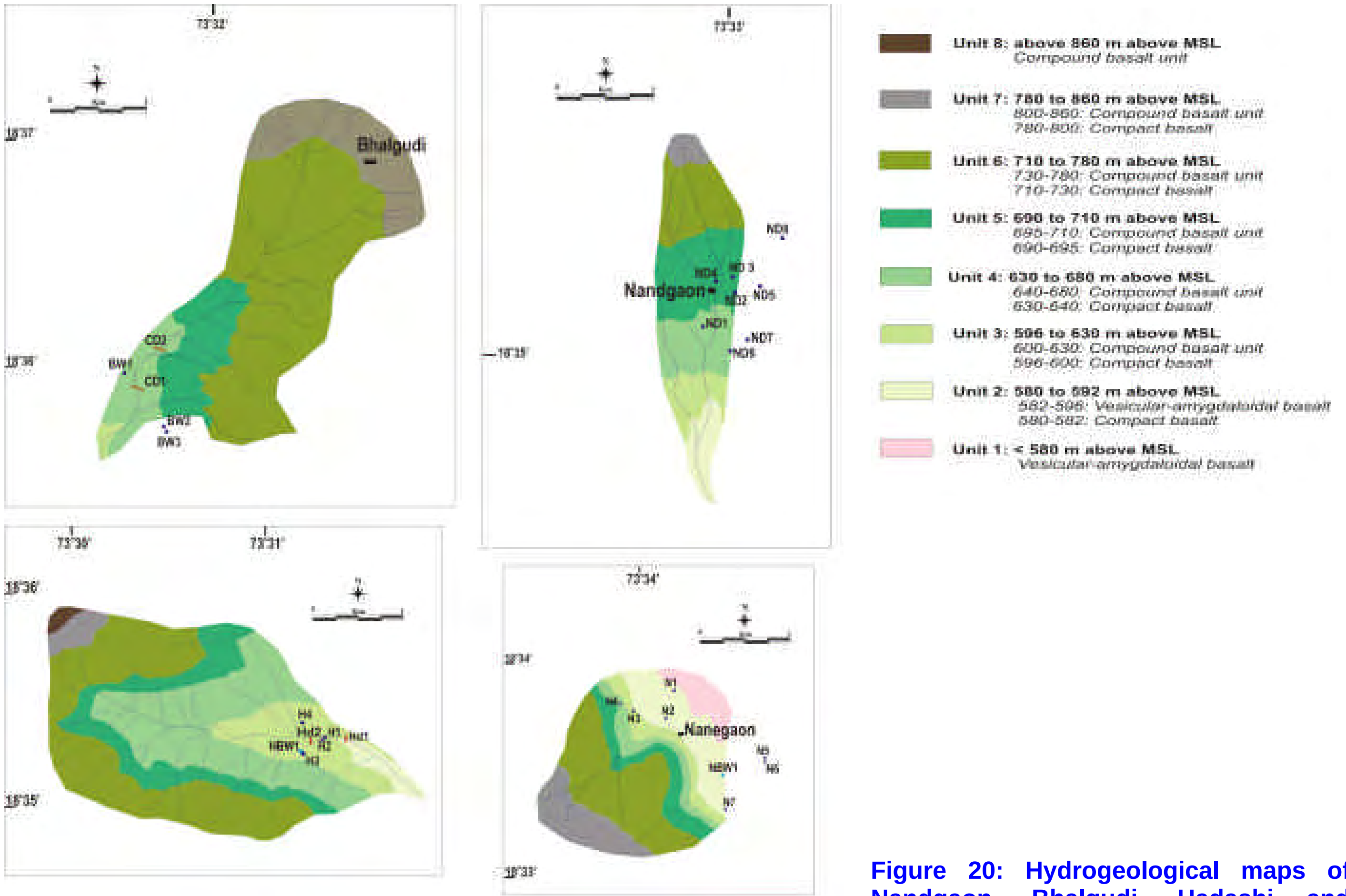


Figure 20: Hydrogeological maps of Nandgaon, Bhalgudi, Hadashi and Nanegaon watersheds *(including wells and check dams used for monitoring on the AGRAR project)*

2.4.2 Socio-economic setting

There are 18 villages in the Walki river basin. Out of these only five villages have been selected for the AGRAR study. These five villages are Bhalgudi, Chikhalgaon, Hadashi, Nandgaon and Nanegaon, for which the respective watersheds were monitored as mentioned above. Figure 21 indicates the location of villages selected for studies under the AGRAR project with respect to Kolwan river basin. Some socio-economic details of these villages are provided below.

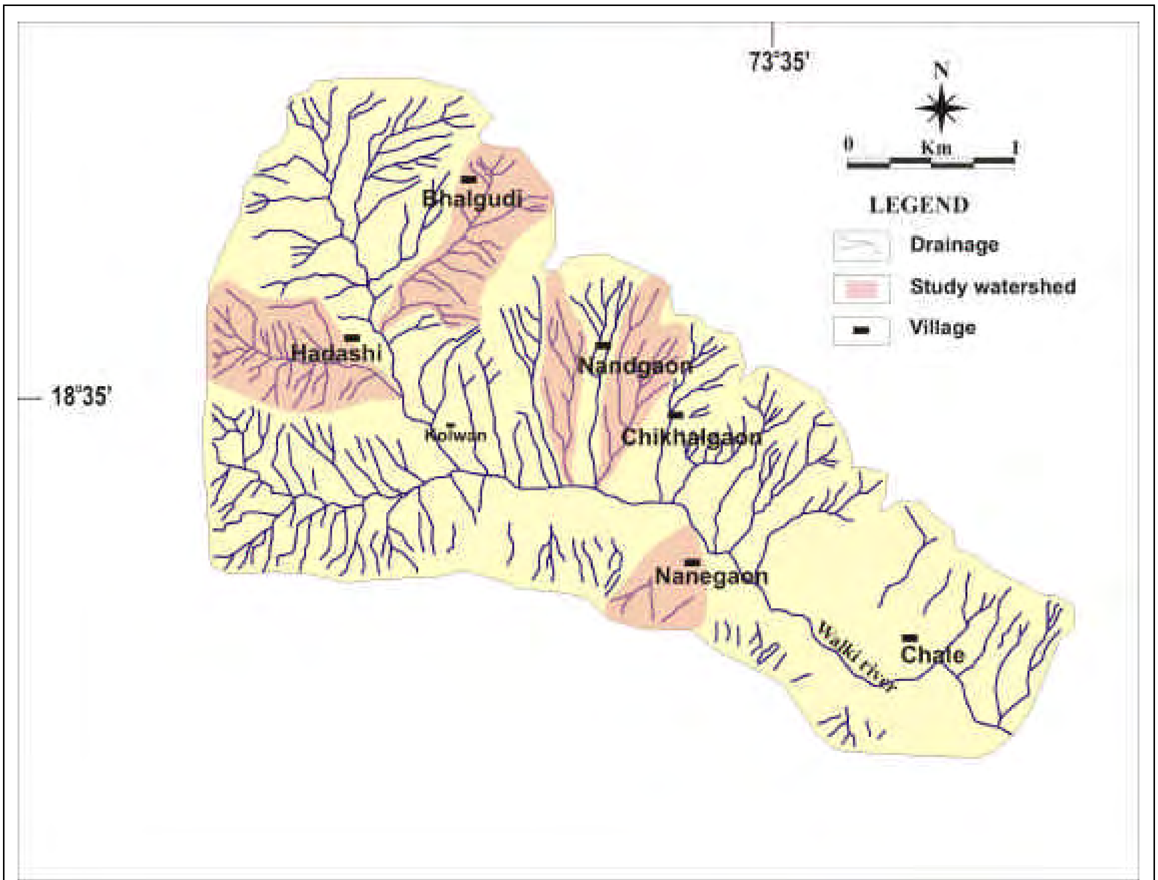


Figure 21: Map showing watersheds and location of respective villages in Kolwan valley *(watershed boundaries on this map are approximately shown)*

2.4.2.1 Population

With a population of 1014, Bhalgudi is largest village from among the five study villages. Nandgaon and Hadashi with populations of 978 and 943 respectively come next. Chikhalgaon and Nanegaon have populations of 764 and 604 respectively (Maharashtra Census Directorate, 2005). In four out of the five villages, the male population is less than the female population. The sex ratio in Chikhalgaon, Hadashi, Bhalgudi, Nanegaon and Nandgaon is 1164 , 944, 1121, 1134 and 1016 females respectively, to 1000 males. The SC/ST population in all the five villages is less than 10% (Figure 22). Table 8 indicates population data for the five project villages.

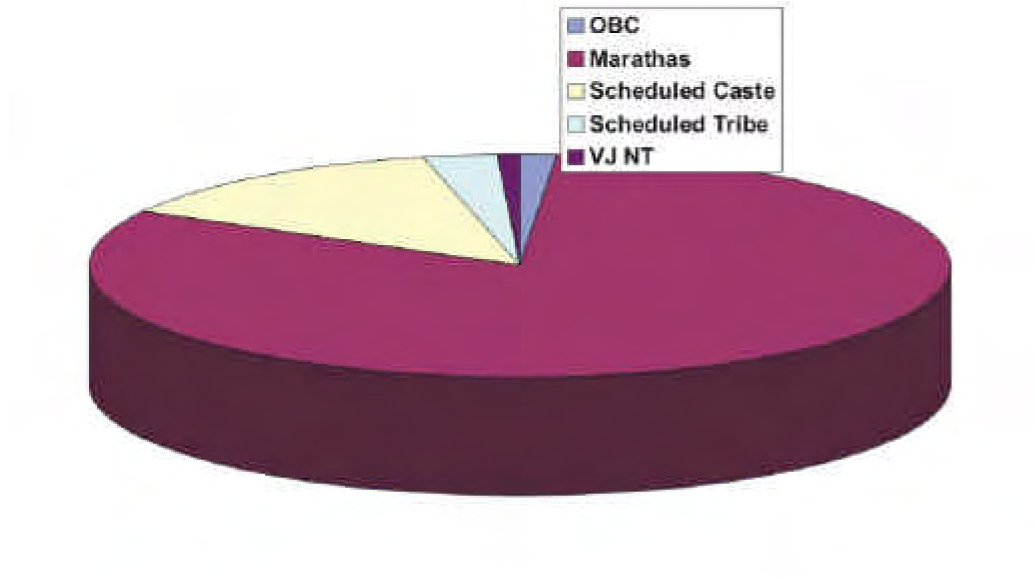


Figure 22: Castewise breakup of population from the AGRAR study villages
(Maharashtra Census Directorate, 2004)

Table 8: Population in five villages (as per 2001 census, *after* Maharashtra Census Directorate, 2005)

Village	Number of households	Population (number)		Household size	SC population	ST population
		Male	Female			
Chikhalgaon	148	353	411	5.2	9	8
Hadashi	158	485	458	6	94	18
Bhalgudi	172	478	536	5.9	106	0
Nanegaon	123	283	321	4.9	54	28
Nandgaon	162	485	493	6	92	15

SC= Scheduled castes; ST= Scheduled tribes

Table 9: Population in five villages (as per 1991 census, *after* Maharashtra Census Directorate, 1995)

Village	Number of households	Population		
		Total	Male	Female
Chikhalgaon	140	738	341	397
Hadashi	133	835	421	414
Bhalgudi	162	1058	488	570
Nanegaon	122	690	320	370
Nandgaon	143	915	442	473

Data for 1991 to 2001 indicate there has not been a significant change in the population figures for the five villages. Chikhalgaon and Nandgaon indicate an increase of 3 to 5% in the population. In Hadashi the population has increased by almost 13% while in Bhalgudi and Nanegaon there is a decline of 5% and 13% respectively. Large tracts of land in Hadashi have been sold to people from outside Kolwan valley, especially during the last 8-10 years. These lands are now used for intensive commercial purposes like plantations, intensive commercial farming like floriculture and irrigated agriculture. In Bhalgudi, there has been a steady migration to the cities of Pune and Mumbai for employment and education. In case of Nanegaon, lands have been sold to the people from Pune city, on a large scale, attributing decrease in population as some sellers permanently moved off to cities.

There has been a significant increase in the rate of literacy in all five villages (Figure 23). The literacy rate in Chikhalgaon, Hadashi, Bhalgudi, Nanegaon and Nandgaon has gone up by 31%, 29%, 27%, 13% and 38% respectively. Census data also indicates that there is also an average increase of 29% in the female literacy rate in the five villages.

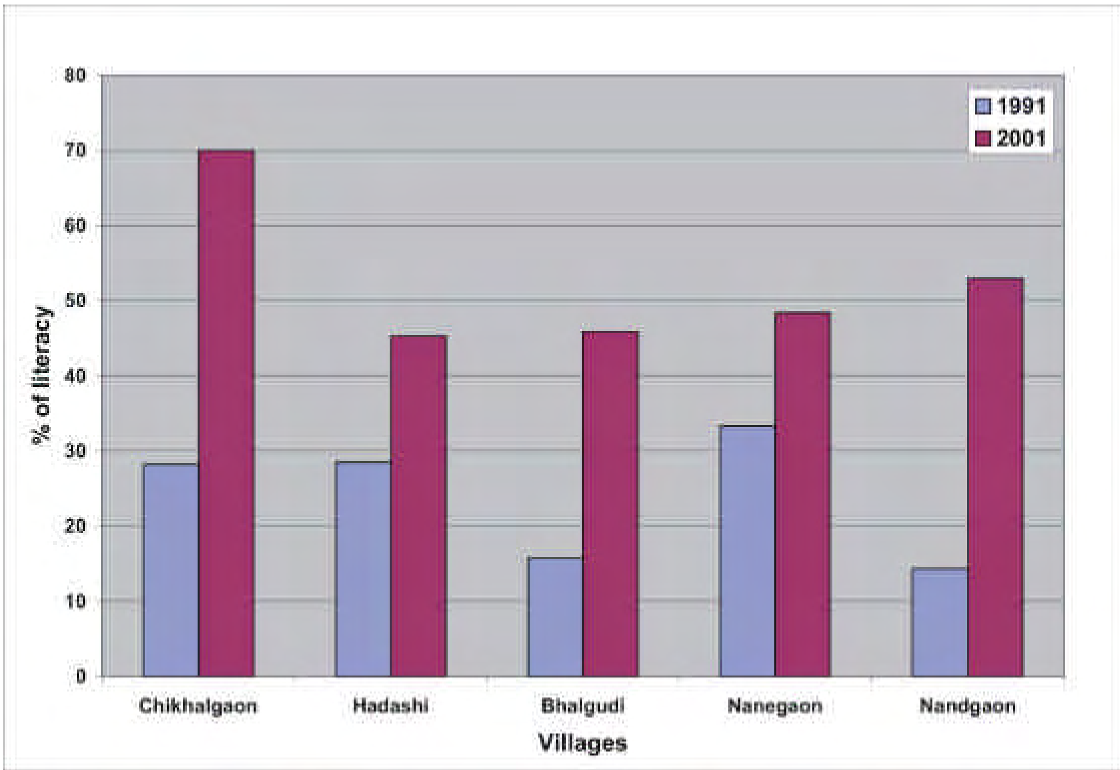


Figure 23: Increase in literacy rate between 1991 and 2001 *(after Maharashtra Census Directorate, 1995 & 2005)*

2.4.2.2 Livelihoods and occupation

Agriculture is the major occupation of the people of Kolwan valley and this is in agreement with statistics for Mulshi taluka. Around 80% population is involved in this activity. Most of the people cultivate their own land. The average land holding per household was 1.45 ha, of which the 0.95 ha was cultivable land (based on socio economic bench-mark survey of ten villages from Kolwan area-part I, (*Empirical Research Agency Pvt. Ltd. report, 1996*). In all the five villages it was observed that the percentage of female cultivators and agricultural labourers was more than their male counterparts. Again, in the absence of concrete data, one may presume that more male members tend to work on occupations outside agriculture. *Table 9* indicates the work distribution in the five villages as per 2001 census.

Table 9: Work distribution in five villages (*Maharashtra Census Directorate, 2004)*

Village	Cultivators		Agricultural Labourers		Workers in household industries		Other workers	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*
Chikhalgaon	74.6	86.9	1.8	2.1	0.6	0.5	23.1	10.5
Hadashi	84.2	89.1	6.1	7.8	1.1	1.6	8.6	1.6
Bhalgudi	79.1	82.1	4.7	11	1.6	2.3	14.6	4.2
Nanegaon	79.1	83.1	2.1	7	2.6	1.5	16.2	8.5
Nandgaon	66.3	75.1	10.3	14.5	0.3	0	23	10.4

Agriculture is the main source of income in the valley. The other major sources of income are livestock, service and business. The average livestock per household was 2.69 (*Empirical Research Agency Pvt. Ltd. report, 1996*). Some people have been working in cities like Pune and Mumbai for some years now. There are very few people engaged in tertiary activities like transport and shop keeping. The average annual income per household was Rs.26323/- (*Empirical Research Agency Pvt. Ltd. report, 1996*). It was observed that the percentage of female cultivators has gone up by 50% in all the villages since the last census. There has been an increase of Rs. 5000/- to Rs.7000/- in the average annual income per household in the valley, since 1991, based on the sample household surveys conducted as a part of the AGRAR project. Discussion with villagers indicated that some degree of livelihood diversification per household has occurred since 1991, primarily in response to increased literacy rates and improved education opportunities. However, despite such diversification, most households hold on to agriculture as the main occupation.

2.4.2.3 Land use, cropping and irrigation pattern

Some 400 to 800 ha in each village is area under revenue land (commonly referred to as village area) for most villages in the valley. The area near the river is plain and is mostly used for agriculture. Some forest areas are also part of some villages. *Table 10* shows the distribution of land under various heads for the five project villages.

Rice, jowar (sorghum), wheat, sugarcane and vegetables are the major crops grown in the valley. In villages like Hadashi, a larger livestock implies growing of fodder crops on large areas. Orchids are planted on the mountain slopes in villages like Nanegaon, where soil thickness is consistent. Rice is mainly a kharif (rainfed) crop grown during monsoon. Along with rice, jowar (sorghum) and some pulses are also grown, especially on field bunds during the rainy season. Wheat used to be the major irrigated crop grown during winter, some years back. In the last few years, there has been a steady increase in the cultivation of vegetables like potato, tomato and peas during the rabi (irrigated) season. Sugarcane is the major 'annual' crop grown since the last five years, especially after increased irrigation facilities.

Table 10: Land distribution in the five study villages ((as per 1991 census, *after* *Maharashtra Census Directorate, 1995*)

Village	Area (in ha)	Forest	Irrigated land	Unirrigated land	Cultivable waste	Area not suitable for cultivation
Chikhalgaon	400.01	16.43	--	163.28	144.07	76.23
Hadashi	773.11	103.21	--	116.13	413.21	140.56
Bhalgudi	617.33	149	1	9.06	306.63	138.64
Nanegaon	404.72	--	--	269.47	58.06	77.19
Nandgaon	499.51	--	--	333.30	--	166.21

Until the year 2000, irrigated crops were grown in the area adjacent to the Walki river. The major irrigated crops grown were sugarcane and wheat. But now there is a noticeable change in irrigated cropping. More upstream farmers in the area are planting irrigated crops, using 'lifts' from the river. There are some 100 lifts in the entire Kolwan valley. Out of these 7 to 8 are 'water user associations' promoted by GOMUKH. The length of a lift is as much as 3 km, *e.g. the Sarpanch's lift in Chikhalgaon*. A few farmers are increasingly using wells and springs as sources of irrigation. In Bhalgudi, Nandgaon and Chikhalgaon groundwater is used as a significant source of irrigation, although lifts from the river continue to be more popular and widespread. Vegetables are grown on a large scale, especially where groundwater irrigation is available. Only 1% families had irrigation facilities in 1996 (*Empirical Research Agency Pvt. Ltd. report, 1996*).

2.4.2.4 Sources of water

Walki river is the main source of water for the Kolwan valley. The river is nearly perennial, in the sense that there is flow in parts of the river during the whole year now. It is reported that the river used to run dry during the winter season some ten 15-20 year ago. There are a number of check dams constructed along its course in the form of water impounding structures, some by GOMUKH. There are three minor irrigation tanks constructed in the upstream area at Hadashi and Walen. Two of these tanks (Hadashi MI tank 1 and Walen MI tank) were constructed between 1986 and 1992. Hadashi MI tank 2 was constructed in 1998.

Water is released from these tanks during the dry season, which keeps the river flow nearly perennial. River water is used for domestic purposes as well as for irrigation. More than 60% of irrigated crops are supported by lift irrigation schemes from the river (*Empirical Research Agency Pvt. Ltd. report, 2004*). There are a number of dug wells in the Kolwan valley. It is estimated that there are some 100 wells in the valley. The 32 dug wells in the five study villages (monitored in the AGRAR project) are mainly used for domestic purposes and irrigation. GOMUKH has identified 126 springs in Kolwan valley, some of which are used for irrigation, while others are used purely as drinking water sources. There are a few boreholes in the valley. Some are used for irrigation but these are few and far between. In villages like Chikhalgaon and Nanegaon, drinking water is provided by the Gram Panchayats, through community taps that draw water from elevated storage reservoirs, which in turn are fed by dug wells located near the Walki river. Besides these there are a number of structures constructed by the Government and GOMUKH in the valley. The farmers owning land near some such structures use this water for irrigating their crops. Groundwater use for irrigation (springs and wells) is reported to have increased but its relationship with artificial recharge is difficult to quantify in light of other impacting factors.

2.4.2.5 Changes in livelihood trends

Livelihoods are changing in the Kolwan valley, slowly but surely. In a nutshell, the following livelihood changes were observed in the valley during the last six years or so.

1. Average land holding has decreased as compared to that reported at the time of the baseline study by GOMUKH. This may be the result of numerous land transactions taking place in this area. Almost 17 % of the total sample of 1300 households had reported land sale during the baseline survey *(Empirical Research Agency Pvt. Ltd. report, 1996)*.
2. The average family size has increased as compared to that at the time of the baseline survey. This may be due to reverse migration that has taken place during the past few years.
3. Improved living standards of people are noticed during the last few years. This is evident from the fact that the number of *pucca* (well-built) houses has increased by almost 35 % as compared to the baseline survey done prior to the watershed project. Similarly, there is a 6 % increase in the households reporting availability of latrine facilities.
4. There is a significant change in the cropping pattern in the valley. Earlier only 1% farmers in the valley were growing rabi (irrigated, winter) crops. At present, 36% have reported growing wheat during this season and almost the same percentage has started growing vegetables, while 26% have shifted to sugarcane.
5. The average income shows an increment of Rs. 3000/- as compared to the baseline survey. On the other hand, the families depending on labour income have

reduced to 13 % from 40 % at the time of baseline survey. This is in contrast to the figures presented earlier for Mulshi taluka, as a whole, where proportion of people with agriculture as an occupation has reduced, at the same time indicating an increase in the proportion of farm labourers.

6. The availability of water in summer during the last 6 to 7 years has meant increase in the amount of green fodder for livestock in the valley. There is a 22 % increase in milk production in the five study villages.

2.4.2.5 Local Institutions

There are 55 women's Self Help Groups (SHGs) in the valley for mobilizing women, helping them achieve economic independence and thus enhancing their social standing. In addition, 10 village watershed committees, 20 Self help groups consisting of women were started during the last few years. Some 100 water users' associations around lift irrigation schemes are functioning in Kolwan valley. These associations were set up either through villagers' own initiative or through GOMUKH's efforts. However, there are no such institutions around artificial recharge structures like CD3 in Chikhalgaon.

2.5 RECHARGE STRUCTURES

Three check dams were constructed along the mainstream in Chikalgaon watershed as a part of GOMUKH's watershed development programme implemented in 1997-98. Out of these, CD1 is an earthen check dam whereas CD2 and CD3 are masonry check dams (refer Figure16). CD1 has a top width of 33.5m with a separate concrete masonry spillway that has a top width of 6 m. CD2 is masonry structure with a top width of 25.8m and is located at a distance of 200m upstream of CD1. CD3 is also a masonry structure with a top width of 22m. It is located some 500 m upstream from CD2. The masonry check dams CD2 and CD3 are 'top-over' structures with their spillways designed as rectangular weirs on their crests.

Check dam CD2 in Chikhalgaon, overflowing during the monsoon.

The structures were constructed by GOMUKH as a part of the watershed development programme in Chikhalgaon watershed. They were funded under the Drought Prone Area Programme (DPAP). GOMUKH acted as the project-implementing agency (PIA). The guidelines of the DPAP are implemented through either the district administration (Zilla Parishad) or through the District Rural Development Authority (DRDA).

All the structures that were monitored under the AGRAR project have the same background as the Chikhalgaon structures. Two check dams in Bhalgudi and two in Hadashi formed the satellite structures used for comparison to the in-depth monitoring in Chikhalgaon. The Hadashi structures (HD1 and HD2) are gated structures and receive both natural stream flow as well as releases from Hadashi MI Tank 2. The structures in Bhalgudi (BCD1 and BCD2) are masonry structures, similar to the Chikhalgaon structures. All the structures were monitored on a weekly basis where stage heights were measured. The Chikhalgaon structures, whenever required, were monitored on a more frequent (hourly or daily basis) to capture short and sharp runoff events. However, the satellite structures were monitored only on a weekly basis.

3 Methodology

3.1 INTRODUCTION

Data collection at the AGRAR case study site in Kolwan valley was based upon the AGRAR Guidelines for Field Work (Gale et al, 2003). This chapter describes, in detail, the methodology of data acquisition at the field site in Kolwan valley. Secondary information (presented in Chapter 2) was obtained from Government agencies as well as from information available with GOMUKH. Secondary information was obtained after interacting with Government officers and has been duly acknowledged wherever it is quoted in this report. The sources of such information have been appropriately referenced at the end of the report, in the section labeled references.

Despite a large quantity of secondary data collected in India, access and utilization of such data are not always easy (Batchelor et al, 2000). Having said that, it was a real challenge to bring in secondary information on various aspects like hydrology, geology, agriculture and demography because of reasons like fragmentation of data, varied data formats, 'scale' factors and variability of a single data set obtained from different sources. This constraints are not discussed in the report, but have been mentioned, wherever they are of direct relevance to the results.

Secondary and primary data (where necessary) were subjected to ground truthing. These data were then stored either in the form of maps or in the form of a database (mostly as Microsoft Excel spreadsheets). Analysis was carried out using simple tools like charting as well as through software for specific purposes like water level data, pumping tests, water quality etc. These are described in detail later in this chapter.

Two special workshops that included AGRAR partners and a seminar on artificial recharge (held in Pune, in October 2004) were used to stimulate discussion and comments on results obtained at various stages of the project. Results, during all these meetings, were presented as Microsoft Power Point presentations. The discussions and comments led to incorporating new ideas, concepts and even information that would otherwise have been impossible to obtain and integrate into the report. Useful specific and generic information could therefore be incorporated into the report. Sharing of information across the three case study sites also proved beneficial because of individual strengths of the three organizations involved in conducting detailed research under the AGRAR project.

The methodology for the AGRAR case study in Kolwan valley included three components:

1) Background information, especially at the district, taluka and river basin scale (this information is described in Chapter 2).
2) Baseline physical surveys including geological, hydrological and hydrogeological aspects, followed by detailed spatial and temporal data acquisition pertaining to the relevant components of artificial recharge.

3) Socio-economic studies to understand the management and institutional frameworks within which artificial recharge measures were executed, specific water-livelihood aspects and an impact assessment of recharge measures on the livelihoods of village communities at the site.

3.2 BASELINE PHYSICAL SURVEYS, MONITORING AND GROUNDWATER MODELLING

The aim of the physical aspect of the AGRAR case studies was to quantify all relevant aspects of the hydrological system within the watershed and specifically in and around the recharge structure and in doing so, to understand the physical processes that impact upon water resources, especially groundwater at the study site as well as in the river basin. The importance of artificial recharge measures, especially in watershed development programmes, is clearly an accepted fact and forms an integral part of project implementation. However, the scientific implications of recharge measures on the resource base, i.e. water resources in general, and groundwater, in particular, have not been fully understood. In order to achieve a complete understanding of artificial recharge of groundwater in a Deccan basalt aquifer, the following methodology was adopted at the Kolwan valley site.

3.2.1 Baseline physical surveys

Baseline physical surveys in the Kolwan valley were undertaken on three different scales, namely the river basin scale, the watershed scale and the recharge structure scale (refer chapter 2). The ACWADAM team conducted these physical surveys, with field-support from GOMUKH. The methodology involved the following steps during the preliminary investigations:

- Reconnaissance surveys of the Kolwan valley, using Survey of India Topographic Sheets (mainly 47 F/10 and part of 47 F/6), on the scale of 1: 50000. Preparation of base maps on various scales using these topographic sheets
- Study of Geological Survey of India (2001) District Resource Map for Pune district.
- Study of Remote Sensing Data (from Landsat-TM, IRS-1B, IRS-1C and P4 satellites).
- Detailed geological field surveys to determine the nature and disposition of basalt lavas in the basin and to map these units on a map. In addition, these surveys also included determining the type of lineaments identified from the study of remote sensing data through detailed groundtruthing.
- A detailed inventory of water features including drainage lines, wells and boreholes, habitations, land-use features and watershed development measures including recharge structures.
- Regional mapping (on river basin and watershed scales) was undertaken using a Global Positioning System (GPS).

- Precision mapping (recharge structure scale) was done with the help of surveying instruments, compasses and a Paulins' altimeter (to cross check elevations).
- The elements of the baseline physical structure monitoring included the geology, topography water features and other geographic features of relevance. These elements are described below.

3.2.1.1 GEOLOGY

ACWADAM has been working on the hydrogeology of Deccan basalt in many areas of Maharashtra and India. Regional information on the extent of the Deccan basalt as well as district level information was obtained from secondary sources. The geology of the Kolwan valley was mapped in the field using topographic sheets, which formed the primary tool for generating base maps on various scales. Geological transects in different parts of the Kolwan river basin were used to map the geology onto these base maps. The mapping involved identification of all the basalt units exposed in the basin from the ridges to the river channel. The lavas in this region are horizontally disposed and therefore, the contacts between different basalt units correspond to specific contour lines, although locally undulations do exist. However, these undulations are within 1-2 m with respect to their regional disposition (contour value). These contacts were identified and mapped. Satellite data from the Indian Remote Sensing Satellites (IRS-IB, IRS-IC and IRS-P4) was used to identify lineaments, for which ground-truthing was subsequently done to ascertain the nature of these lineaments. The geological mapping in Kolwan valley was conducted on the scale of 1: 50000.

Regional mapping was cross-checked with detailed geological and hydrogeological mapping in each of the five watersheds selected for monitoring. Hence, the geology of each watershed was also mapped through a thorough field mapping in these watersheds. Watershed mapping was conducted at a higher scale (at a scale of about 1 : 25000) than the geological mapping of the river basin. The geological mapping on the scale of each recharge structure was conducted elaborately, approximately at the scale of 1 : 10000. Minor variations, on the watershed and recharge structure scale were mapped, especially with regard to the weathering, jointing and fracturing patterns in the basalt units. Surveys, including resistivity soundings were conducted to determine the subsurface configuration of the basalt units, especially in the vicinity of recharge structures. These details were used in the development of a conceptual hydrogeological model described later in this chapter.

The entire geological field mapping exercise was conducted by ACWADAM, drawing also on the experience of some its founder trustees who have been involved in work related to various aspects of Deccan basalt geology (Deolankar, 1980; Peshwa et al, 1987; Kale and Kulkarni, 1992; Kale et al, 1992; Lalwani et al, 1995; Kulkarni et al 2000).

3.2.1.2 TOPOGAPHY

Toposheets, on the scale of 1: 50000, were used to determine the regional topographic picture of the Kolwan valley. The contour interval for the regional mapping was 20 m. However, at the scale of watersheds, rapid surveys were conducted to modify base maps prepared from the toposheet. The topographic maps of the five study watersheds are presented at a contour interval of 20 m. The topographic map for Chikhalgaon watershed (where the main recharge structure is located) was prepared using toposheet data combined with surveys using levelling instruments.

All the three check dams in Chikhalgaon were surveyed using levelling instruments, with surveys carried out on a close-spaced grid, at the contour interval of 0.3 m. Data from these surveys was used to prepare maps, both by graphical plotting on drawing sheets and using the software AutoCAD 14.0 and SURFER 7.0 (Figure 24). The drawings and software plots were found to be in close agreement with each other.

ACWADAM and GOMUKH conducted topographic surveys jointly. GOMUKH engineers conducted dumpy level surveys on a grid basis, whereas altimetric surveys using toposheet data and the plotting of all data was carried out by ACWADAM.

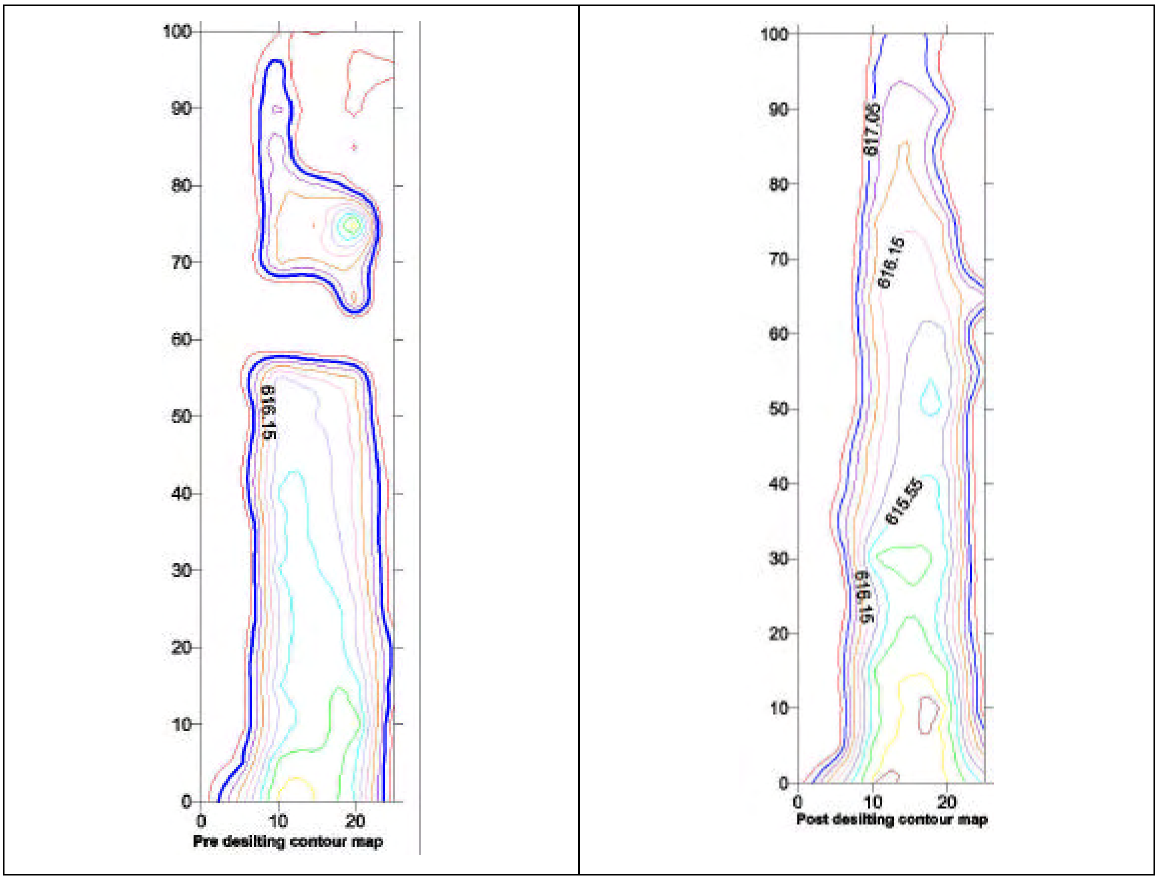


Figure 24: Contour map for CD3, prior to and after desilting in May 2004. Contours in the map correspond to levels of decline of water levels in the dry seasons for 2003 (pre desilting state) and 2004-2005 (post desilting state)

3.2.1.3 WATER AND OTHER GEOGRAPHIC FEATURES

A base map containing drainage lines, wells, boreholes, habitations, roads, agricultural and forest land was prepared using the topographic sheet, on a scale of 1: 50000 (Figure 6, Chapter 2). Further, the geographical disposition or location of these features was confirmed through detailed GPS (Global Positioning System) surveys in each of the five watersheds as well as in some other selected locations in the Kolwan valley. GPS surveys were found to give reliable locations (geographical co-ordinates in the form of latitude and longitudes) but were found to have a limited accuracy as far as the measurement of elevations with respect to mean sea level were concerned. Hence, only the latitude and longitude values were used to plot features on various thematic maps.

Well head and other elevations like measuring points on check dams and boreholes were estimated using close grid surveys combined with altimeter surveys (using a Paulins' altimeter with a least count of 1 foot, i.e. 0.3 m).

Satellite data for 1986 (Landsat-TM), 1992 (IRS-1B), 1998 (IRS-1C) and 2004 (IRS-P4) were used to map significant changes, especially in land and water features such as reservoirs, roads and vegetation. Satellite data were also used to correct changes that have occurred to toposheet data between toposheet surveys (1971 or earlier) and subsequently. All the above remote sensing images were procured in both digital and hard-copy (print) formats. The details regarding satellite data are given below in *Table 10.*

Table 10: Satellite data used in the Kolwan valley case study

Satellite	Sensor	Date of image	Scale
LANDSAT	Thematic Mapper	20 December 1986	1: 50000
IRS-1B	LISS-II	13 January 1992	1: 62500
IRS-1C	LISS-III & PAN (merged)	1 February 1998	1: 25000
IRS-P6	L3	25 January 2004	1: 25000

ACWADAM planned and executed the regional and local mapping exercises, with special emphasis of water features such as streams, rivers, check dams, wells etc. The fieldwork to collect relevant information and take measurements was jointly undertaken by ACWADAM and GOMUKH.

Drainage lines were obtained from topographic maps but were verified through satellite images for changes in alignment, if any. Drainage maps and topographic maps were used to plot watershed boundaries for the five watersheds chosen for watershed-scale studies. Watershed boundaries were then further verified by ACWADAM and GOMUKH staff, who ran traverses along ridgelines, using natural and anthropogenic landmarks as benchmarks to verify these maps.

3.2.2 Hydrological Monitoring Infrastructure And Protocol

Impacts of interventions on a water resources base remain unquantified since data is rearely available to assess these impacts (Dougherty and Walmsley, 1995). Gauging the precise impacts of artificial recharge structures on the underlying aquifers as well as attempting to assess the broader changes taking place on various scales due to artificial recharge requires a well-planned monitoring infrastructure and protocol. A knowledge base, an inference engine and a user-interface is necessary while evolving an 'expert system' in analysing the impacts of watershed development, especially artificial recharge (Samaj Pragati Sahayog, 1994). Setting up a comprehensive monitoring framework in the Kolwan valley, bearing in mind the project objectives was a challenge, especially considering the rugged terrain and difficulty in accessing some locations.

Using ACWADAM's experience in setting up hydrogeological monitoring processes in the Deccan basalt region as well as in other parts of India (ACWADAM, 2001), a systematic groundwater monitoring process was set up in the Kolwan valley. However, to capture various other dimensions of artificial groundwater recharge, a more exhaustive monitoring infrastructure was desired. This infrastructure was established on the basis of the AGRAR guidelines for field work (Gale et al, 2003) and the practical introduction provided in the book by Gunston (1998). In fact, the broad process followed at the Kolwan valley site was based on the following activities (after Gunston, 1998):

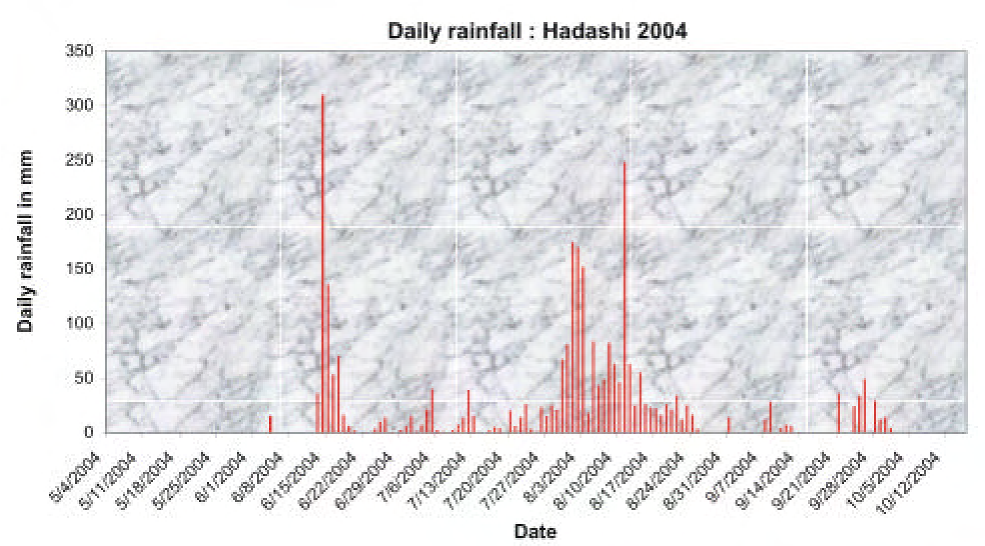
1. Planning instrument and monitoring networks.
2. Installing and maintaining equipment.
3. Co-ordinating the regular collection and recording of data.
4. Smooth and safe movement of field data to ACWADAM's offices.

3.2.2.1 WEATHER DATA

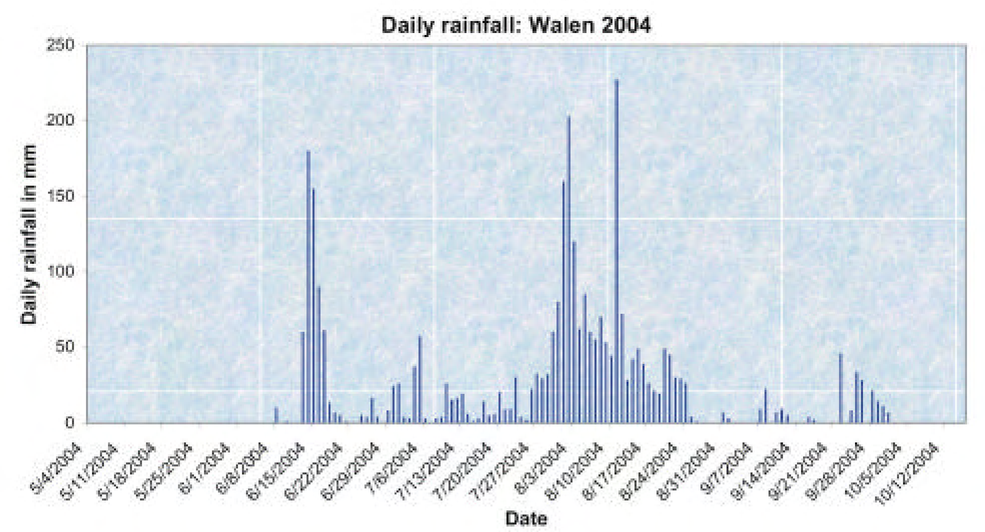
Reconnaissance studies carried out during the planning phase of the AGRAR project revealed the following:

1) Absence of comprehensive meteorological data (apart from two rain gauge stations near two of the three minor irrigation tanks in the valley, i.e. for Walen and Hadashi-1).
2) A manned weather station (Irrigation Department, Government of Maharashtra) at Karmoli, near the tail end of the Walki river had daily data for all weather parameters.
3) Rainfall data from the three stations mentioned above indicated a high degree of variability in rainfall across the river basin, necessitating establishment of a few more raingauge stations.
4) The variation in the elevation across the valley is of the order of 720 m, indicating the possibility of variations in other weather parameters as well.

Rainfall variability is evident for the data for the three stations existing in the area prior to the AGRAR project. Data collected during the period May to October 2004 is presented in Figure 25, wherein it is obvious that not only is the total rainfall during the monsoon different, but there is also an obvious difference in the day to day rainfall during the season (*also refer Figure 11*, *chapter 2).*



A



B

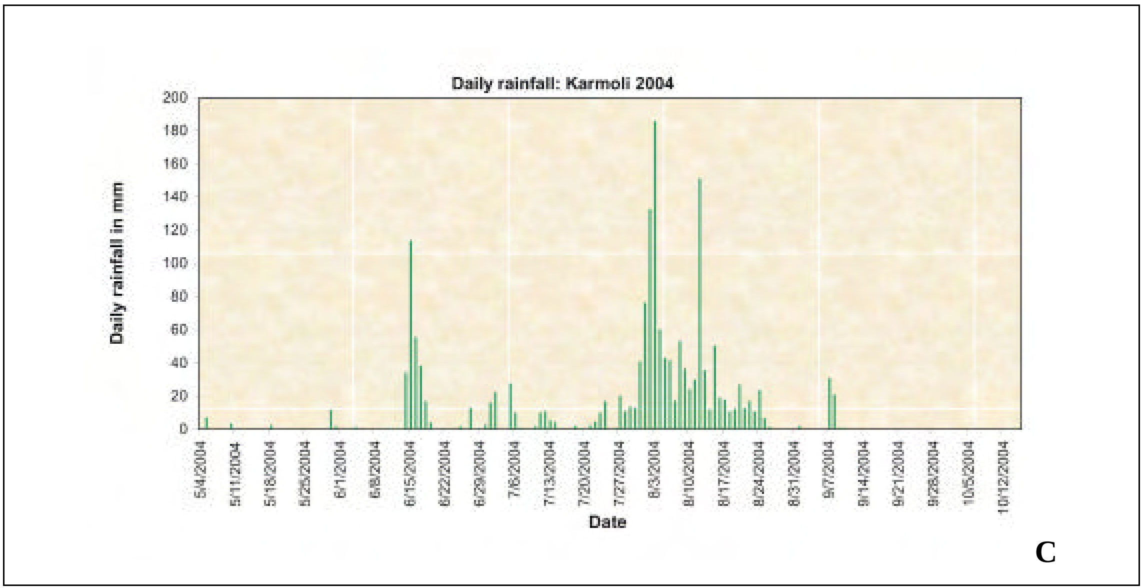


Figure 25: Rainfall variability in Hadashi (A), Walen (B) and Karmoli (C)

Bearing in mind the above factors and taking into account budgetary considerations, one automatic weather station (near the main site in Chikhalgaon), 4 rain gauging stations and 2 evaporimeters were ordered, calibrated (at the Regional Weather and Climate division of the Indian Meteorological Department-IMD in Pune) and installed in the Kolwan valley between November 2003 and March 2004. The locations of these gauging stations are depicted in Figure 26.

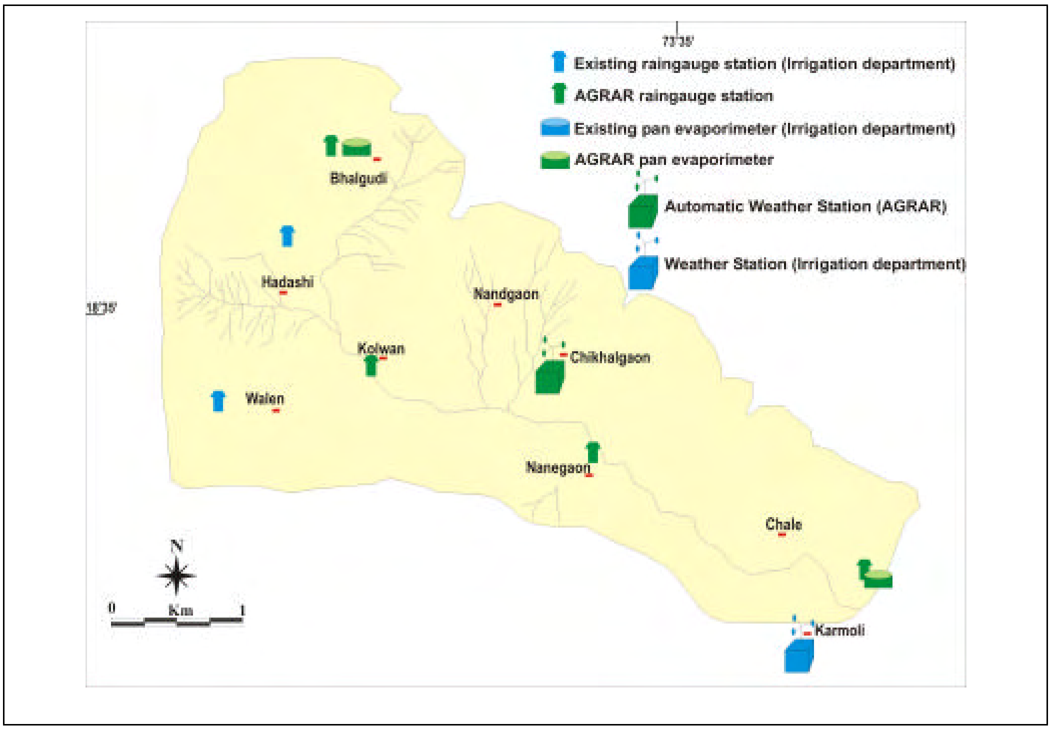


Figure 26: Location of all gauging stations in Kolwan Valley

Automatic weather station in Chikhalgaon

An Automatic Weather Station (AWS) was installed in Chikhalgaon on 8 November 2003. Due to constraints imposed by difficulty in access, security and power supply, the AWS site had to be placed some 500 to 600 m from CD3, the main recharge structure around which monitoring was done in great detail. However, considering the overall conditions within the Chikhalgaon watershed, the observations at the AWS were safely assumed to represent conditions that are in close agreement to those prevailing around CD3. The AWS was installed in Chikhalgaon village, on village common land, behind the nursery school and close to the secondary school. The installation was done by DYNALABS, an experienced firm dealing in climatological measurement instrumentation (recommended by IMD, Pune). GOMUKH constructed the security fencing, through a participative process involving the Chikhalgaon community, which was kind enough to donate the village land for the said purpose. ACWADAM supervised the whole operation.

The AWS is powered by a solar panel, with a battery back-up, considering the unreliable electric supply in the area. However, there were some constraints in alternating between solar and battery power, especially during the rainy season, causing some loss of data. Danger from rodents was an ever-impending problem and despite precautions, rats chewed into the power cable once, again resulting in loss of some data. Despite these minor hiccups, the AWS functioned effectively and was able to deliver data that enabled calculation of various parameters like empirical evaporation. It also provided useful indicators on variability in various parameters over different periods.

Rain gauges and evaporimeters were installed by DYNALABS on the boundary between Bhalgudi and Kashig villages, at Kolwan, in Nanegaon and in the premises of GOMUKH's Cold Storage and Green Peas Processing Plant near Chale. This monitoring infrastructure was meant to produce data representative of conditions (including variability in rainfall and evaporation) in the Kolwan valley.

Evaporimeter and rain gauge installed at Chale

In addition to providing data for the AGRAR project, the AWS is being perceived as a major milestone in providing useful information to the village folk as well as giving some degree of exposure to school children as well as visitors to GOMUKH and ACWADAM. ACWADAM and GOMUKH hope to disseminate some of the information as a tool to increase village participation in developing scientific understanding about hydrological and hydrogeological systems in Kolwan valley, especially as a follow-up on the AGRAR project. The AWS consists of a 12-channel data logger with the following sensors.

1. *Air temperature sensor with weather shield.*
2. *Relative Humidity sensor with weather shield.*
3. *Rainfall sensor.*
4. *Solar Radiation sensor.*
5. *Evaporation sensor.*
6. *Wind velocity sensor.*

Acquisition of data for these parameters was set to a frequency of 15 minutes, the data logger collecting and storing all these data at an interval of 15 minutes. For the purpose of analysis, however, the data was converted to averages for one hour, which in turn, was used to compute daily values, wherever desired. Rainfall data from the 7 remaining rain gauge stations was collected on a daily frequency, between 8.00 and 9.00 am each morning. It was ensured that all rainfall data from these stations was 'thrown back' because a larger time period for the data (15-16 hours) belonged to the day previous to that of data recording.

Pan evaporimeters installed at two locations (apart from the one in the AWS) was recorded twice a week due to constraints relating to human resources commissioned for the project. However, the recording personnel strictly maintained the twice a week routine of collecting evaporation data from the pans. Average daily evaporation was computed using the compounded evaporation for 3 or 4 days.

Data from the AWS was brought to ACWADAM's office, in Pune, every week (generally on Fridays) using a set of two memory modules, each one functioning for a week. The data was downloaded, initially at GOMUKH's office in Chale village and then at ACWADAM's office in Pune, but later only at ACWADAM's office due to interrupted electric power supply to computers at Chale.

Data from the AWS was used to compute the following parameters, which were subsequently used in the calculation of water balances at various scales:

a. Daily rainfall

b. Daily evaporation (from pan)

c. Daily evaporation from other weather parameters (*using the Penman, 1948 & 1963; Shuttleworth, 1993 methods*)

Data from other raingauges and pan evaporimeters were used to compare rainfall and evaporation values between different sites. This helped obtain an overall idea about the variability in these parameters across the valley as well as to attempt calculation of a regional water balance for the Kolwan valley.

3.2.2.2 GAUGING AT RECHARGE STRUCTURE AND OTHER CHECKDAMS

A detailed topographic survey of the main structure (CD3), was carried out to enable calculation of volume changes and level, relative to other monitoring points like dug wells and observation boreholes. These topographic surveys were conducted twice for CD3, once before the silt was removed in April 2004 and immediately thereafter, so as to estimate the total silt volume deposited in the structure since 1998 (refer Figure 24, earlier in this chapter). A similar survey is planned early next year to ascertain the amount of silt deposited during the course of the period from June 2004 till January 2005 (when CD3 is expected to dry up). Similar surveys were also conducted for CD1 and CD2, the two check dams located downstream of the main recharge structure, i.e. CD3. Staff gauges were installed in all the three check dams to measure water level fluctuations for the estimation of volumetric changes in these structures during the wet and dry seasons. Staff gauges were installed in CD2 and CD3 during the monsoon of 2003, hence stage data from staff gauging for these two structures was available from October 2003 onwards. Staff gauging in CD1 was done only after June 2004 due to problems encountered in installation of the staff gauge during the monsoon of 2003.

A stilling well was constructed in CD3 for installing a continuous, stage-monitoring probe in May 2003. The actual installation of the continuous water level recorder could be completed only in September 2004 on account of technical difficulties in the design of the recorder. Despite this setback, stage measurements using the continuous recorder and staff gauge readings were compared for the period after September 2004 and were found to be in close agreement with each other. This comparison helped in computation of discharges over the weir for CD3 and also helped confirm overflow discharges for CD2 and CD1 downstream. Staff gauge and continuous recorder readings were also recorded after cessation of the monsoon rains and the overflow from CD3, to study the water level decline (and corresponding storage depletions in CD3). Also staff gauge readings in CD1 and CD2 helped estimate the storage declines during the dry season this year. Staff gauges were also installed on two check dams in Hadashi (HCD1 and HCD2) and two in Bhalgudi (BCD1 and BCD2).

Staff gauge and automatic water level recorded (stilling well) in CD3, Chikhalgaon

Constructing two rectangular weirs, using the columns and base of an abandoned aqueduct just at the inlet of CD3 helped monitor the inflow into the check dam CD3. Additionally, a 90° v-notch was fabricated and installed at the inlet to CD3. The rectangular weirs were used to monitor flows during the rainy season for large discharges. The v-notch was used to measure lean season flows, especially after cessation of the monsoon, i.e. during the decay in the storage of the check dam.

(a)

(b)

Inflow to CD3 measured using (a) 'V' notch and (b) rectangular weir

Inflow and overflow discharges from the check dams were first calculated using the discharge estimation tables and formulae provided in Driscoll (1986), i.e. using the Francis equation for flow over rectangular weirs and the Thompson equation for flow through the 90° v-notch. However, in the final calculations, the Herschy's equation (1995) was used as it seemed to provide more realistic estimates of discharge. The Francis and Thomson's equations seemed to provide very high estimates of flow over weirs and the v-notch. During the reconnaissance phase of the AGRAR project, observations to decide upon the frequency of measurements of inflow and overflow were made. These observations clearly indicated very small changes on a day-to-day basis, except during very heavy spells of rainfall (exceeding 50 mm /day) resulting in flood discharge events. Hence, the monitoring frequency for inflow and overflow measurement was set on a weekly basis and was jointly carried out by ACWADAM and GOMUKH staff. During the peak monsoon season, apart from the weekly readings, the field staff from GOMUKH's office at Chale separately monitored flood discharges and took readings even on a daily basis, wherever and whenever such readings were desired.

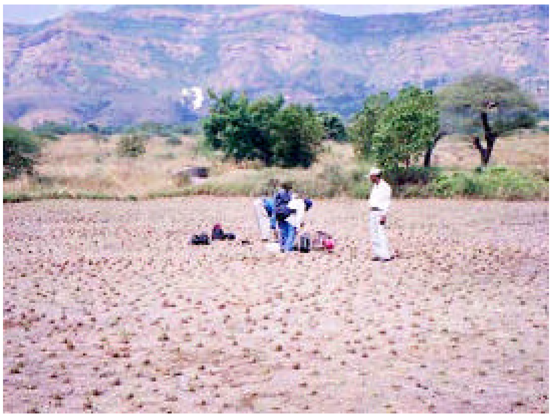
There was no direct abstraction of water from CD3. The other two check dams in Chikhalgaon, CD1 and CD2 were pumped a couple of times and the pumping volumes estimated from the discharge of the diesel pump used and the duration of pumping.

3.2.2.3 GROUNDWATER LEVELS

Nine observation boreholes were drilled near CD3 during the month of December 2003. Sites for the boreholes were selected by spacing them out at different distances from CD3, so as to study the effect of infiltration from the check dam with respect to directions and distances. The sites for these boreholes were selected primarily to ascertain the influence of the check dams on the water levels in the adjoining aquifer (?or vice versa). One of the boreholes was to be equipped with a continuous water level recorder but initial readings (taken manually) indicated little fluctuations at hourly and daily frequencies, unless prompted by a high rainfall or abstraction event. Budgetary limitations also implied that only one continuous recorder was feasible due to its high cost. This is was installed in the stilling well during the period that it held water. Subsequently, in early January 2005, it was moved to observation bore well BH7.

The sites for observation boreholes around the check dam were finalised after conducting electrical resistivity measurements and detailed geological observations of surface exposures and in existing dug wells. Vertical Electrical Sounding was carried out at four places in and around the CD3 to ascertain the depth of the shallow basalt aquifer and the variation therein. This was intended to decide completion depths for observation boreholes and also aid in developing a conceptual geological model of the shallow aquifer in the vicinity of CD3. Depth profile data were obtained at four sites by taking a series of resistance readings at different electrode spacings. Depths of 25 to 35 m were probed in these four resistivity soundings.

The Schlumberger array of electrode spacing using the Earth Resistivity Meter (ANVIC-CRM-50) was employed for the resistivity sounding. In this method four metal electrodes were driven into the ground. Current was applied to the ground through the two outer electrodes and the potential drop across the other two inner electrodes was measured as a digital output on the resistivitymeter. The apparent resistivity was computed from the potential drop, the applied current and the electrode spacing. The apparatus is usually designed so that the ratio of the potential drop to the applied current is read directly as resistance in ohms. The apparent resistivity value is the value of all the earth material down to a depth proportional to the electrode spacing. Interpretation of earth resistivity data was done through an analysis of graphs wherein apparent resitivity is plotted against one-half current electrode spacing. Graphs were interpreted using the approach given by Lalwani (1993), using Koefoed's methods (1979) for electrical resistivity data interpretation.




Vertical Electrical Soundings were conducted to determine the lithological layering in the vicinity of CD3, prior to drilling of observation boreholes.

This resistivity data helped correlate subsurface geoelectrical properties with the conceptual geological model derived on the basis of geological mapping and well-inventory. All this information helped interpret the underlying geology and the probable variations therein, eventually to describe the shallow aquifer that forms the focus of the AGRAR research in Kolwan valley. Also, probable directions and distances of groundwater movement around the check dam were considered while finalising the observation bore well sites. Of the seven boreholes drilled, six were completed within the shallow aquifer only, whereas one bore well (BH1) was drilled into deeper basalt aquifers, casing off the shallow aquifer identified in Chikhalgaon watershed. All observation boreholes are 152 mm in diameter.

The observation boreholes were drilled by commissioning a down-the-hole-hammer (DTH) drilling rig, commonly employed for drilling boreholes in hard rock, especially the Deccan basalt. The DTH technique uses a rotating bit of alloy steel hammer with heavy tungsten-carbide inserts, delivers 10 to 15 impacts per second at the bottom of the hole with the action of a pneumatic hammer. Compressed air at a pressure of about 100 to 110 psi is supplied to the borewell and this air, moving at high velocity in the annulus, carries the cuttings to the surface. Each drilling rod is of 15' (4.57 m) and the length of the bit rod is 4' (1.22 meters). The objective of drilling the boreholes was explained in detail to the drilling contractor.

ACWADAM staff logged each of the 9 observation boreholes, whereas GOMUKH staff worked on logistics for transporting the drilling rig to various sites. The Chikhalgaon community helped in transporting the drilling rig and accessory equipment from one site to another, especially through ploughed lands and uneven terrain that was devoid of roads. Without this local support, drilling of observation boreholes would have been impossible. Samples were collected from all the boreholes at an interval of 5' (about 1.52 m). In BH1, samples were collected at the change of each drilling rod, i.e. at an interval of 15' (about 4.57 m). Logs were compiled after studying the log-samples in the form of generalised sections.

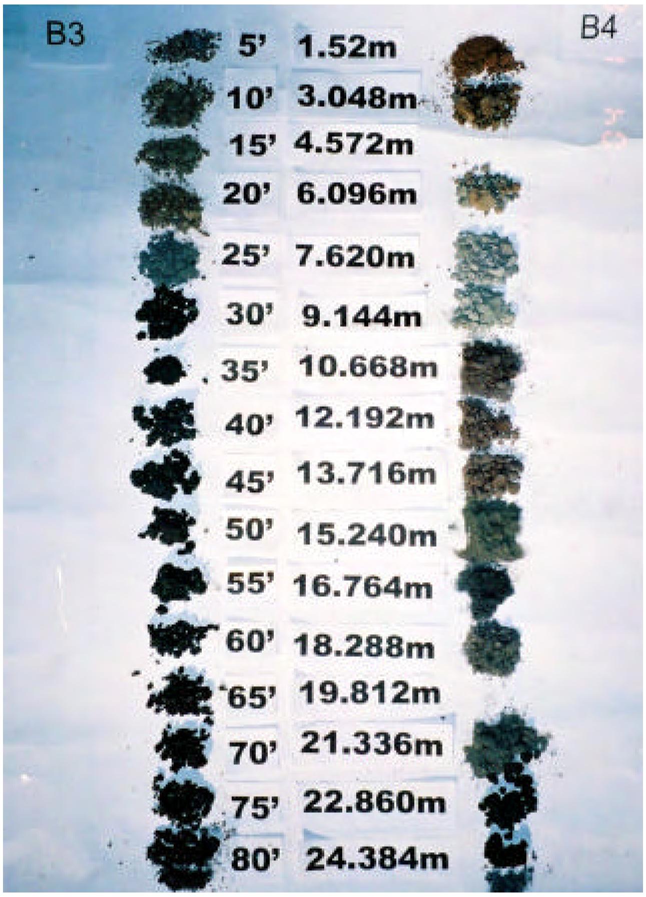
Figure 27: Borehole location (in plan)

All the boreholes were cased to a depth of about 6 m from the ground surface to prevent caving in of the topsoil and weathered mantle. BH1 was fully cased and cement-grouted to a depth of about 16m from the ground surface. This was done to fully isolate the deeper aquifers from any influence of water inflows from the shallow aquifer. BH6A had to be abandoned at a depth of 9 m, because the drill bit fell off into the borehole. Instead of plugging the borewell it was left open for monitoring its water level. The details of observation boreholes drilled are provided in Table 11 below.

Table 11: Observation boreholes drilled in the vicinity of CD3

Bore well code	Aquifer tapped	Depth in m	Well head elevation in m above msl
BH1	Deeper confined basalt aquifer(s)	100.30	623.31
BH2	Shallow unconfined aquifer (Chikhalgaon aquifer)	30.30	623.5
BH3	Shallow unconfined aquifer (Chikhalgaon aquifer)	23.165	617.1
BH4	Shallow unconfined aquifer (Chikhalgaon aquifer)	23.165	617.5

BH5	Shallow unconfined aquifer (Chikhalgaon aquifer)	23.165	616.5
BH6	Shallow unconfined aquifer (Chikhalgaon aquifer)	23.165	614.3
BH6a	Shallow unconfined aquifer (Chikhalgaon aquifer)	8.165	614.4
BH7	Shallow unconfined aquifer (Chikhalgaon aquifer)	23.15	618.80
BH8	Shallow unconfined aquifer (Chikhalgaon aquifer)	23.165	619



A sample borehole-log for BH3 and BH4

Groundwater levels in the Kolwan valley were monitored for large diameter dug wells from the five sites selected for study. All dug wells in Chikhalgaon, Nandgaon, Nanegaon and Hadashi watershed were monitored, whereas three dug wells in the vicinity of the two check dams in Bhalgudi were monitored during the project period.

Hence, 30 dug wells in Chikhalgaon, Nandgaon, Bhalgudi, Hadashi and Nanegaon were inventoried and mapped before the weekly monitoring commenced in early July 2003. One abandoned bore well in Hadashi was also chosen for measurement of water levels. The locations of all these dug wells were marked on watershed maps, using GPS surveys. Table 12 provides basic details about dug wells in the AGRAR monitoring set-up.

Table 12: Dug wells being monitored in Kolwan valley

Dug wells	**Location**	**Diameter in m**	**Depth in m**	**Use**	**Aquifer** **(*Unit in hydrogeological map)***
CH1	Chikhalgaon	12.1	15.07	Drinking water supply well for Chikhalgaon	Compound basalt (*Unit 1*)
CH2	Chikhalgaon	9.95	6.24	Private well (domestic and irrigation)	Compound basalt (*Unit 1*)
CH3	Chikhalgaon	8.35	8.75	Private well (seasonal irrigation)	Vertically jointed compact basalt (*Unit 2*) (Chikhalgaon aquifer)
CH4	Chikhalgaon	7.14 m x 3.00 m (rectangular)	3.65	Old community well (not in use)	Compound basalt (*Unit 2*) (Chikhalgaon aquifer)
CH5	Chikhalgaon	12.5	8.25	Private well (seasonal irrigation)	Compound basalt (*Unit 2*) (Chikhalgaon aquifer)
CH6	Chikhalgaon	3.79	4.16	Private well (limited, domestic use)	Compound basalt (*Unit 2*) (Chikhalgaon aquifer)
CH7	Chikhalgaon	8.1	5.00	Private well (seasonal irrigation)	Compound basalt (*Unit 3*)
CH8	Chikhalgaon	7.55	8.25	Private well (seasonal irrigation)	Compound basalt (*Unit 2*) (Chikhalgaon aquifer)
ND1	Nandgaon	8.95	6.38	Private well (seasonal	Compact basalt

				irrigation)	(*Unit 4*)
ND2	Nandgaon	9.35	5.3	Community well but no longer in use	Compound basalt and compact basalt (*Unit 5*)
ND3	Nandgaon	9.5	6.32	Community well	Compound basalt and compact basalt (*Unit 5*)
ND4	Nandgaon	4.82	8.95	Irrigation well sometimes used as Community well	Compound basalt (*Unit 5*)
ND5	Nandgaon	4.15	5.15	Private well (seasonal irrigation)	Compound basalt (*Unit 5*)
ND6	Nandgaon	12.6	13.8	Private well (seasonal irrigation)	Compound basalt (*Unit 4*)
ND7	Nandgaon	8.5	4.4	Private well (seasonal irrigation)	Compound basalt and compact basalt (*Unit 4*)
ND8	Nandgaon	11.3	3.25	Private well (seasonal irrigation)	Compound basalt (*Unit 5*)
H1	Hadashi	5.50	8.7	Community well (drinking water)	Compound basalt (*Unit 3*)
H2	Hadashi	4.8	3.65	Private well (seasonal irrigation)	Compound basalt (*Unit 3*)
H3	Hadashi	16m x 36 m	12.00	Private well (used intensively for private facility of temple and orchard)	Compound basalt (*Unit 3*)
H4	Hadashi	5.00	7.00	Community well	Compound

				(drinking water, seasonal)	basalt (*Unit 3*)
HBH1	*Hadashi (Bore well)*	*152 mm*	*75.5*	*Abandoned* *(Private)*	*No information on aquifers but located in area immediately underlain by Unit 3*
B1	Bhalgudi	8.00	4.78	Private well, Occasionally used for irrigation	Compound basalt and a portion of the underlying compact basalt (*Unit 3*)
B2	Bhalgudi	5.70	8.43	Private well (seasonal irrigation)	
B3	Bhalgudi	8.40	3.43	New well, not yet pumped	
N1	Nanegaon	10.8	6.45	Private well, occasionally used for supportive irrigation	Compact basalt (*Unit 2*)
N2	Nanegaon	9.5	8.8	Community well, drinking water well	Compound basalt and compact basalt (*Unit 2*)
N3	Nanegaon	8.7	5.1	Private well (seasonal irrigation)	Compact basalt (*Unit 3*)
N4	Nanegaon	11.5	11.1	Private well (seasonal irrigation)	Compound basalt and compact basalt (*Unit 4*)
N5	Nanegaon	8.3	4.2	Private well, occasionally used for supportive irrigation	Compound basalt (*Unit 2*)
N6	Nanegaon	6.5	3.4	Private well, occasionally used for supportive irrigation	Compound basalt (*Unit 2*)

N7	Nanegaon	7.2	4.4	Private well (seasonal irrigation)	Compound basalt (*Unit 2*)
NBH1	*Nanegaon*	*152 mm*	*65*	*Abandoned (Private)*	*No information on aquifers but located in area immediately underlain by Unit 2*

Water level data from observation boreholes was thought to provide clearer insights to what happens within the vicinity of the check dam, especially after the first rains when the aquifer dewatered somewhat due to the dry season discharges, most likely in the form of pumping of dug wells and natural outflows.

Measurement of water level in a dug well in Kolwan valley

Dug wells in the Kolwan valley are generally not pumped intensively. Therefore, a frequency of weekly monitoring was thought enough to provide information regarding seasonal fluctuations of the water table in the shallow aquifers from the five study watersheds. Measurement of water levels in observation boreholes was also done on a weekly basis. Groundwater level measurement was done using mechanical and electronic water level measuring devices. GOMUKH's field staff undertook dug well measurement, whereas ACWADAM and GOMUKH staff measured water levels in boreholes jointly, usually each Friday.

In Chikhalgaon, there are around 8 wells, which were monitored during this study. The well depth and water levels were measured and the data was plotted for each well. Similarly, data for some dates was used to plot water table contour maps, by hand. The water level data show that the groundwater flow in the watershed follows the general trend of topography. The same data was used for plots prepared using SURFER 7.0. The SURFER plots were found to be in close agreement with the maps drawn manually. Using the same process, water level contour maps were generated for dug well and borehole data, not only in Chikhalgaon watershed, but also in other watersheds as well.

3.2.2.4 PUMPING TESTS

One of the biggest challenges in Deccan basalt hydrogeology is conducting systematic pumping tests. The nature of water bearing openings in an aquifer determines its storage and transmission properties. These properties control the response of the aquifer to pumping, and therefore, affect wells yields. Large diameter dug wells have been the traditional sources of tapping groundwater from Deccan basalt aquifers. The difficulties in pumping these dug wells and analysing pumping test data have also been greatly discussed (Athavale et al, 1983; Deolankar, 1980; Deolankar and Kulkarni, 1985; Kulkarni and Deolankar, 1997; Kulkarni et al, 1997; Kulkarni, et al 2000). The difficulties in performing and analysing pumping tests in the Deccan basalt environment has been aptly summarised by Macdonald et al, 1995 as:

1. *It is virtually impossible to avoid interference effects during pumping Deccan basalt aquifers. The drawdown and recovery of water levels measured therefore do not necessarily reflect pumping from the test well alone. This creates difficulties in the precise estimation of aquifer parameters.*
2. *There is often a residual drawdown in a well at the beginning of a test, as wells in many parts tend to be pumped daily or even 2-3 times every day, without enough time for their full recoveries.*
3. *The analysis of pumping tests on large diameter wells is more difficult than for slim bore holes due to the large storage within the well itself and the uncertainty in estimating well dimensions.*
4. *Basalt aquifers are heterogeneous in nature and do not meet the assumptions and conditions of homogeneity, isotropy and infinite extent that form the basis for many methods developed to analyse pumping test data.*
5. *Water discharged from the pumping well is often used for irrigation and may flow into the well as return irrigation flows, offsetting the values obtained from such a test.*

Bearing in mind the above limitations, pumping tests were conducted on some of the observation bore holes during January 2005, after the check dam CD3 ran dry. In order to ensure uninterrupted, undisturbed water level data from these bore holes, none of them were pumped for more than a year. As described earlier, groundwater abstraction from the Chikhalgaon aquifer in general, and in the vicinity of the check dam CD3, in particular, is quite limited (there is virtually no abstraction from near the observation boreholes because of the absence of any wells). The first three difficulties listed above were therefore overcome as a consequence of the selection of boreholes for pumping tests and their location in the surrounding hydrogeological environment. The heterogeneity of the Chikhalgaon aquifer was better understood through resistivity data and drill logs. This helped, not only in planning and executing the tests, but also in interpreting data. Discharge from these tests was kept low and although it was variable, the pumped water was discharged at least 100 m downstream (in the stream channel) from the pumping borehole, a distance considered safe, especially in basalt aquifers with low transmission and storage characteristics.

A low discharge submersible pump (1 HP) was used to conduct tests on the pumping boreholes, with the network of boreholes around CD3 providing a good representation of observation boreholes during the drawdown and recovery measurements of each pumping test. No long duration test was possible on any of the boreholes, but all the tests were run for a period that recorded a complete drawdown in the pumping borehole and the pump was allowed to run dry. Recoveries, in most cases were measured for a period it took to complete 80-90% of the recovery in the borehole(s). However, for very slow recoveries, the period of measurement was atleast 6 to 7 hours from the stoppage of pumping.

(a)

(b)

Pumping tests conducted on boreholes involved measurement of water levels (a) and measurement of discharged water (b)

Water levels were initially measured at half a minute interval (drawdown) and for 1-2 minutes of the initial recovery period. Thereafter, measurements were taken at 5, 10, 15 and 30 minutes as the test progressed and it took longer periods for the boreholes to recover, as time progressed. Discharges (and changes therein) were recorded using a stopwatch and a 100 litre container to which the pumped water was delivered. Discharge, during pumping, was measured as a continuous process because there was a significant reduction in discharge even over the short duration of each test. The analysis of pumping test data was carried out by several methods, including the suite of analytical methods in AQUIFERTEST PRO 3.5. Data was also analysed using the BGSPT package developed by *Barker (1989)* and later refined by *Barker and Macdonald (2000).* Values were also generated using other software, simply as a tool to compare values between methods but this comparison has not been presented here because this component is outside the scope of this study.

One pumping test was also conducted on the dug well CH2 in Chikhalgaon watershed in February 2004. The data for this test was analysed using BGSPT.

3.2.2.5 HYDROCHEMICAL MONITORING

Water quality sampling was done for five seasons namely, November 2003, February 2004, June 2004, November 2004 and February 2005. Sampling sites included boreholes, dug wells, springs, river and irrigation tanks mainly from the Hadashi and Chikhalgaon catchments. Samples from 11 sites were drawn for all the five seasons mentioned above (Figure 28). Sampling from additional sites was possible during some of the four sampling periods, with a maximum of 21 samples drawn in November 2004. Samples from 17 sites were taken in February 2005, the latest water quality sampling under AGRAR. At each site, pH, temperature, specific electrical conductance (SEC) and Eh were measured, although it was not possible to collect pumped samples or use a flow-through cell at any of the sites. Samples, therefore, represent a mixture of groundwater and surface water with different inputs and influences, like evapotranspiration. Nevertheless, valid conclusions can still be made when interpreting regional variations in the hydrogeochemistry of the aquifer.

Grab samples were collected at each site using a bucket or bottle, both of which were sterilised and dedicated to water quality sampling. Water samples were passed through 11 µm filters by gravity and collected in new 1 litre plastic bottles. Each bottle was rinsed with some filtrate before the sample was collected and all sampling equipments were cleaned with distilled water between sample sites. Samples were kept as cool as possible and all on-site measurements and observations were recorded on fieldsheets. Samples were analysed at the Polytest laboratory in Pune, who recommended that the samples were not to be acidified but to be delivered as soon as possible. All samples were analysed within a day or two after their retrieval.

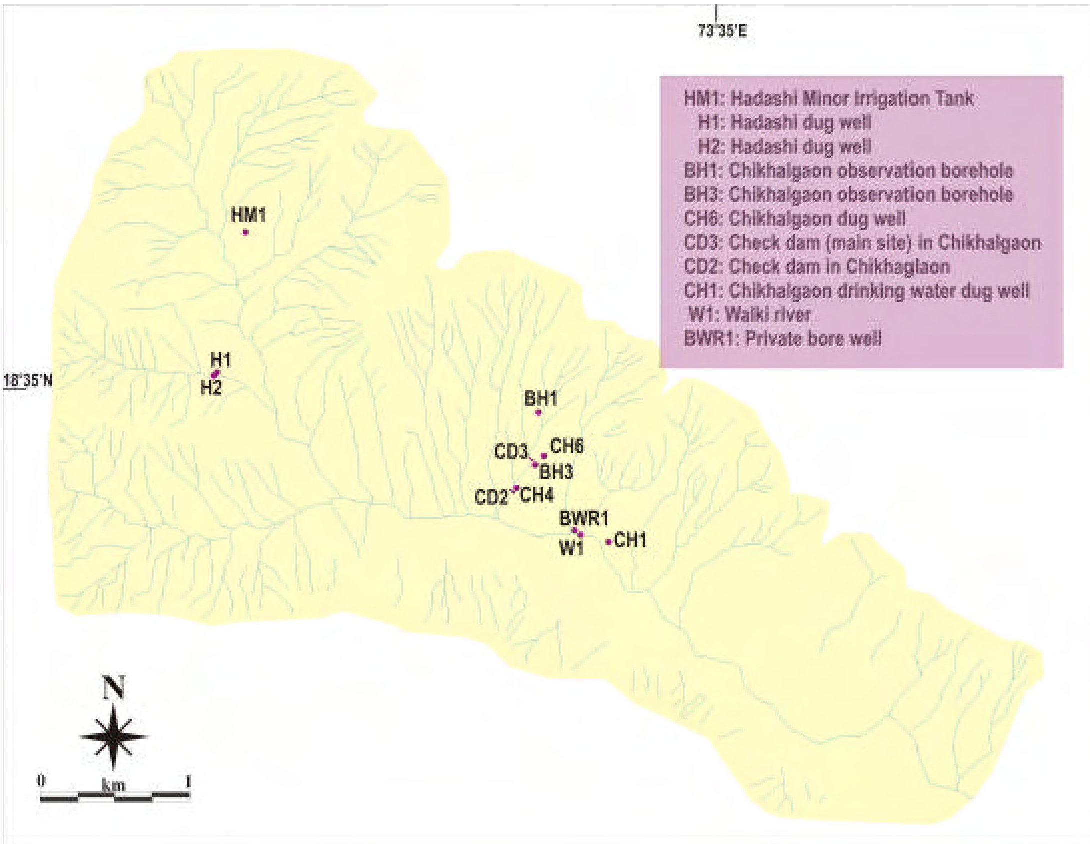


Figure 28: Map of water quality sampling sites where sampling was carried out during all the five sampling periods in the AGRAR project. ***For more specific details, refer to Chapter 4 (Section on Hydrochemical Characteristics)***

(a)

(b)

Hydrogeochemical monitoring included collection of water samples from boreholes (a) and other sources like dug wells, river and springs; In situ measurement of field parameters like conductivity and pH were also done (b).

3.2.2.6 DATABASE

All data, i.e. weather data (including rainfall), data from water harvesting structures, i.e. check dams and water levels in wells and boreholes, hydrochemistry data and socio-economic survey summaries were maintained in the form of a simple database, using Microsoft Excel Workbooks. Some of these data were plotted alongside each other, e.g. daily rainfall and well water level hydrographs, to interpret the relationship between such parameters. Similarly, inflows into and overflows from check dams were plotted as hydrographs to cumulate periodic discharge volumes. It is virtually impossible to present all the data here. However, the more significant results and interpretations of data are presented in the next three chapters. The database is maintained with ACWADAM, which hopes to continue monitoring the site and add information over the next two to three years.

3.3 SOCIO-ECONOMIC EVALUATION

GOMUKH began work on 'Comprehensive Watershed Conservation and Development Programme' in Kolwan Valley in 1996. Some 600 hectares of land was brought under irrigation after the implementation of this programme. About one hundred households donated the land to the extent of 40 hectares to complete the programme. The programme has covered a population of 20,000 people in ten villages in Kolwan valley. The construction of 11 cement bunds, 2 earthen bunds, excavation of 80 farm ponds, 3 water impounding structures, afforestation and contour trenches over 150 hectares of land and raising of 800 dry-rubble bunds for soil moisture conservation were the major activities completed during the implementation of this programme.

The overall purpose of the socio-economic component of the AGRAR project was to assess the various impacts of groundwater recharge activities on livelihoods, and to flesh out differences between stakeholders in livelihood impacts, if any.

A mixed methods approach is the best means of evaluating projects like watershed development because of the heterogeneity of approaches to such projects as well as to get an idea about exogenous factors, especially on socio-economic conditions of communities *(Kerr and Chung, 2001)*. Having said that, it was quite apparent even before conducting household surveys that it would be difficult establish a one-to-one relationship between livelihoods and artificial recharge activities. This difficulty stemmed from the highly complex environment of 'push and pull' factors that seemed to dictate livelihoods on a much regional scale as compared to the 'local' scale on which artificial recharge was implemented. The main challenges, in light of the complex external environment and the scale effect were:

(a) Spatial scale factors, attributing causality (how to separate-out the impacts of groundwater recharge from other watershed-project activities and wider socio-economic changes);

(b) Time scale factors, wherein some impacts may be only be realised over the long term;

(c) Upstream versus downstream interdependencies, although not all that significant in Kolwan valley (on account of a high rain – high runoff situation), often seemed to crop up during initial surveys, especially on the river basin scale, and therefore could not be completely ignored.

Broadly, it was thought that these challenges could be overcome through an approach that attempted to analyse the situation of water related aspects in peoples' livelihoods by asking about the situation before and after watershed development, and before and after recharge activities; and/or by comparing the experiences of villages - households 'with' recharge against those 'without' – outside the project area. In fact, this approach was thought to be in line with a similar logic for interpreting the physical impacts of artificial recharge, explained earlier in chapters 2 and 3.

One important aspect of the socio-economic evaluation was the need to study management and institutional arrangements, as these were thought to bear upon the nature and distribution of livelihood impacts, e.g. recharge augmentation is usually on of many management objectives envisaged in watershed projects. Similarly, location/targeting of recharge activities is often dictated by the nature and extent of participation, financing (norms for financing may be different for different agencies), subsidy arrangements etc.

The socio-economic surveys were conducted essentially by GOMUKH, since they had conducted similar surveys earlier. However, ACWADAM also obtained information, especially while conducting technical surveys and monitoring around different water spots like dug wells, streams, springs, rivers, drinking water schemes etc. Baseline and background information was available for villages in which GOMUKH had already implemented watershed development projects. Fresh surveys were conducted in the five project villages selected for the AGRAR study, i.e. Chikhalgaon, Nandgaon, Bhalgudi, Hadashi and Nanegaon (Figure 20, Chapter 2).

3.3.1 Management and Institutional arrangements

The main objective of check dams that act as recharge structures, in watershed development programmes, is to increase recharge to groundwater, improve soil moisture in the vicinity of these structures, check the surface runoff and reduce soil erosion. The check dams in Kolwan valley were constructed on the lines of GOMUKH's aim "to make the water walk where it is running and make it creep where it is walking." A meeting was organized in Kolwan, prior to the implementation of this programme. Some 10 village watershed committees and 20 self help groups consisting of women were formed during the project. This watershed programme was instrumental in creating the direct employment of 2.1 lakh days. GOMUKH and some village leaders took the lead in the entire planning and implementation of the project. User groups and the villagers in general were given the responsibility of operation and management of watershed structures in the village. The villagers participated in operation and management through *shramadan*, i.e. labour contribution (GOMUKH, 2000). Subsequently, water users' groups for lifting water from the Walki river were initiated by GOMUKH in some villages.

3.3.2 Water and livelihood surveys

Prior to commencement of the watershed development programme, GOMUKH carried out a baseline survey of all the ten villages in the year 1996. Overall, some 1300 families were covered in this baseline survey. The socio-economic survey conducted for the AGRAR project involved a sample survey and informal interviews with some villagers. Both these were conducted to flesh out trends after the watershed project was completed. The objectives of this study were to understand:

1. Household classification according to caste and income groups
2. Changes in ownership pattern of assets
3. Purchases of new assets, including changes in nature of houses
4. Land holding pattern
5. Changes in cropping pattern
6. Changes in annual income
7. Changes in livestock (and possible reasons)

It was envisaged that these objectives would also yield information on benefits of the watershed programme, including recharge structures, as well as benefits from other factors. A sample of 279 households was covered during the survey, representing some 45% of the total population in the five villages. The sample was drawn using purposive sampling method. It was seen that proper representation of all the landholding categories was covered. Similarly, the sample also covered the households from various caste groups.

The survey was carried out using a structured questionnaire for 279 households from five villages. Three out of five villages viz. Chikhalgaon, Bhalgudi and Hadashi were the villages from project area where watershed programme is implemented and Nandgaon and Nanegaon were the villages outside the project area where the watershed programme was not implemented. Information was thought to divulge a mix of ‘before and after’ and ‘with and without’ watershed development situations in Kolwan valley.

Along with landholding families, landless families were also covered in the present survey. Eight percent of the families covered in the project area were landless families and 11 percent of the families covered in satellite villages were landless families. It was decided to cover fifty percent households from each of these villages. The number of households covered in the present survey is given in table 13.

Table 13: Samples for household surveys from the five AGRAR villages

Village	**Sample**
Bhalgudi	35
Chikhalgaon	57
Hadshi	78
Nanegaon	45
Nandgaon	64
Total	**279**

Village-wise list of households maintained in GOMUKH' office was used as the basic document for this purpose. Secondary data was collected from various government offices located at block level and the trust office. A structured questionnaire was prepared to undertake the primary survey. The questionnaire also provided for open-ended questions. It was prepared in the light of objectives decided for the survey. The questionnaire was pilot tested in the village Chikhalgaon prior to the actual survey in the five villages. The data collected was computerized to obtain analytical output tables.

A team of 5 investigators was assigned the job of primary data collection. One day training of these investigators was organized at the trust office. The same team participated in the pilot survey. This helped in exposing the investigators to field level realities. Both scenarios, i.e. 'before and after' and 'with vs without', were used while formulating the questionnaire. Although data was analysed using a computer programme developed by Mr. Pramod Sadolikar, one of GOMUKH's associates, ACWADAM used the raw data from questionnaires to produce most of the results presented here.

3.3.2 Impact assessment

During the research, a mix of before and after comparison was attempted to assess the changes and their causes. The comparison was done using the baseline survey conducted in 1996 and the current survey conducted in 2004. The impact assessment was done on the basis of social and economic status of the villagers as well as on the basis of their living conditions. An attempt was made to study changes in cropping, irrigation sources and availability of water resources.

Besides this, change detection was attempted using the satellite data for two different seasons February, 1998 and February, 2004. Inputs from remote sensing and sample field data for Chikhalgaon village (presented as an appendix to Chapter 5) was used to develop a comparison of the before versus after situation. The emphasis of this study was to assess any changes in irrigated cropping (annual as well as rabi-season irrigation) for this period, using crops like sugarcane, wheat and vegetables as indicators. For this study the secondary data about the crops was collected from the local land records department, under the offices of the *Talathi*. The land plots were identified and the ground-truthing was done by interviewing individual farmers. This data was compared for the four seasons and the changes in the cropping pattern were identified.

In addition to the process described above, village meetings, informal discussions at tea shops and interaction with villagers during technical work like water level surveys and pumping tests provided significant information with regard to relationships between water resources and changes in socio-economic aspects in Kolwan valley. The ACWADAM and GOMUKH teams have been visiting the area since 1996. For the AGRAR project the ACWADAM team is visiting the area on a weekly basis since 2003. During the last two and a half years several formal and informal meetings and gatherings were organised for the villagers.

4 Results: physical aspects

4.1 INTRODUCTION

The aim of the hydrological assessment was to undertake a systematic evaluation of the effectiveness of small-scale artificial recharge structures in terms of recharging the aquifer (Gale et al, 1993). The assessment involved catchment based surveys and monitoring to relate potential additional recharge resulting from the recharge structure to the water budget in the catchment. The methodology used to obtain data has been explained in Chapter 3. This Chapter deals with the results of monitoring, including explanation regarding the degree of detail for monitoring various parameters as well as some of the constraints and difficulties encountered in estimation of results from field data.

The concept and methodology of monitoring various meteorological, hydrological and hydrogeological aspects in the Kolwan valley at different scales has been explained in Chapters 2 and 3. The check dam CD3 was constructed as a part of the watershed development programme undertaken by GOMUKH in Kolwan valley, again a typical scenario for constructing recharge structures, not only in the Deccan basalt region but in other geological settings of India as well (Gale et al, 2002; Kulkarni, 1998). Similar recharge structures in Chikhalgaon, Bhalgudi and Hadashi villages (watersheds) were used to compare results across areas within the Kolwan valley where intensive artificial recharge has been attempted through a similar watershed development programme, by GOMUKH, although monitoring in these structures was not to the extent of detail as in CD3, i.e. in Chikhalgaon. The monitoring of physical parameters in the Kolwan valley, involved:

- Recharge structure scale: One recharge structure (CD3), along with two check dams downstream (CD2 and CD1), formed the main site for monitoring. This main site was chosed because it is underlain by the Chikhalgaon aquifer, a well-defined, reasonably well-bounded, shallow unconfined aquifer.
- Watershed scale: Chikhalgaon watershed was used as the main area of study (since the main recharge structure was located there), with limited monitoring in the four other watersheds of Nandgaon, Bhalgudi, Hadashi and Nanegaon villages. These four watersheds, especially the check dams and wells in these areas, were considered to be *satellite* sites with respect to the Chikhalgaon watershed in general, and to CD3, in particular.
- River basin scale: Limited monitoring was done on the scale of the Walki river basin, to pick up some information that was expected to help obtain rough estimates regarding the river basin water balance.

The major constraints in data acquisition, especially primary data acquisition, revolved around the fact that most water-related events (peak flow discharges, high-intensity rain showers and even infiltration-recharge responses to rainfall) were short and could not be anticipated every time. Therefore, although the nature and occurrence of such events could be qualified, quantification was not always possible. Secondary data, such as reservoir releases from the three minor irrigation tanks of Hadashi (1 and 2) and

Walen, was difficult to obtain and is still awaited despite repeated efforts by ACWADAM and GOMUKH. Most other constraints were practical in nature and were usually overcome with the help of co-operation from local residents and communities.

Two major constraints that affected the monitoring process to some extent were:

1. The malfunctioning of the AWS meant data-loss for continuous periods, although these were not very long, except at the initial period of installation. Some data records like evaporation and rainfall, for Chikhalgaon, are therefore extrapolated on the basis of manual records from other stations like Nanegaon, Kolwan, Chale and Karmoli (based on relationships between data available for dates when all five stations were functional). However, for rainfall, such data represents less than 5-10% of the total data (in terms of the amount as well as the number of days when data was not recorded at the AWS).

2. Installation of the continuous water level recorder for CD3 could not be completed prior to the monsoon of 2004, due to a faulty design by the manufacturing company; however, we could salvage the problem somewhat by installing another probe, some three months later, bought from another company. Nevertheless, a manual staff gauging station had been put in place to counter such an eventuality and there was no data gap, although high-frequency data had to be compromised with weekly (and sometimes daily) measurements.

A large amount of data was generated during the AGRAR study. It is impossible to present all this data in this section. Instead of burdening readers with a huge amount of data, only data and analysis relevant to the main objectives of the AGRAR study are presented below.

4.2 RECHARGE SITE: CHECK DAM CD3

An intensive monitoring network was established in Chikhalgaon watershed, including monitoring of the check dams CD1, CD2 and CD3 and the surrounding area overlying the Chikhalgaon shallow aquifer. This was done with the aim of also attempting to assess the effects of the recharge structure superimposed on the natural process of recharge in the Chikhalgaon watershed. All monitoring equipment like AWS, automatic water level recorder, observation boreholes, staff gauges, inflow and overflow weirs are located within a maximum distance of 500 m from the main recharge site, i.e. from CD3. Figure 29 illustrates the location of the three-recharge structures with respect to the location of AWS and Chikhalgaon village.

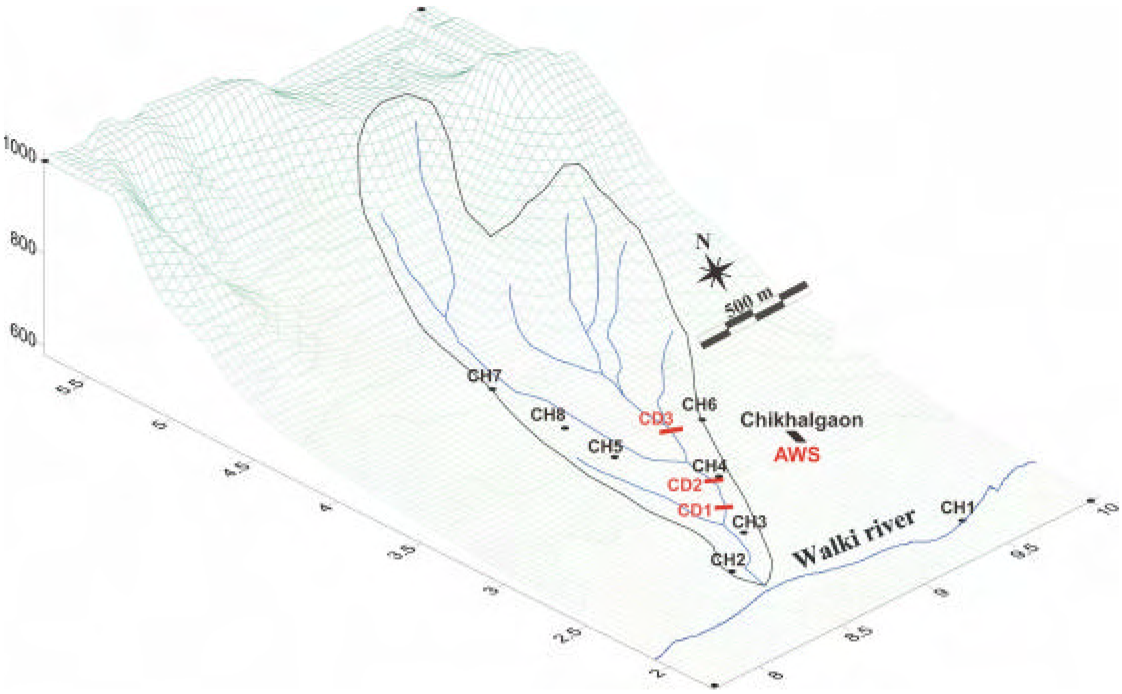


Figure 29: Wireframe for Chikhalgaon watershed, indicating the location of the three recharge structures CD1, CD2 and CD3. Figure also shows the location of the AWS and Chikhalgaon village.

The area of Chikhalgaon watershed is 1.98 km^2, with the three structures located within a length of 1 km from each other. The catchment areas for the three checkdams vary, with CD3 having the smallest catchment size and CD1 nearly equalling the total watershed area. The structures are relatively small in the volume of water they hold, say in proportion to the total rainfall in the watershed. The total bank full volume in the three check dams equals only 3.24 mm of water, with reference to the Chikhalgaon watershed area, where the rainfall recorded for the year 2004-05 was 1840 mm.

Table 14: Basic data for check dams in Chikhalgaon watershed

Structure	Type	Top elevation, in m above MSL	Height at center of structure, in m	Capacity of structure, i.e. bank full volume, in m^3	Catchment area of structure, in km^2
CD1	Earthen	598.5	4.50	2070	1.72
CD2	Masonry	599.2	1.20	583	1.60
CD3	Masonry	617.05	2.00 (before desilting and levelling)	1236	0.79
			2.05 (after desilting and levelling)	1530	

4.2.1 Geology

The type of basalt units, degree of weathering and the nature of openings such as joints, fractures and contacts between different basalt units in a sequence control groundwater accumulation and movement in the Deccan basalt (Lawrence and Ansari, 1980; Deolankar, 1980; Lawrence, 1985; Kulkarni et al, 2000). The Chikhalgaon watershed is made up of 7 basalt units, one less than the sequence of eight units mapped for the Kolwan valley. Each basalt unit in Chikhalgaon watershed is typically made up of an upper compound basalt unit and a lower compact basalt unit. Only the lowermost unit in Chikhalgaon watershed, i.e. basalt unit no. 1, is the more 'classic' simple type vesicular-amygdaloidal basalt.

The compound basalt in Chikhalgaon watershed, forming the upper portion of basalt unit 2 for the sequence of basalts mapped, both on the river basin and watershed scales (refer Figures 16 and 19, Chapter 2), is generally quite weathered and sheet jointed. It is underlain by the compact basalt, vertically jointed in its upper portions, with a poorly jointed / unjointed base. This unjointed base marks the base of the shallow aquifer in Chikhalgaon watershed. The near-horizontal geometry of the basalts in Kolwan valley, like in many parts of the Deccan volcanic province, implies that this framework of basalt units not only repeats itself laterally, at the same elevations but also is evident as a vertical sequence from the ridges to the valley portions (Figure 17, Chapter 2). A typical basalt unit from the Chikhalgaon watershed is described in Table 15.

Table 15: A basalt unit in the Chikhalgaon watershed shows the following features

Basalt type	Lithological characteristics	Range of thickness in Chikhalgaon watershed / Kolwan valley	Nature of water bearing openings
Compound basalt / Vesicular-amygdaloidal basalt	Dominantly vesicular or amygdaloidal units, sometimes made up of small, bun-shaped vesicular-amygdaloidal sub-units.	15 to 60 m thick units	Largely sub-horizontal sheet joints, variable laterally and vertically even over distances of 10s of metres; these sheet joints sometimes form an interconnected network of openings. Some sheet joints are quite open in nature, although these are few and far between.
Compact basalt	Fine grained, often, dark grey or black coloured basalts, largely devoid of vesicles or amygdales.	2 to 10 m thick units	Sub-vertical to vertical joints, clearly apparent on vertical faces such as escarpments and well faces, but are not as open as the sheet joints described above.

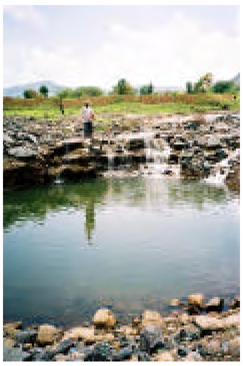
The interconnectivity between units and the fracture openings of each unit control the storage and transmission of groundwater in these basalts. The compact basalt is hard and compact. It has very little storage and transmission capabilities, except when jointed or fractured. Even when fractured, its hydraulic conductivity remains quite limited

(Kulkarni, 1987; Kale and Kulkarni, 1992).

On the other hand due to the horizontal sheet jointing (related to the degree of weathering) and greater lateral interconnectivity, the compound basalt units or the vesicular-amygdaloidal basalts usually form major locales for storage and transmission of groundwater, with better transmission and storage characteristics (Kulkarni, 1987; Kale and Kulkarni, 1992, Macdonald et al, 1995; Kulkarni and Deolankar, 1997 and Kulkarni et al, 2000). Again, simple vesicular-amygdaloidal units tend to be more sheet jointed than compound units, and consequently possess a greater hydraulic conductivity (Joseph, 1998, Kulkarni 2000).

Basalt unit 2 (Figure 30) constitutes the shallow unconfined aquifer in the vicinity of CD3. The sheet joints in the compound basalt units have a highly variable distribution, both laterally and vertically. This is apparent in well and stream sections in the vicinity of CD3. Generally, the network of sheet joints in the compound basalt unit is better developed in areas close to the stream channel. At the watershed boundaries, the compound basalt unit appears unjointed and massive, e.g. as exposed in the dug well section of CH4. The underlying compact basalt is in hydraulic connection with the compound unit above, and forms a part of the shallow unconfined aquifer, henceforth referred to as the *Chikhalgaon aquifer*.

The local geometry and thicknesses of individual portions of each unit controls the variability in the storage and transmission characters of such aquifers not only at different elevations in the Chikhalgaon watershed but even within the same unit in different parts of Kolwan valley. Although lineaments, in the form of fracture zones and a dyke, were identified in the Kolwan valley, none of them traverses the Chikhalgaon aquifer. A conceptual model of the Chikhalgaon aquifer, based on geological observations and a detailed inventory of dug wells, was developed (Figure 30C). The Chikhalgaon aquifer in the immediate vicinity of the check dam CD3, i.e. in proximity to the stream channel, is relatively more sheet jointed. As one moves away from the stream channels, the sheet jointing reduces, both in frequency and intensity, i.e. there are fewer and less open sheet joints near the watershed boundary than those near the stream channel.

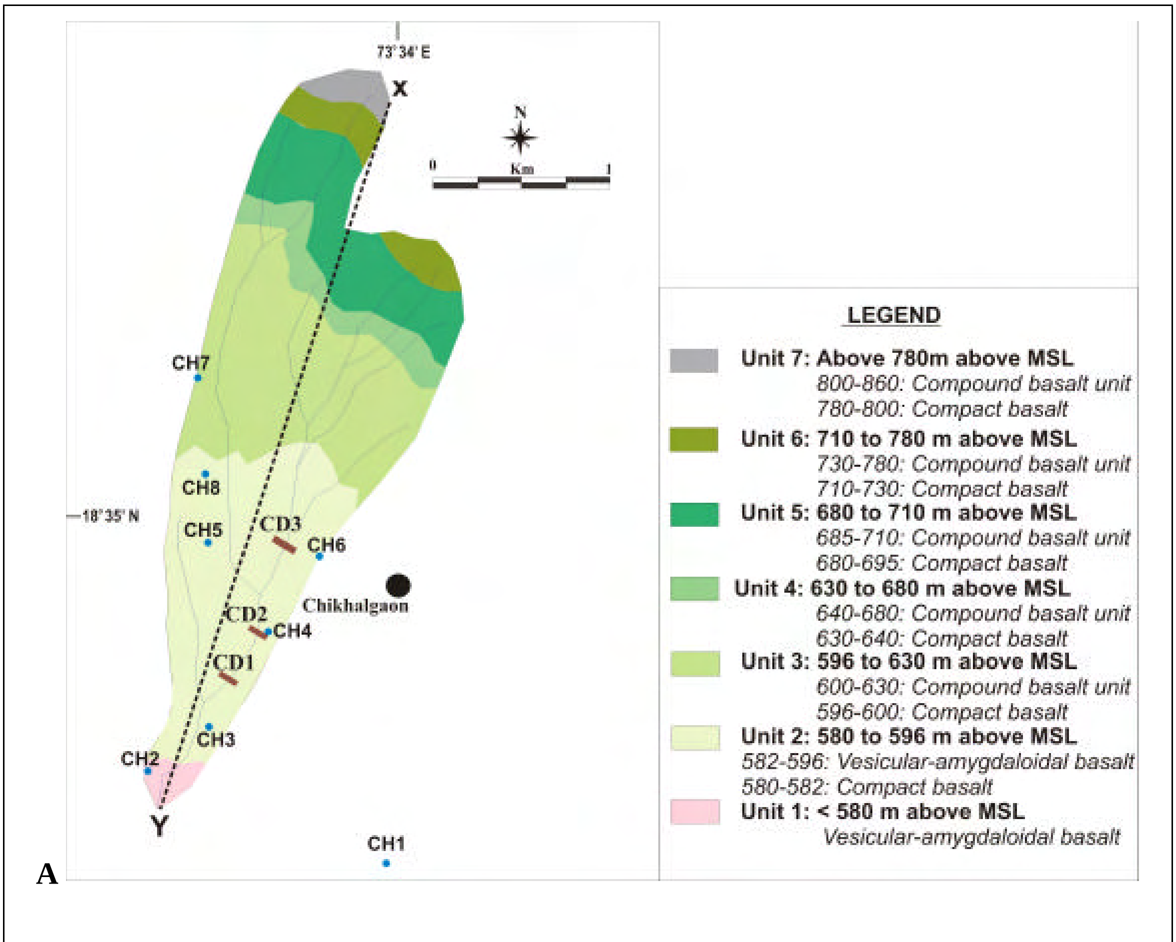


(A)

(B)

Dug well CH5, located on the Chikhalgaon watershed boundary is like a cistern (the basalt has limited permeability) and fills up very quickly with surface water (A). The same basalt unit, near the stream, is weathered and shows sheet joints (B).

The geological observations made above were also testified through electrical resistivity data and more directly from lithologs compiled during drilling of the observation boreholes. Hence, although the cross section in Figure 30 shows generalized horizontal contacts between the main units, the contacts between units and particularly between sub-units of any unit, are often locally undulating. Borehole logs constructed using observation borehole data along and across stream sections clearly indicate the undulating contacts (Figure 31).



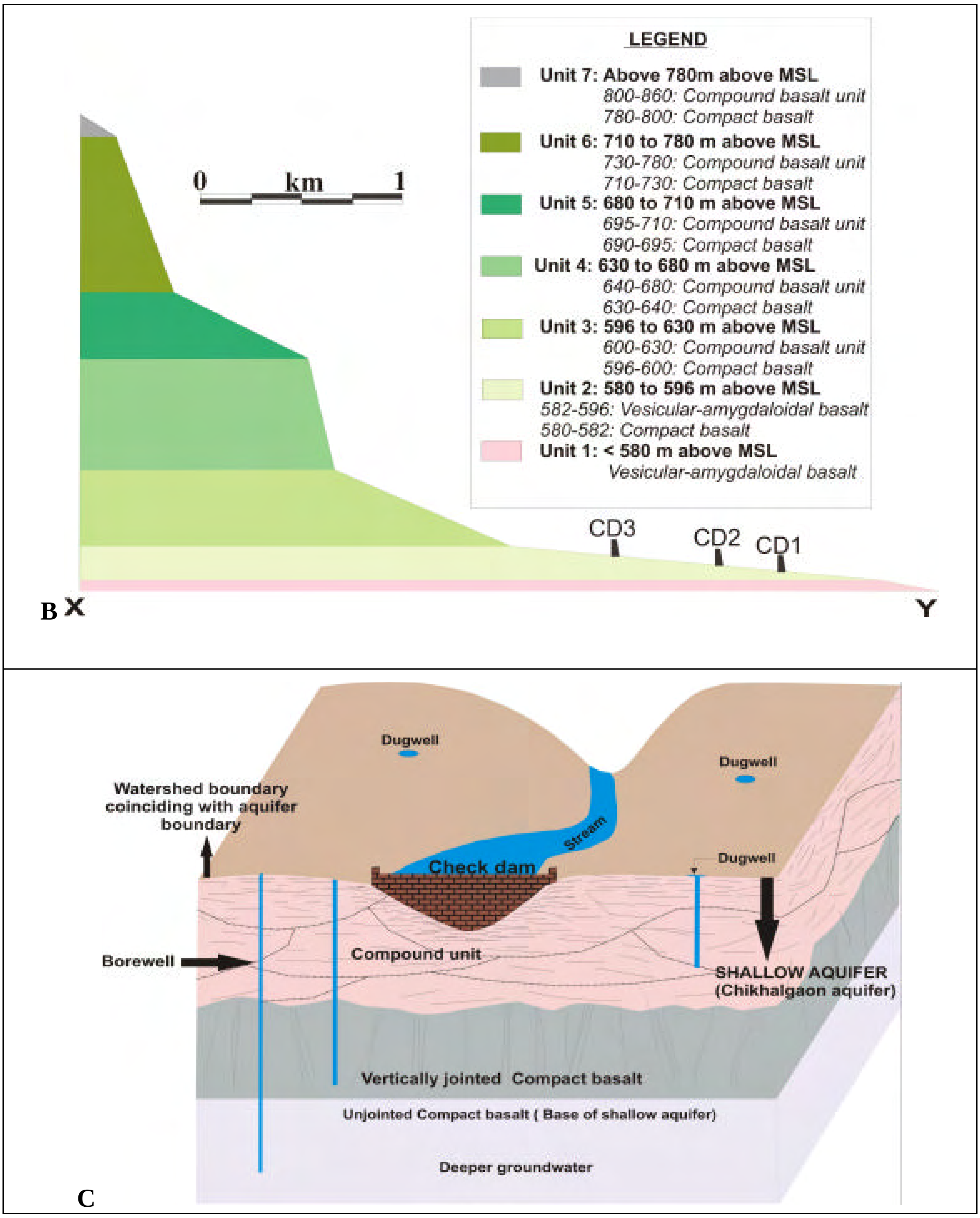
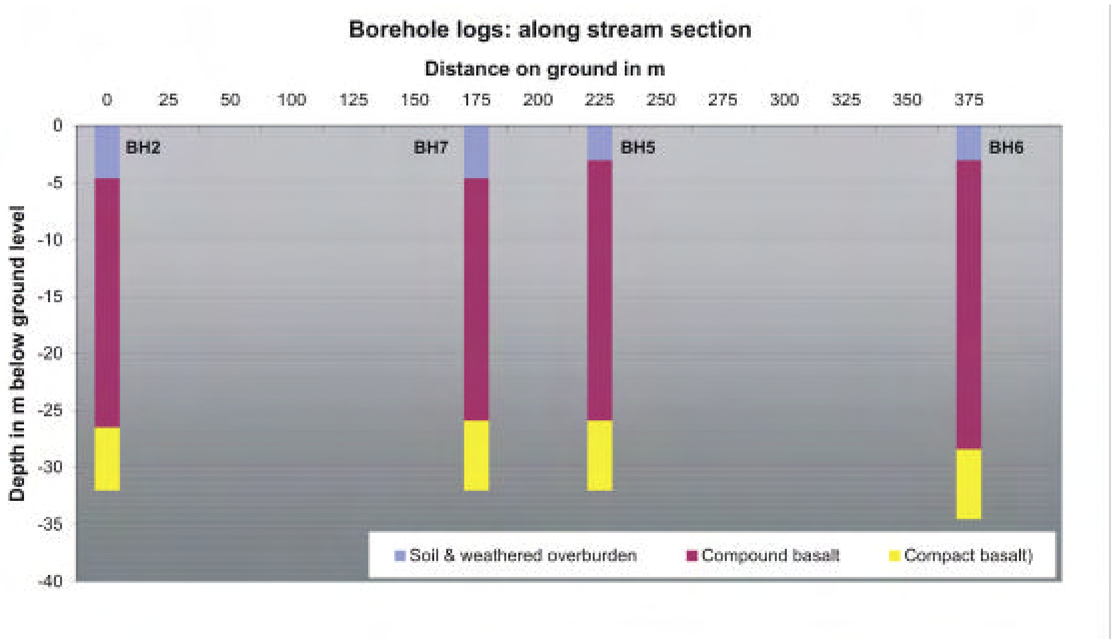
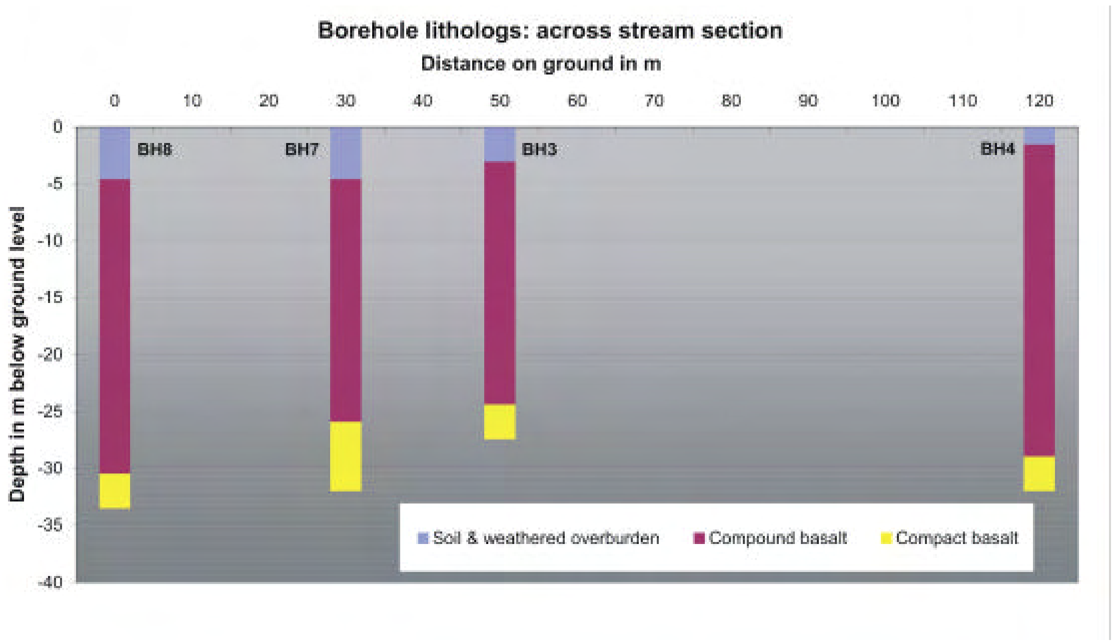


Figure 30: Hydrogeological map of Chikhalgaon watershed (A), with cross section of along the line XY (B). Basalt units 2 to 7 are further divided as described in Table 15. Conceptual model of the Chikhalgaon aquifer based on various geological and geophysical data is shown in C. *Vertical scale in the cross section (B) is exaggerated.*



A



B

Figure 31: Borehole logs (A is roughly along the stream, while B is across the stream) showing undulating nature of contact between the upper compound and lower compact sub-units of the Chikhalgaon aquifer. ***Tops of boreholes have been adjusted to a common datum by considering zero level to coincide with the top of the most low-lying borehole (BH6 and BH3, in A and B respectively)***

PLEASE REFER TO FIGURE 27 FOR LOCATION OF BOREHOLES

4.2.2 Pumping test results

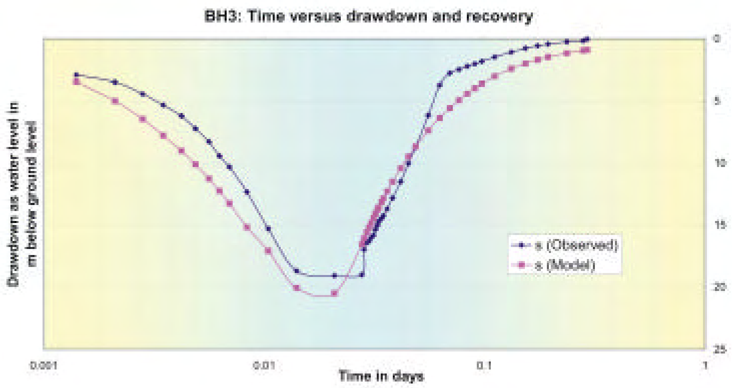
Pumping tests conducted on some of the observation boreholes were analysed comprehensively using the software AQUIFERTEST PRO 3.5 and BGSPT, the package developed by the British Geological Survey to analyse pumping test data (*Barker and Macdonald, 2000*).

Pumping test data from boreholes indicates that the Chikhalgaon aquifer is a low transmissivity and low storativity aquifer. Limited transmissivity implies a slow development and dissipation of the mound created just downstream of CD3. The summary of values of transmissivity and storativity obtained from borehole data using various methods of analysis is given in Table 16. It is apparent that the transmissivity is of the order of 1-5 m^2/day, whereas the storativity (specific yield) varies over several orders of magnitude. However, comparison of the specific yield values with those obtained for similar settings in the Deccan basalt (Deolankar, 1980; Kulkarni et al, 2000; Macdonald et al, 1995; Lawrence and Ansari, 1980; Herbert and Kitching, 1981) imply that the Chikhalgaon aquifer has a specific yield varying between 0.0001 and 0.01, with an average value of about 0.005.

Table 16: Generalised transmissivity and storativity values for the four boreholes in Chikhalgaon

	BH3		**BH5**		**BH6**		**BH8**	
	T(m^2/d)	*S*	*T(m^2/d)*	*S*	*T(m^2/d)*	*S*	*T(m^2/d)*	*S*
AQUIFER TEST PRO	4.00	0.055	2.50	0.0017	1.00	0.01	3.5	0.001
BGSPT	4.29	0.073	5.2	0.0001	4.306	0.0001	2.96	0.0001

Notwithstanding the values of T and S obtained from pumping test data, it was interesting to note the relative trends in drawdown and recovery between these wells (Figure 32).



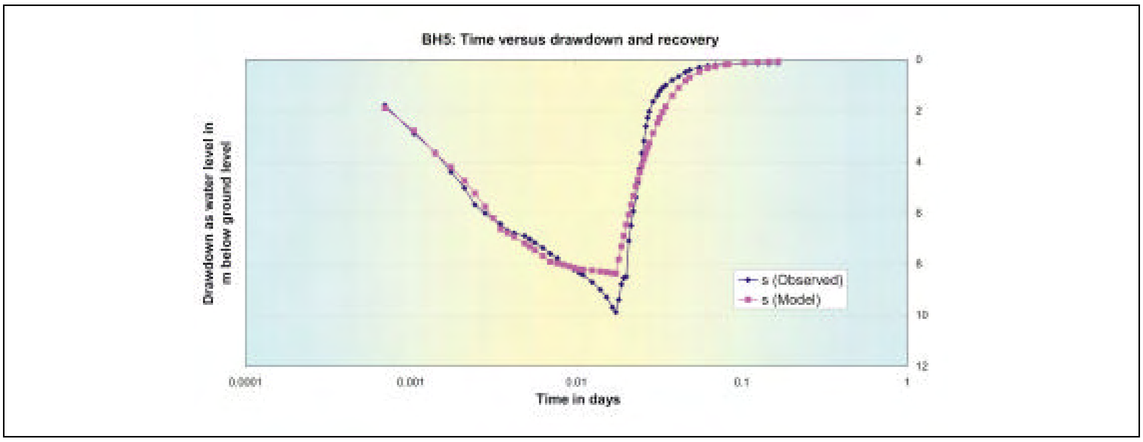


Figure 32: Time drawdown plots for two of the pump-tested boreholes in Chikhalgaon. Observed and BGSPT model graphs show an average fit for BH3 and a fairly close fit for BH5.

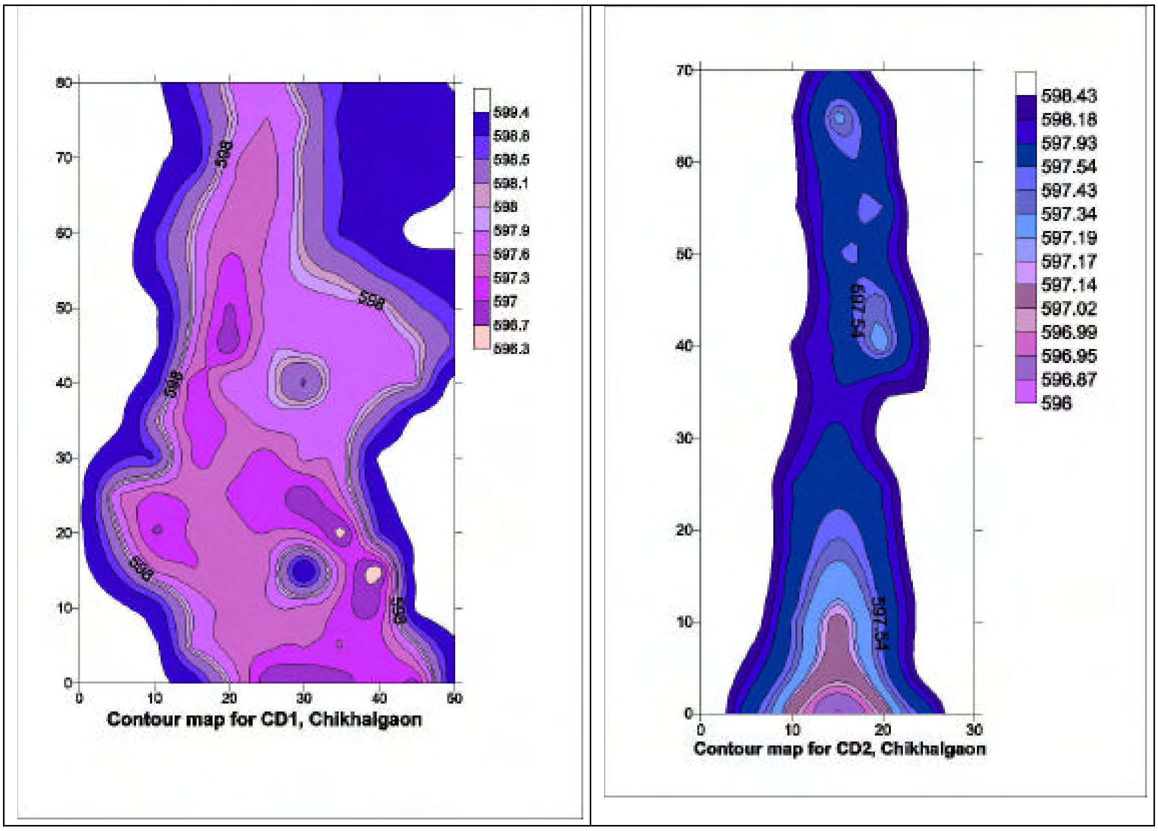
Pumping tests on all four boreholes were conducted under a uniform set of conditions, making it easy to summarise the generalized observations below.

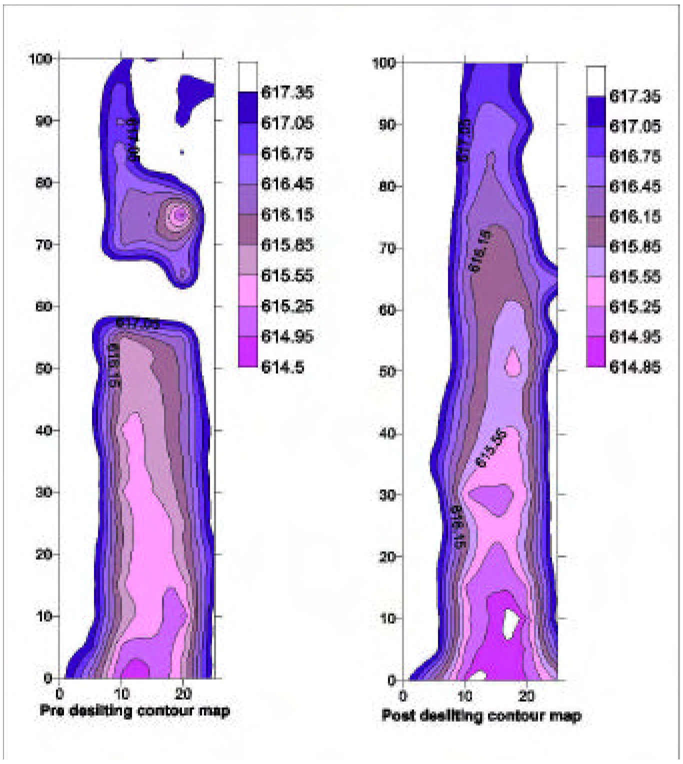
- *Boreholes BH8, BH5 and BH3 recovered quite rapidly (40 minutes to 4 hours) after having been dewatered significantly (drawdowns of 8 – 20 m were recorded in all the pumping test boreholes)*
- *Borehole BH6, which took more than two days to recover.*
- *Boreholes close to CD3 (BH8, BH5 and BH3) were drawing water from nearby, (from the 'recharge boundary' in the form of a small mound just downstream of CD3), despite being located in a low-transmissivity basalt.*

Pumping tests on observation boreholes involved a team effort, with ACWADAM and GOMUKH teams lending full support to this activity.

4.2.3 Check dams and hydrological time series data

The topographic configuration of CD1, CD2 and CD3 is quite different from each other. The storage capacity of each check dam (Table 14, earlier in this Chapter) is different and so is the geometry of its storage defined by contours plotted from survey data for each of the three structures (Figure 33). Check dam CD2, for instance is long and narrow, whereas CD1 has a large surface spread area as compared to the other two check dams. It is also clear from the contour maps that the bottom of the structure is skewed, with the deepest portions closer to the structure wall than to the centre. Check dam CD3 was desilted in May 2004 and hence, the diagram illustrates pre and post-desilting configurations. The amount of silt removed from CD3 was estimated using the tractor load count of silt taken away. This load was measured to be 64 m^3, implying an average siltation rate of 7 mm per year (assuming an area of just of 1500 m^2 over which siltation occurs), with the desilted configuration of the structure being very close to that at the time of its construction.





Contour map for CD3, Chikhalgaon

Figure 33: Contour maps of CD1, CD2 and CD3. These maps were compiled using level surveys conducted for the three structures. *All scales in m, with contours in m above msl.*

Check dam CD3 was desilted in May 2004. *Some 7 mm of silt accumulates in the structure every year.*

Hydrological time series data were collected for the following parameters in Kolwan valley. The data acquisition locations have been described in Chapter 3 (Figure 26).

- Rainfall
- Evaporation
- Other weather parameters: wind velocity, solar radiation, air temperature and humidity
- Water levels (dug wells and observation boreholes)
- Stage measurements in check dams

As described earlier, weather data (mainly, rainfall and evaporation) from some stations is secondary data. Data from stations installed under the AGRAR project was collected through a team effort involving ACWADAM, GOMUKH and students from village communities. The salient findings from the AGRAR site are discussed below.

4.2.3.1 RAINFALL

The average rainfall for Kolwan valley during 2004, based on the above data (from 7 stations), is 2208 mm. Chikhalgaon, located nearly at the centre of the valley recorded an annual rainfall of 1860 mm. Figure 34 shows the daily rainfall distribution for Chikhalgaon, for the period 2003-2005. The rainfall for 2004 was obtained from the AWS and the rainfall for 2003 was deduced for Chikhalgaon, comparing the 2004 data between Chikhalgaon and Karmoli stations, where Karmoli data has been corrected for Chikhalgaon using the relationship between the two data-sets for 2004. Karmoli recorded a rainfall of some 1388 mm in 2003, implying that Chikhalgaon received a rainfall in the range of 1300 to 1400 mm during 2003.

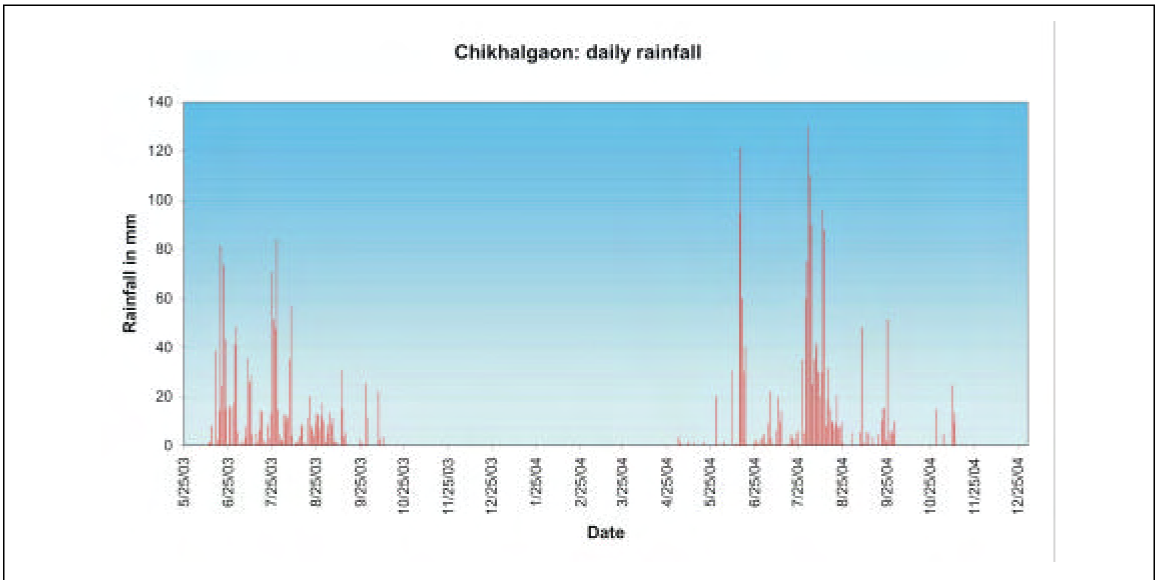


Figure 34: Rainfall data for Chikhalgaon: 2003-04 and 2004-05

The monsoon season in Kolwan valley generally begins in June and ends in mid-October. Using this period, the mean daily rainfall for Chikhalgaon, based only on the AWS data is 13.1 mm, with a standard deviation of 25.66, implying a variability of nearly 100% around the mean. The cumulative monthly data for Chikhalgaon also shows how rainfall during different months varies. In August 2004, Chikhalgaon received 47% of the total annual rainfall (Figure 35).

Most of the other rainfall is distributed over the months of June, July and September, although locally, people reported that rainfall in July 2004 was below what is normally recorded in the area. The months of May, October and November experience some rain, although this is meagre as compared to the main spells from June to September. The rainfall in May is usually in the form of pre-monsoon showers, as evidenced in May 2004. These are typically short-duration, high intensity spells of rainfall, lasting a couple of hours in duration, preceded by stormy weather. Rainfall in the months of October and November is the period of 'retreating' monsoon, again in the form of short, sharp spells contrasting the longer spells of the main monsoon precipitation.

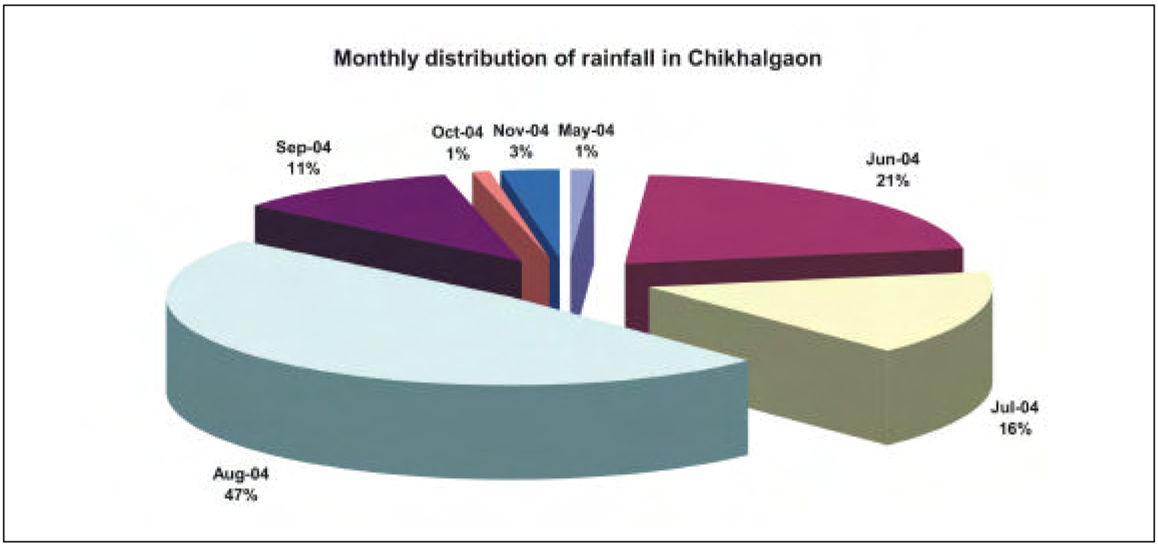


Figure 35: Chikhalgaon- monthly rainfall for 2004

In order to understand the rainfall a little better, hourly rainfall for six days during the six months in which rainfall was recorded for the monsoon of 2004 was plotted, using data from the AWS (Figures 36A and 36B). Rainfall in June and August indicates that rain spells are fairly continuous, although the ranges of minimum to maximum hourly rainfall varies significantly. In July, the rainfall was not continuous, with breaks between sharp showers. Rainfall intensities in June and August were as much as 20 mm/hour, but in July, it seemed to be lower and steadier with about 5 mm/hour of rainfall. In September, October and November, rainfall occurred over a period of 2-6 hours during the day with the main spells having intensities between 8 and 25 mm/hour.

Figure 36A: Hourly rainfall records for some days during the six-month rainy season in Kolwan valley. *Data from AWS, Chikhalgaon*

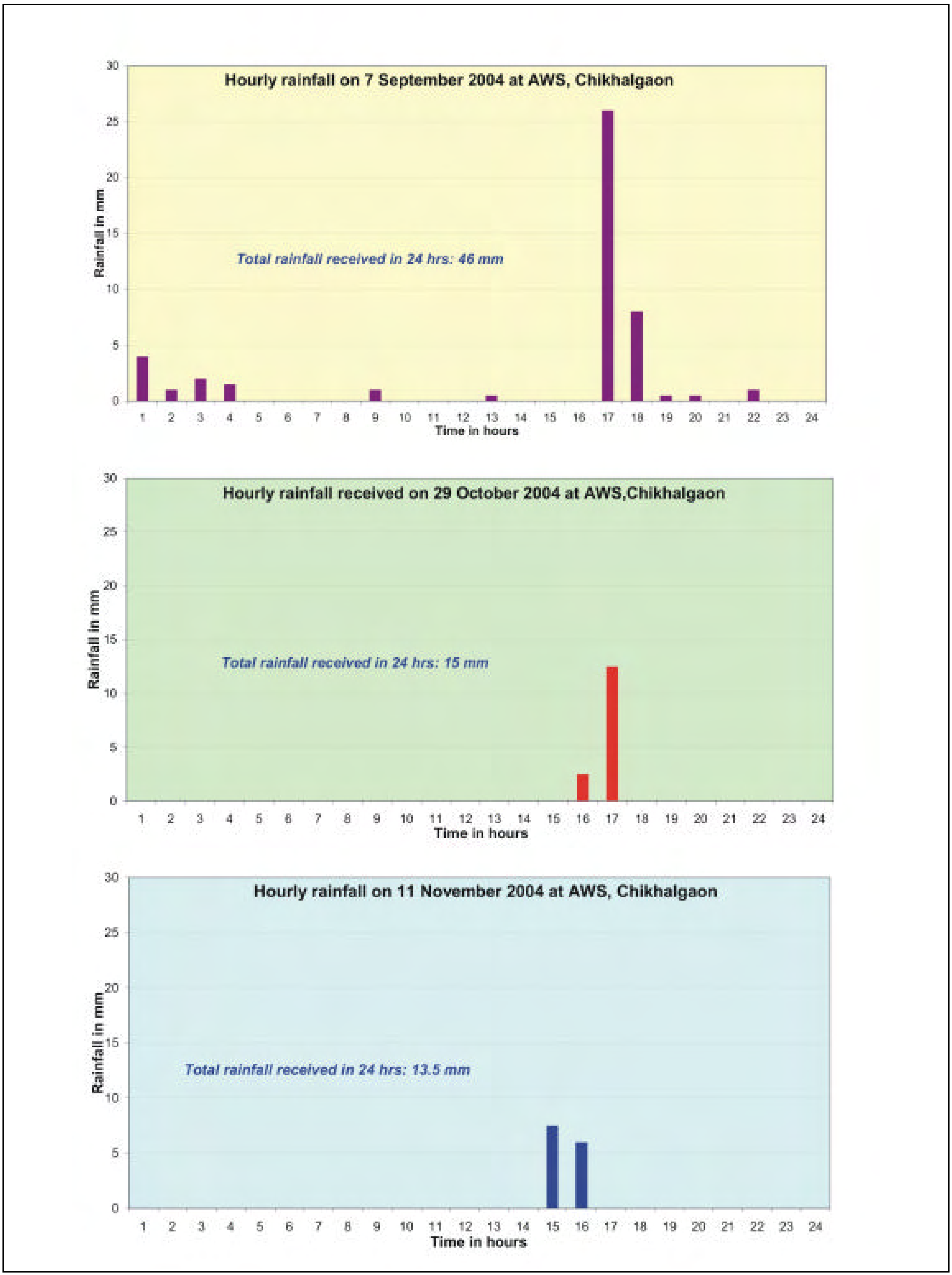


Figure 36B: Hourly rainfall records for some days during the six-month rainy season in Kolwan valley. *Data from AWS, Chikhalgaon*

4.2.3.2 EVAPORATION

The rate of evaporation was calculated by direct method using pan measurements as well as using the Penman-Shuttleworth formula {based on Penman (1948 and 1963) and Shuttleworth (1993)}. In case of Chikhalgaon it was observed that the rate of evaporation calculated by the Penman-Shuttleworth formula was slightly more than that of the pan evaporation rate. It was observed that wherever the rate of evaporation was close to 5 mm/day, results from both the methods were similar. However, during summer there was a difference of almost 20% in the two methods. During the monsoon, the rate of evaporation measured by these two methods was in compliance with each other.

Figure 37 shows the rate of evaporation by the two methods. There were data gaps, especially in the pan data. However, these could be adjusted on the basis of a comparison between common data sets for the four evaporation-gauging stations, which included included larger data sets for using the Penman-Shuttleworth formula to obtain evaporation empirically. Data from the AWS indicated that the estimates of evaporation from the pan were about 0.6 times the estimates from the empirical equation (Penman-Shuttleworth formula).

The Penman Shuttleworth equation used to estimate evaporation using data from the weather station was in the form

$Ep = ? /? + \gamma (Rn+An) + \gamma/\gamma+? \ * 6.43(1+0.536 U_2)/\lambda$

where,

Rn = net radiation exchange (water equivalent) at the surface of the body of water (mm d^{-1})

An = Energy advected to the water body (mm d^{-1})

D = Average water vapour pressure deficit (es-e) over the estimation period

U_2 = Wind speed

l = function of temperature, is the latent heat of vaporization

g = Psychrometric constant

? = rate of change of temperature with respect to time.

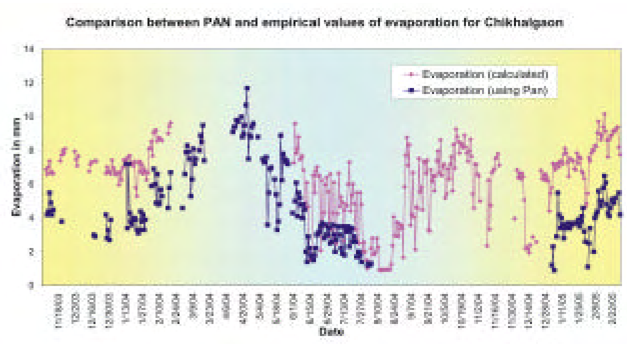


Figure 37: Rate of evaporation calculated by two methods in Chikhalgaon

The pan evaporation data for Chikhalgaon was plotted out almost for the entire period of record (Figure 38A). There was a significant data gap during November 2004, when some technical snag developed in transfer of data from the pan sensor to the data logger of the AWS. However, to get a better picture, evaporation data from the pan in the AWS at Chikhalgaon was plotted using monthly averages, to get an idea about the annual pattern of evaporation (Figure 38B). Evaporation in Chikhalgaon is minimum during the rainy season, i.e. between June and September, after which is rises just after the monsoons cease, decreases slightly during the winter months and peaks during the following months of March and April. It is still quite high in the month of May, but decreases from that in April to reduce significantly as the rains return to Chikhalgaon in June. Of course, this cycle is based on a limited data set for 2003-2005, but this is the broad trend that is expected during most years, with a typical weather cycle represented by the current set of data.

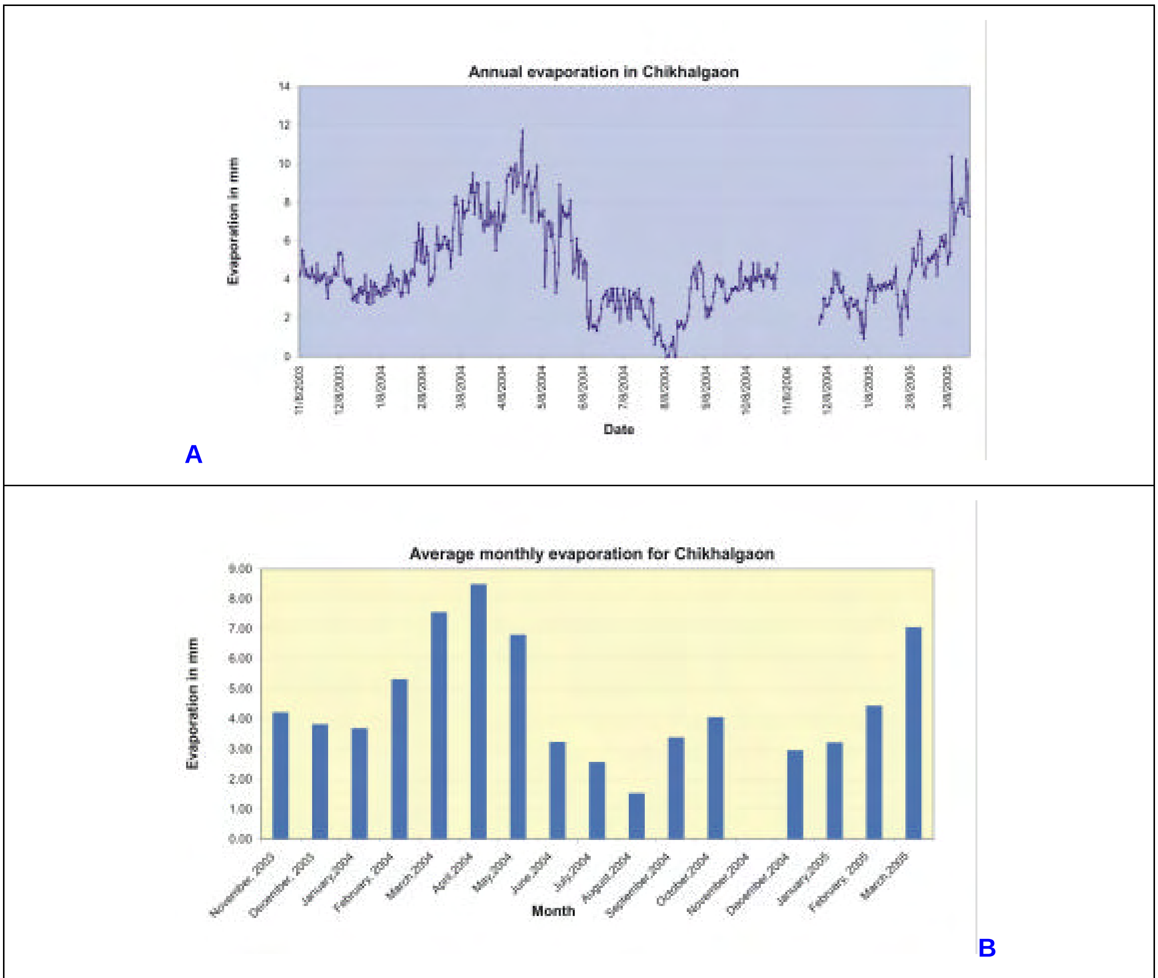
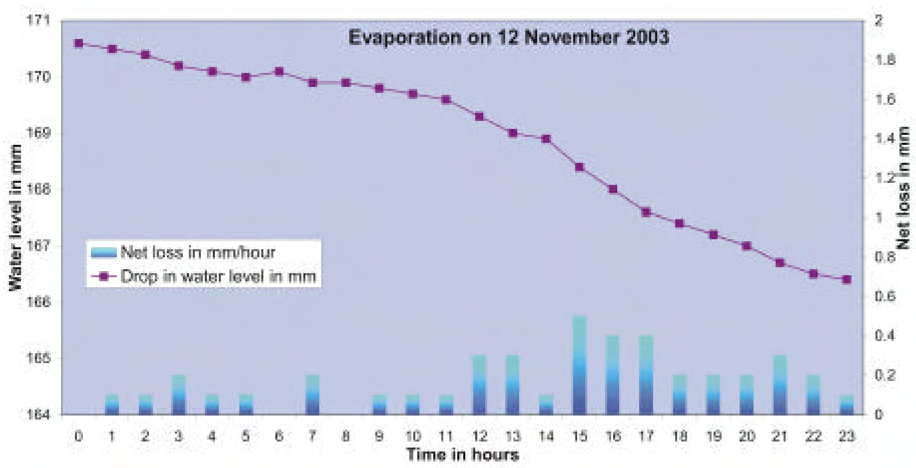
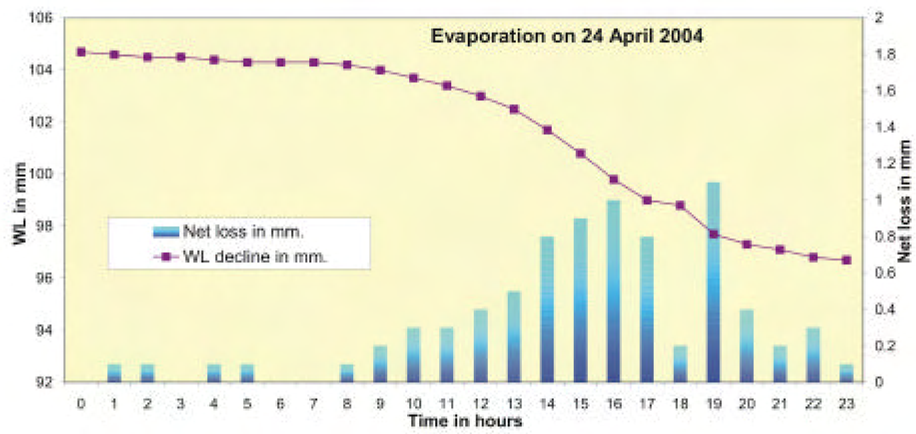


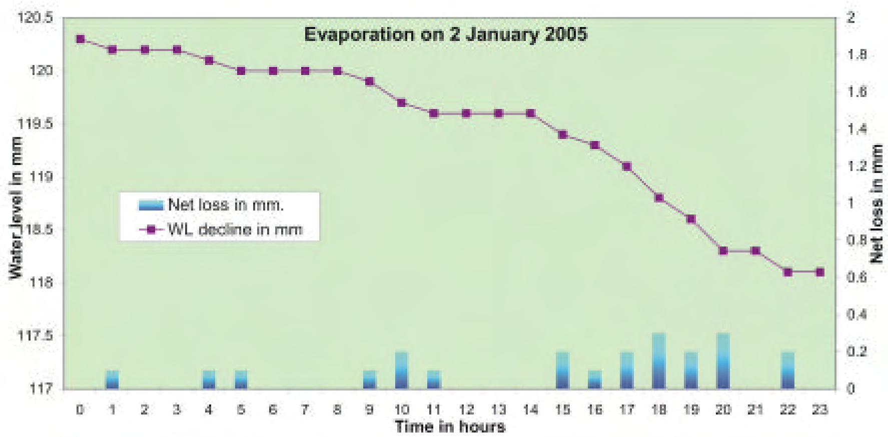
Figure 38: Monthly evaporation in Chikhalgaon (based on AWS pan data). ***Daily evaporation calculated from the AWS is shown in A, while monthly averages calculated on the basis of hourly data from the AWS is shown in B.***

Both, the water level decline in the pan and the net evaporation loss from the pan in Chikhalgaon, indicate that the daily trend in evaporation differs from season to season (Figure 39). Since, evaporation values were more significant during the dry season, especially with respect to water in the check dams, it was thought relevant to compare four such trends from different periods of the monitoring in Chikhalgaon. Firstly, it is clear that the main component of evaporation in Chikhalgaon takes place between 1.00 and 6.00 pm, i.e. between afternoon and early evenings, i.e. before the sun sets. The hourly variability in evaporation was significantly high in April 2004 and March 2005, as compared to January 2005 and November 2003. In fact, on 12 November 2003, there was an addition to the pan during the early hours, through dew.

Peak hourly evaporation rates touch 1mm and even go upto 1.5 mm during the months of March and April, whereas they remain within 0.5 mm during the winter months (November to February). Most of the check dams dry out by about February and therefore the winter rates for evaporation would be relevant to the dry season water balances of the check dams.




Evaporation on 24 April 2004
Net loss in mm.
WL decline in mm.
WL in mm
Net loss in mm
Time in hours


Evaporation on 2 January 2005
Net loss in mm.
WL decline in mm
Water level in mm
Net loss in mm
Time in hours

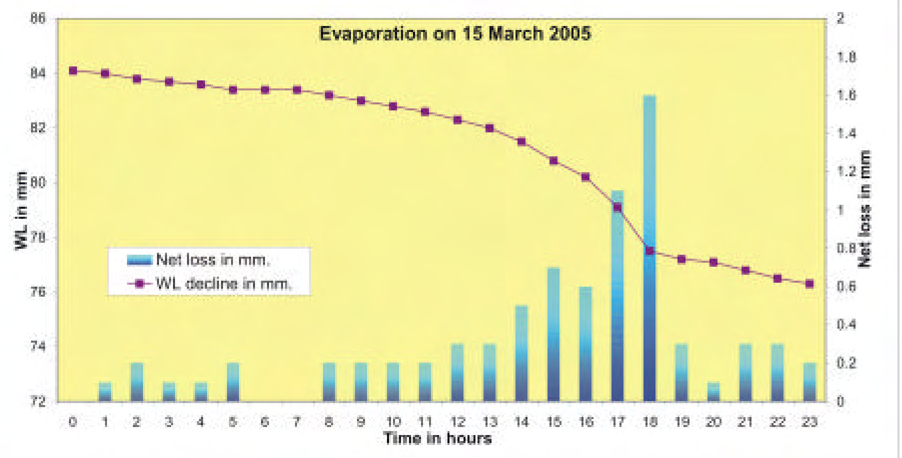
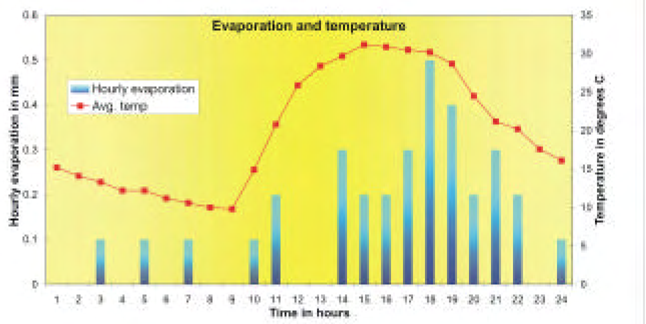


Figure 39: Hourly changes in evaporation during four typical periods during the dry season. ***Dates chosen are random, with data from AWS, Chikhalgaon***

Having estimated evaporation empirically, using weather parameters such as relative humidity, temperature, wind speed and solar radiation, it was thought pertinent to compare each of these with evaporation. Figure 40 compares the effect the above four parameters have on evaporation, by charting hourly evaporation rates against the hourly estimates for each of the four parameters as separate graphs. Data for a single day (15 January 2005) was used for this comparison. It is obvious how all the factors affect evaporation and how they too correspond to the rise and fall of evaporation depending upon the time of the day. Evaporation peaks during periods of the day when the temperature and solar radiation are at their maxima, when relative humidity ebbs and when wind speed also picks up.



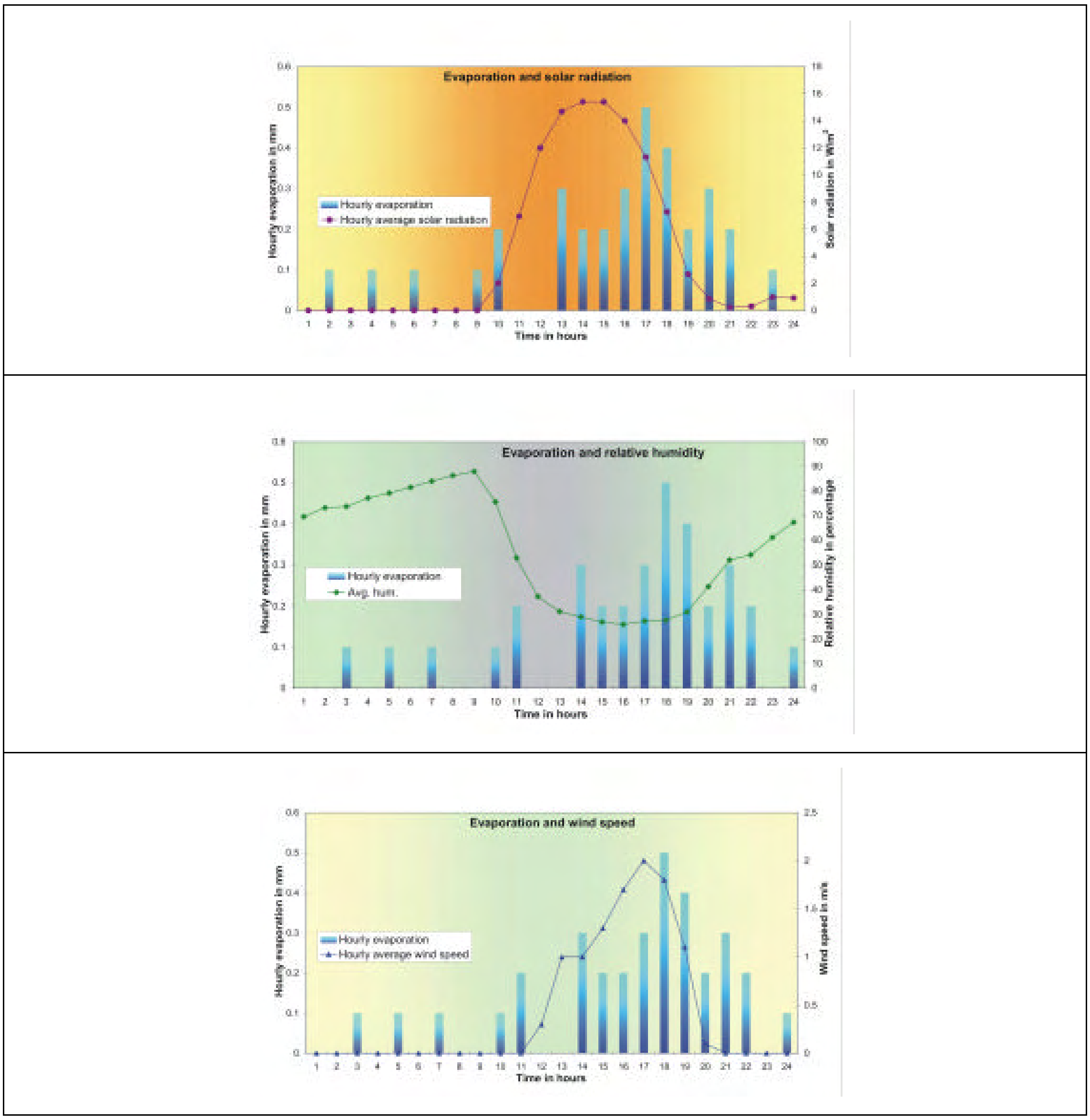


Figure 40: Hourly rates of evaporation (from the pan) in comparison to other parameters used in the Penman-Shuttleworth method *Sample data plotted here for 15* January 2005.

4.2.3.3 GROUNDWATER LEVELS IN DUG WELLS

Dug wells and observation boreholes provided the means to map water levels, both in space and time. Eight dug wells in Chikhalgaon provided information on water level behaviour, most of these falling outside the major influence of CD3, the main recharge structure. Observation boreholes were drilled to monitor water level behaviour around CD3. This section describes water level behaviour across the area surrounding the structure and how this water level configuration changes with time.

Rainfall data (as illustrated in Figure 34) for the Chikhalgaon AWS was used as a reference to chart water level behaviour for each dug well in Chikhalgaon. The hydrograph for CH6 is used to demonstrate how water levels in dug wells generally change in response to the rainfall (Figure 41). The hydrograph clearly illustrates how most wells attained the maximum level between 4th and 9th September 2003 and in mid-August of 2004, for the two monsoon periods. Although there was no quantitative water level data preceding July 2003, the current year data and qualitative observations from last year (June 2004) show that the initial rapid rise in water levels in wells (and therefore in the shallow basalt aquifer) is caused as a response to two steps in the first rainfall:

1. *The first 50 mm rain is accounted for overcoming soil moisture deficits. Water levels in dug wells remained at a minimum even after the first few spells of rain, cumulating to about 50 mm. These spells of rain occurred between 3 May and 9 June 2004.*

2. *Thereafter, a continuous spell of about 200 mm of rainfall brought about a rapid rise in water levels in the wells, indicating an augmentation of the aquifer storage. This rise is in the range of 2.5 to 5m over a period of 7 days (except for CH1 where it is greater, but some levels in CH1 may be pumping water levels) and may have actually been caused by even the first two spells of major rainfall, 30.5 mm on 9 June 2004 and 95 mm on 14 June 2004.*

Some wells like N2 (Nanegaon) respond very quickly to the first spell of rain, with water levels rising to ground level.

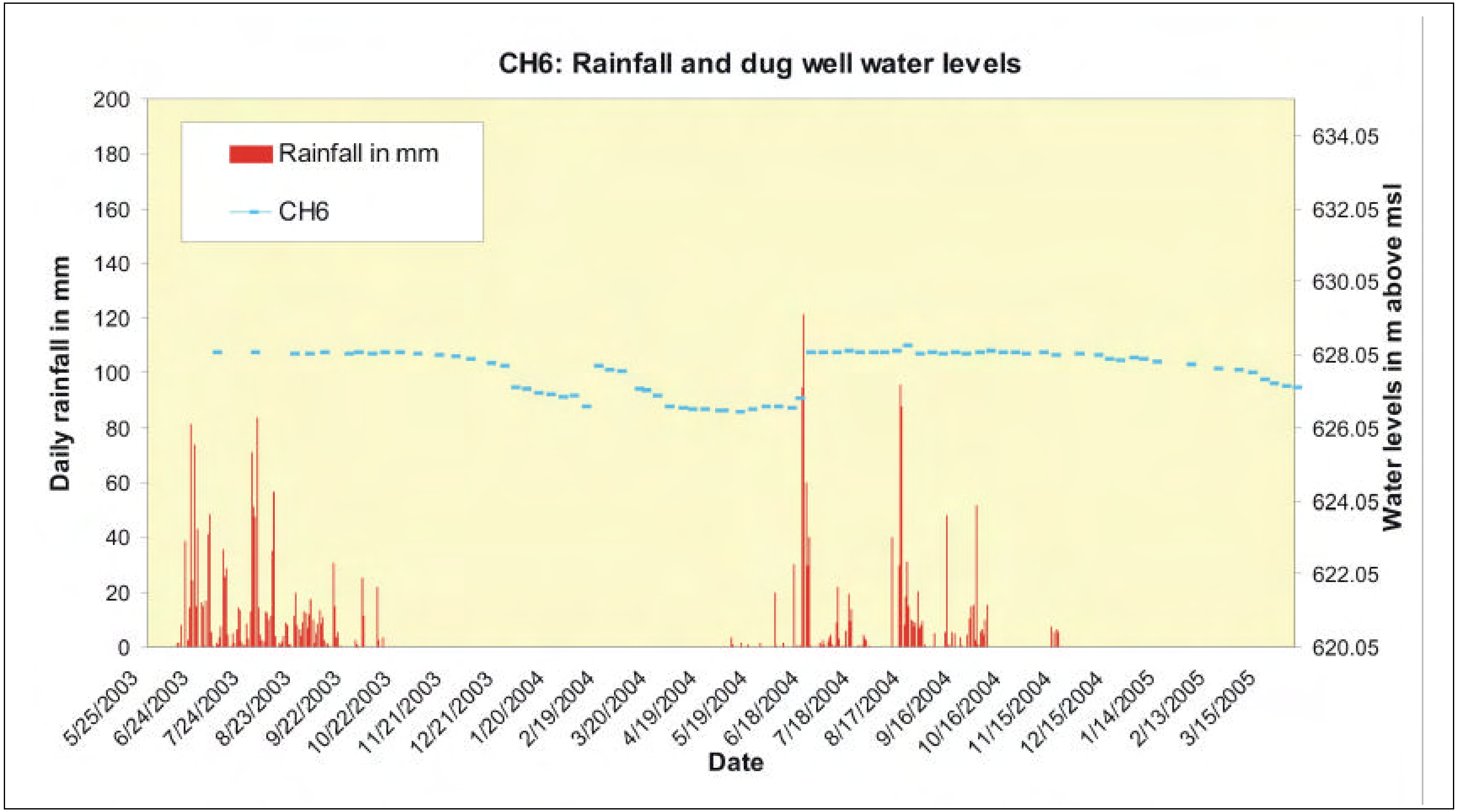


Figure 41: Hydrograph showing weekly water levels in dug wells CH6 from the Chikhalgaon watershed, along with rainfall for the two seasons. ***Data from May 2003 to March 2005.***

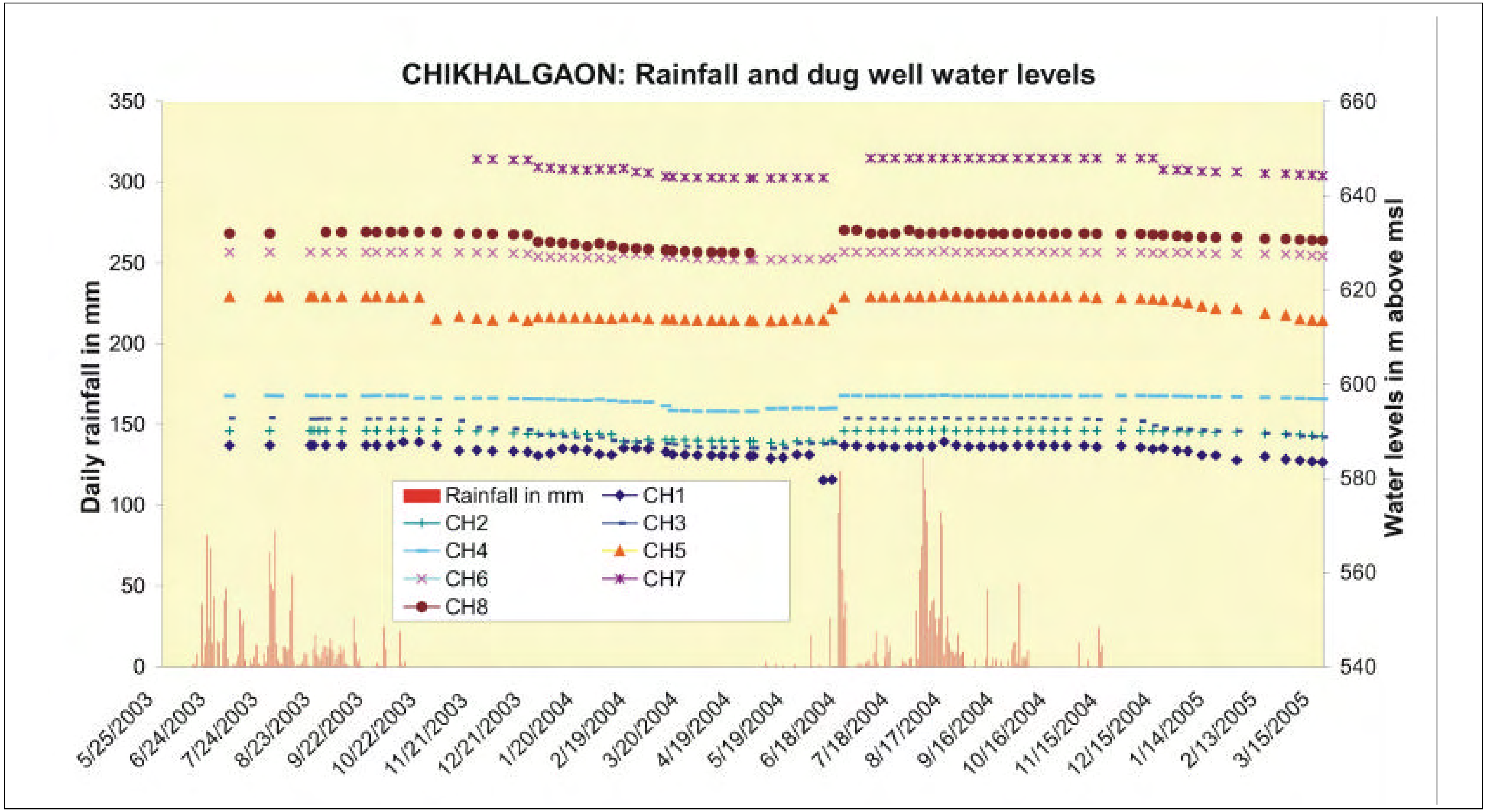


Figure 42: Hydrograph showing weekly water levels in dug wells from Chikhalgaon watershed, along with rainfall for the two seasons. ***Data from May 2003 to March 2005.***

Dug well water levels in Chikhalgaon respond both to a natural decline in the aquifer water level as well as to pumping from some dug wells (Figure 42). The individual dug well water level behaviour is summarised below:

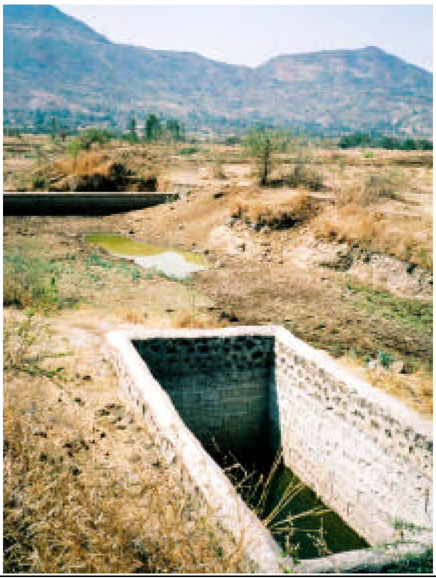
CH1: Although not within the boundaries of the Chikhalgaon watershed, CH1 represents groundwater conditions in the vicinity of the Walki river channel. CH1 is also the water supply well for Chikhalgaon village. It is pumped almost daily with an estimated daily pumping of about 25 to 30 m^3/day. The pumping varies, perhaps not so much on account of a variable daily requirement but due to the erratic power supply that drives the pump. It is estimated that the annual pumping from this well is about 7500 m^3. The annual hydrograph for the dug well indicates water levels that are mostly pumped water levels (PWLs). The water level in the well, during the period July 2003 to May 2004, dropped by 7m. Other anomalous fluctuations in the water level in the well reflect prolonged periods of non-pumping (recovery) and/or surges in the river flow of Walki that brought water into the well. The well was cleaned during the period 1 June to 10 June 2004, when the hydrograph shows an anomalous drop in water level (about 5 m or so). CH1 is pumped throughout the year, but water level fluctuations are apparent during the post-monsoon periods, indicating that during the monsoon season, the well receives enough water from the river and through groundwater flow to cause little or no drawdown during pumping for water supply to Chikhalgaon. However, during the dry season, it shows a significant fluctuation in the water level, with a gradual decline in water level, going into summer.

Dug well CH1, with river in the background; the well supplies water to Chikhalgaon village.

CH2: This private well is intermittently used for irrigation. The total drop in water level over the period of one year was about 2.5 m. Nearly 2 m of this drop occurred during the irrigation period from 20 November 2003 to 15 February 2004. Water level remained nearly constant during the last rainy season (July – October 2003). Well yield was reported to be quite good and this was evident during the pumping test conducted on this well in January 2004. This trend continued subsequently, with little water level decline during the monsoon of 2004. The well was again pumped intermittently since December 2004 from when it dropped by more than 2.5 m until March 2005.

CH3: This well in compact basalt, with low yield, was pumped in November-December till end-February, but only intermittently. The hydrograph shows a continuous water level decline from November till mid-May after remaining steady during the monsoon season.

CH4: Located almost within the water-spread area of CD2, this is the old village well that lies abandoned except for very limited use by cattle. The well hydrograph is therefore quite interesting, with a very gradual decline in the water level from Oct 2003 to Feb 2004 (only about 1 m). The water level suddenly dips from 26 Feb 2004 until 11 Mar 2004, the former date coinciding with the period during which the check dam CD2 dried up completely (26 Feb 2004). The water level in the well rose by about 0.5 m between 26 Apr 2004 and 6 May 2004 probably on account of local infiltration induced by about 4-5 mm of rain on the 3 and 4 May 2004. Water level in the well remained close to ground level over the entire monsoon period of 2004, almost into December 2004 after which a small decline was noticed. There was water in check dam CD2 until January 2005. Well behaviour for CH4 was followed more closely this year (2004-05), and it was apparent that although the well showed a very gradual decline since December 2004, water level in the well remained above the stage height of CD2 throughout the dry period over which CD2 held water. Moreover, even after CD2 ran dry on 3 March 2005, the water level in CH4 remained above the bed level of the stream, indicating a hydraulic gradient towards the stream channel.



Dug well CH4 always maintains a water level above the stage in CD2 (when the structure has water) or above the bed level of the stream (summer), indicating that it is located in a groundwater discharge zone.

CH5: A new well located near the western boundary of Chikhalgaon watershed. The well was excavated during March-April 2003 and behaves like a cistern because of limited hydraulic conductivity in the surrounding aquifer. It showed no change in water level between July and October 2003 and between June and November 2004. The well was pumped between 18th and 28th October to irrigate a patch of vegetables. This caused a major dewatering of the well storage. In the absence of recharge to the well, the water level stayed down. It was further pumped twice (end-Nov and mid-Dec 2003). It was not pumped after the monsoon in 2004. The water level decline during this dry season (Nov-04 to Mar-05) was due to natural discharge of groundwater towards the mainstream.

CH2, CH3, CH4 & CH5 show a slight rise in WLs during May 2004. This rise can be attributed to the precipitation of about 5 mm on 4 May 2004. ***It took between 7 and 12 days for water levels in the Chikhalgaon aquifer to attain a stable monsoon (high) water level after the first spell of good rains in June indicating the rapid response of the aquifer to rainfall input.***

CH6: Well to the WNW of village Chikhalgaon; not used at all except for the odd vessel being filled up for domestic use. The hydrograph for CH6 can be split into the following sections:

1. Steady water level from July to mid-November 2003.
2. Gradual decline of about 1.5 m over the period mid-Nov 03 to Feb 04.
3. Water level in the well rose by more than 1 m between 6 and 12 February 2004 – this anomalous behaviour, in the absence of any precipitation and infiltration, could be on account of irrigation return flow to the well from the sugarcane fields in the vicinity (water for irrigation is brought to the field through a pipeline lift from the Walki river). A similar rise was also noticed in January 2005, although it was not of the magnitude noticed in February 2004.
4. Progressive decline in WL thereafter until end-May.
5. Rise in water level by mid June 2004, due to recharge from the rainfall in mid-June 2004.
6. Steady water level from June to November 2004 after which a gradual decline was noticed.

Dug well CH6 with sugarcane in the background. The well receives some return flows from the sugarcane field when it is irrigated from water lifted from river Walki.

CH7: Data for this well was obtained only since November 2003. The well was pumped for irrigation during the rabi (winter season) and hence showed a decline of more than 3.5 m during the period 25 Dec 2003 to 11 Mar 2004. The well dried up gradually by early May but attained full saturation by early July after which the water level remained steady until December 2004. Pumping for irrigation began thereafter, but was not significant. This well actually taps the basalt units in the aquifer system above the main Chikhalgaon aquifer, but shows a water level trend similar to wells in Chikhalgaon and other watershed in the Kolwan valley.

CH8: Water level in the well remained steady from July to December 2003. The WL dropped by almost 2 m because of pumping for rabi irrigation (19 Dec 2003 to 19 Feb 2004). The water level declined steadily but gradually after this period, until the end of April 2004. The water level attained full saturation on 17 June 2004 but showed fluctuating water levels in the early part of the monsoon. This may have been due to intermittent pumping for paddy during the dry spell in July 2004. The well was also pumped intermittently during the period November 2004 to March 2005, again the magnitude of pumping being quite limited.

Except for a marginal effect on CH6, summer showers (approx. 5 mm in early May) ***do not*** *seem to affect CH7 & CH8. This could be because the wells are partially pentrating and the marginal rise in water levels may still have remained below their well bases. Hence, they remained dry during this period.*

4.2.3.4 WATER LEVEL DATA FROM OBSERVATION BOREHOLES

The nine observation boreholes drilled under the AGRAR study were essentially used to study the effects of the recharge structure (CD3) on the Chikhalgaon aquifer. Dug well and borehole data, together were expected to divulge information on natural recharge and recharge induced artificially through CD3. The boreholes were drilled near CD3 (Figure 27, Chapter 3). As mentioned in Chapter 3, BH1 is a deep borehole (100 m) with the shallow aquifer (20 m) sealed off completely. It is located more than 100 m upstream of and outside the influence area of CD3. Borehole BH1 is hydraulically discreet from the shallow aquifer gauged by the other observation bore holes.

Water level in the borehole gradually rose from 526.22 m above msl since drilling (20 Dec 2003) to 566.62 m above msl (on 13 Feb 2004), i.e. over 40 m in 55 days (Figure 43). This effect can simply be attributed to the post-drilling recovery of the borehole tapping a low transmissivity aquifer. Thereafter, its rise was slow until it attained a static level of 567.60 m above msl June 2004. It remained virtually steady since then until 10 September 2004, when it rose by more than 1.2 m. The hydrograph, thereafter, shows a steady continuous rise at the beginning of December 2004. These two main responses were equated to the main rain spells in June and August 2004. The response to recharge by the deeper aquifer was estimated with respect to these two main rain spells and the water level response in BH1. It is estimated that it takes about 85 to 90 days for rainfall to reach the deeper aquifer, based on the response of water levels in BH1. The water level in BH1 started dropping in early January 2005, some 85 days after the last ‘major’ spell of rain in September 2004. ***This implies that it takes about 85 days after the first major spell of rains, for water level in the deeper confined aquifer, to respond.***

Water level monitoring in boreholes (BH1 here) was done using electronic water level recorders with least count of 0.5 cm.

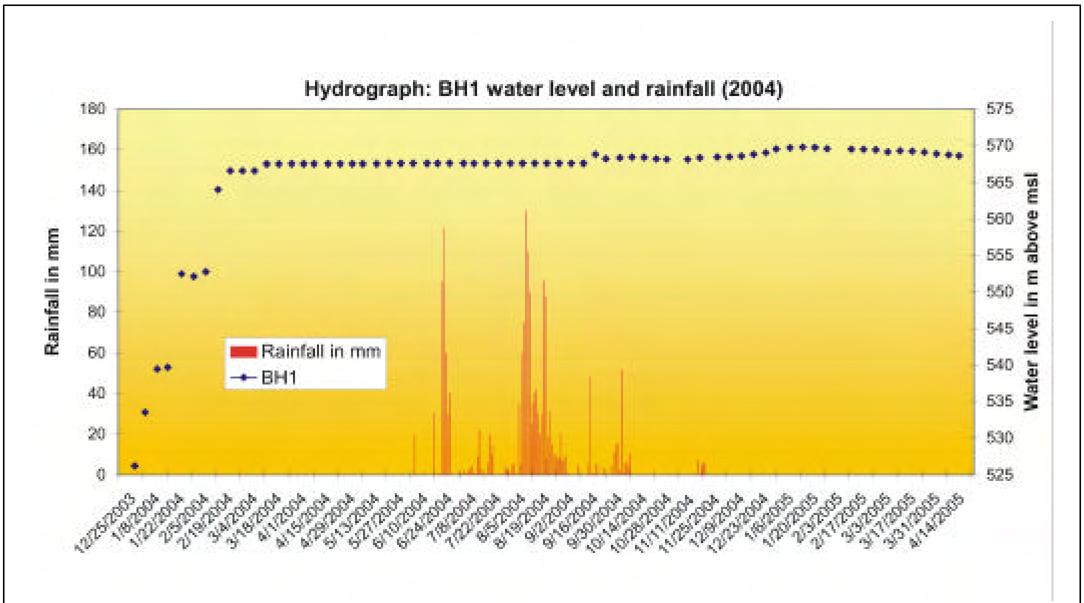


Figure 43: Hydrograph showing water levels in BH1

BH2 is located more than 100 m upstream of CD3 and taps only the shallow aquifer (within 30.3 m from the surface). There was steady rise from 594.33 m above msl on 20 Dec 2003 to 610.68 m above msl on 28 May 2004, i.e. about 17 m over a period of about 150 days (Figure 44). This was originally thought to be a combined effect of very low transmissivity of the shallow aquifer around BH2 and the effect of artificial recharge induced by the relatively high water level near CD3 during this period.

Data for 2004-2005, however, indicated a more stabilised water level than last year (just after drilling), therefore implying the initial rise in water level to be an effect of the Chikhalgaon aquifer in this location to recover from the effects of 'percussion drilling', which is often like purging the aquifer with compressed air, thereby disturbing the static heads in the aquifer in the vicinity of the drilling. Water level data and the overall head distribution in Chikhalgaon aquifer, especially in the vicinity of CD3 imply the location of BH2 outside the influence of the artificial recharge structure.

Figure 44 also indicates the distinct heads in the shallow (BH2) and deeper (BH1) aquifers. These two have been plotted together to show how quickly the shallow aquifer responds to rainfall (and infiltration) as compared to the delayed response in the deeper aquifer, as explained a little earlier.

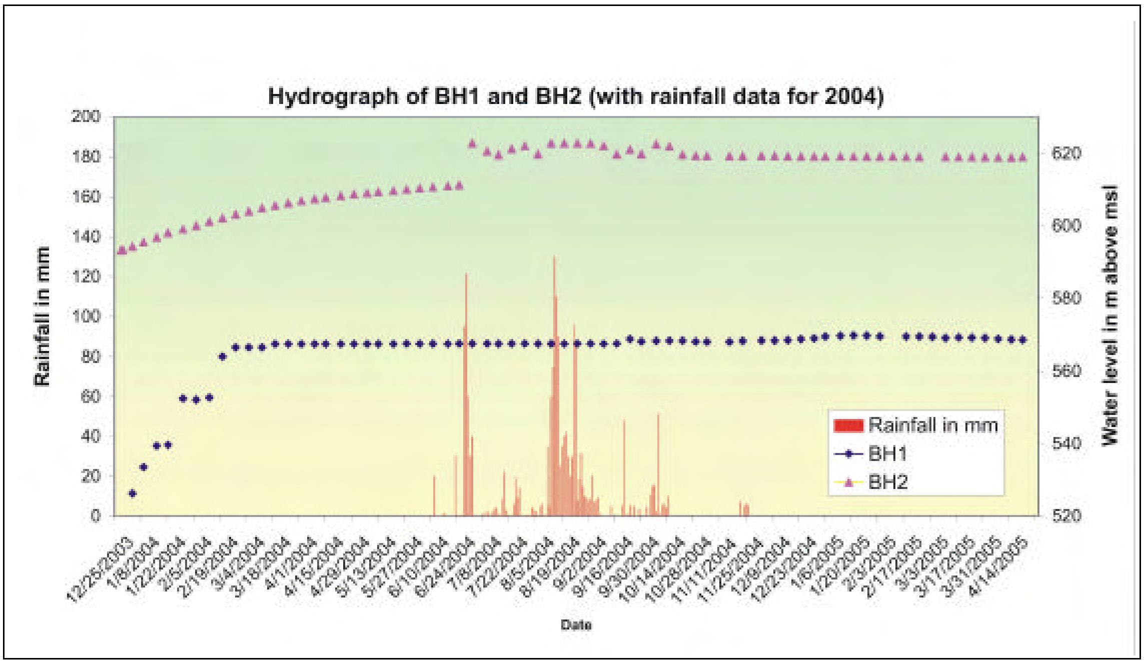


Figure 44: Hydrograph showing water levels in BH2, plotted along with the rainfall and water levels for BH1. ***Note: The initial rise of water levels in both boreholes is the effect of slow recovery in the shallow and deep aquifers due to low transmissivities.***

However, the more fascinating feature of the hydrograph of BH2 is the highly fluctuating pattern of water levels during the course of the monsoon season in 2004, a clear indication that BH2 lies in the natural recharge zone of the shallow Chikhalgaon aquifer and shows rapid responses to rainfall (rise in water level) and infiltrated water moving away quickly downslope into the main body of the Chikhalgaon aquifer (drop in water level). Incidentally, the water level in BH2 stabilised into a gradual water level decline after 8 October 2004, clearly indicating the influence of natural infiltration from rainfall on the borehole water levels. In fact, using these episodes of water level fluctuation, the natural infiltration was estimated for the Chikhalgaon aquifer (Table 17), using the equation given by Price (1996). The equation uses the product of specific yield and the rise in water table to estimate the amount of infiltration. For this estimation the equation used was:

$SQ_i = S(S_y \times \nabla WL_i)$

where,

i= 1 to n, n indicating the number of water level fluctuations during the monsoon season;

S_y= Specific yield of the aquifer (estimated from pumping test data);

∇WL= water level rise in aquifer over 1 km^2 area (assumed as the portion over which rainfall infiltrated the ground to cause a rise in the aquifer water level).

Table 17: Estimates of natural infiltration using water level fluctuations in BH2. ***A specific yield of 0.005, based on values obtained from pumping test data has been assumed***

Date	Rainfall in mm	Rise in water level of BH1over this period (forming part of the major wl fluctuation trend), in m	Infiltration from this rainfall, in mm (estimated using equation above)
11 to 18 June 2004	346.5	11.55	57.75
2 to 16 July 2004	80.0	2.46	12.3
23 July to 13 August 2004	930.0	3.05	15.25
3 to 10 September 2004	59.0	1.35	6.75
16 to 24 September 2004	45.5	2.69	13.45
TOTAL infiltration in mm			**105.5**

Some 106 mm of water infiltrated into the ground over the monsoon period of 2004. A marginal rise was noticed during the November 2004 spell of rains, but this rise is relatively small and the addition of water is less than 0.05 mm and has therefore not been considered in the above table. The total infiltration works out to be 5.7% of the total rainfall of 1860 mm during the monsoon season of 2004.

The other shallow boreholes are BH3, BH4 (eastern flank of CD3), BH7, BH8 (western flank of CD3), BH5 (just downstream from CD3), BH6 and BH6A (more than 100 m downstream from CD3). All of these are essentially downstream from CD3, and therefore, potentially in the influence area of infiltration induced from the structure. At the same time, natural infiltration was also thought to influence water level behaviour in these boreholes, especially after the first spell of rains. Water level data for these boreholes has been plotted out as hydrographs in Figure 45.

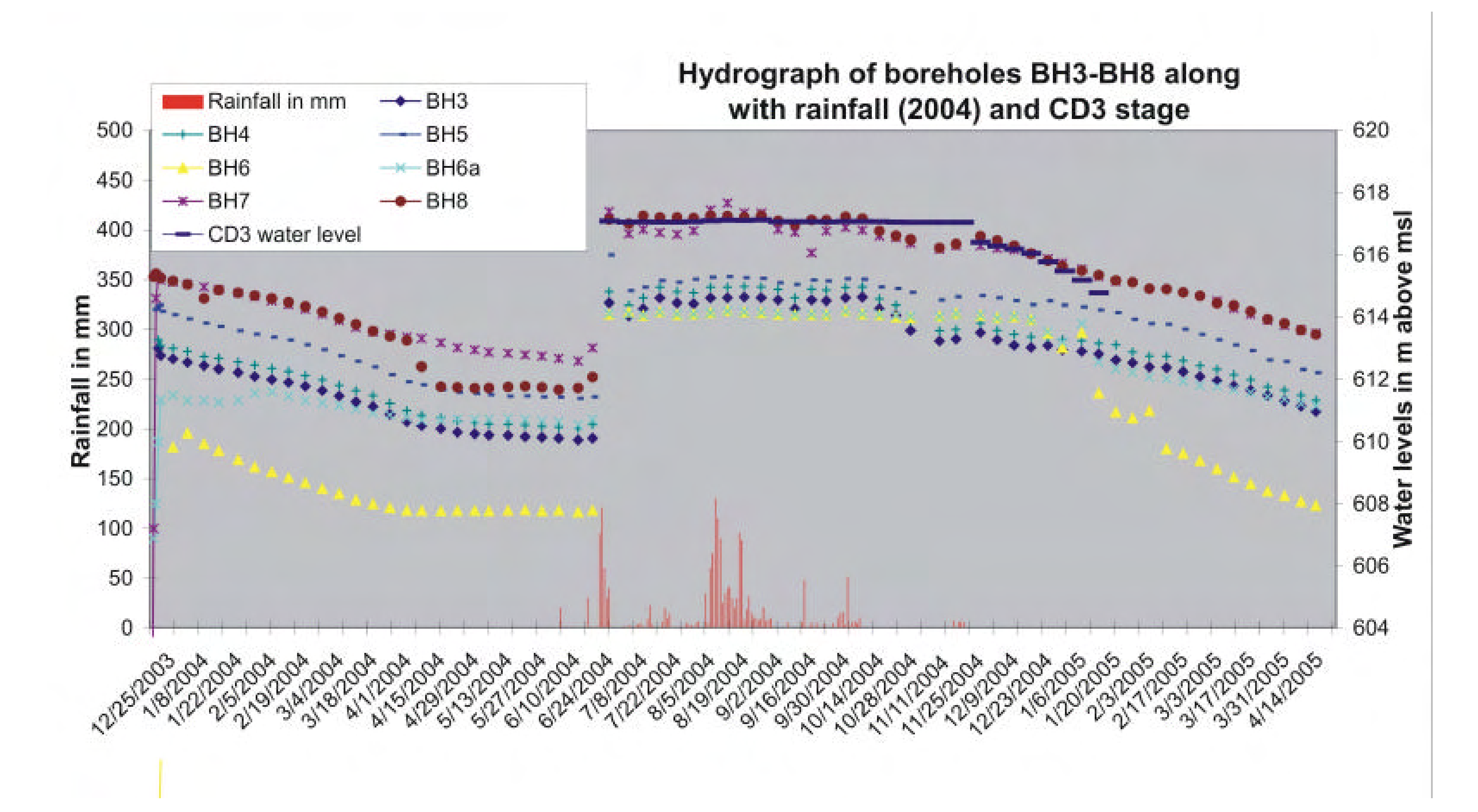


Figure 45: Hydrograph for shallow observation boreholes in the vicinity of CD3. (*Borehole data for BH3, BH4, BH5, BH6, BH6A, BH7 7 BH8; daily rainfall for 2004 and the stage in CD3 from when it filled up in June 2004 until it ran dry in January 2005*).

Except for BH6 and BH6A, which show an initial rise after drilling, all the other boreholes show steady water level decay from 20 Dec 2003 to 28 May 2004. Although BH6 and BH6A are within one metre from each other and have the same well-head elevations, they show a difference of about 3 m in their water levels. It is quite likely that this difference is either due to the presence of a (vertical) fracture boundary inducing a near-vertical gradient across the sub-vertical fracture system in which the boreholes are located or because of a significant difference in the connectivities of BH6 and BH6A with the surrounding aquifer.

The response of the shallow observation boreholes next to CD3 was quite rapid after the first rainfall event, causing a quick filling up of CD3. Some water level rise was noticed in all these boreholes between 5th and 11th June 2004, after a rain spell of 30.5 mm in the 9th June. This rain, however, did not cause any water to flow into CD3, which remained nearly empty till the first heavy spell of rainfall on 14 June 2004. The structure started filling up on the 15 June 2004 and topped up before the 18 June 2004, when nearly all the observation boreholes showed near-full saturation in the Chikhalgaon aquifer. This initial response of water levels in these boreholes may be due to the effect of natural infiltration. Again, assuming a specific yield of 0.005, an average worked out from pumping test data (discussed later in this Chapter), this initial infiltration, which can be assumed to be almost completely natural, is about 23 mm. This is less than 50% of the infiltration around BH2, a natural recharge area.

The relationship between water levels in boreholes and the stage in CD3 can also be summarized here, the important aspects of this relationship are:

- The water levels in BH7 and BH8 remained very close to the CD3 stage during the main monsoon period (June to October 2004). Again, the water level in BH8, except for a short period during the initial decay in the CD3 stage covering the period between 1 October and mid-November 2004, remained higher than the CD3 stage, clearly implying that groundwater flow during much of this period was towards the stream. Interestingly, though, water levels in BH7 rose to levels above the CD3 stage during the two periods of intense rainfall, i.e. in mid-June 2004 and then during the main spell of rain between end-July and 20 August 2004. During other periods, the gradient would have been from the structure towards BH7, implying infiltration from the structure to the aquifer around BH7.
- Water levels in the other boreholes, i.e. BH3, BH4, BH5, BH6 and BH6A, always remained below the CD3 stage, implying some degree of infiltration to the Chikhalgaon aquifer towards the eastern and southern directions. At the same time, borehole water levels also indicate a one-to-one relationship with rainfall spells, clearly implying some degree of influence by natural infiltration from rainfall in their respective vicinities.
- The hydrograph clearly indicates the difficulties in separating the effects of induced infiltration and artificial recharge from the background natural infiltration, especially during the rainy season. All boreholes (except BH6) respond in a more or less a similar manner to the rainfall and the stage in CD3. However, on close examination, BH7 and BH8 fall more rapidly in line

with the water levels in CD3 until it dries up than the rest. ***In other words, the check dam influences water levels to the west (BH7 and BH8) but not in the other directions, even at similar distances away from the structure. Also, natural infiltration from heavy showers of rain, clearly mask the more subtle effects of artificial recharge from CD3.***

Water levels in all the boreholes (apart from BH7 and BH8) dropped significantly faster after CD3 dried up in early January 2005. This increase in decline of the static water levels in the Chikhalgaon aquifer clearly indicate that water from CD3 infiltrates into the ground and influences heads in the Chikhalgaon aquifer, in close proximity to the structure.

As mentioned earlier, in this section, the maximum natural infiltration is in the vicinity of BH2, with local infiltration around other boreholes restricted to well within that around BH2. ***The natural infiltration to the Chikhalgaon aquifer is about 106 mm. The actual net addition to aquifer storage from such infiltration occurs rapidly, during the first episode of the infiltration, i.e. about 58 mm (Table 18). This brings water levels in the Chikhalgaon aquifer to near full saturation. The subsequent episodes of infiltration are thought to induce base flow discharges rather than adding much to groundwater storage because the aquifer is in a state of near full-saturation after this first episode, until the end of the monsoon period (Figures 44 and 45).***

It was therefore thought necessary to gain a better insight to the infiltration from CD3, as separate from natural infiltration. Two approaches were adopted in order to separate the artificially induced infiltration from CD3 from the natural infiltration. In the first case, cross-sections with groundwater levels in observations boreholes, relative to the water levels in CD3 were studied, whereas in the next approach, actual water balances were calculated based on the inflows, overflows and decay in the water levels of the check dam, i.e. CD3.

4.2.3.5 Observation borehole data around CD3, as cross sections over time

Weekly water levels have been plotted out in a cross section across the Chikhalgaon stream, from January 2004 to February 2005. Although the sections consider four boreholes, BH8, BH7, BH3 and BH4 along a straight line, in reality, the section represents, the distance of each borehole from CD3, rather than the directional component. Incidentally, CD3 topped over in mid-June and overflowed until nearly mid-October. Each section also shows the borehole head elevations (borehole top) as well as the top and bottom of CD3, as reference. The spatial distribution of head in the Chikhagaon aquifer, and the temporal changes therein, is provided in the form of water table contour maps, provided along with each section. The water table contour maps have been generated using dug well and borehole water level data and show water table contours at an interval of 1 m. The specific yield of the Chikhalgaon aquifer, on an average, has been assumed to be 0.005 (based on pumping test data, described later on in this Chapter). Also, boreholes in the water table contour maps have been labelled as B2, B4, B7 etc. instead of BH2, BH4, BH7 etc. to ensure clarity to the diagrams. Each section is described separated below:

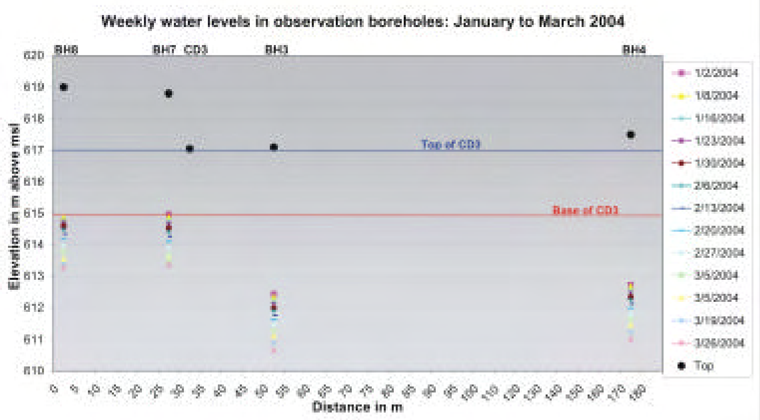
January to March 2004

The water table profile envisaged from the cross section of observation boreholes shows a direct relationship with the surface topography, which is fairly coherent with the borehole top elevations (Figure 46A). There was no water in CD3 from November 2003 onwards, and hence, Figure 46A clearly indicates that water levels remained below the base of CD3. Moreover, the hydraulic gradient on either side of the stream is towards the stream, i.e. it follows the topography. However, during the early period, i.e. in January 2005, the water level in BH7 is higher than that in BH8 by about 30 cm, indicating that a build-up of a small mound through the induced infiltration from CD3 (post-monsoon 2003) was likely. To a lesser extent, this profile is maintained through the month of March as well, although it is not as prominent as in January 2004.

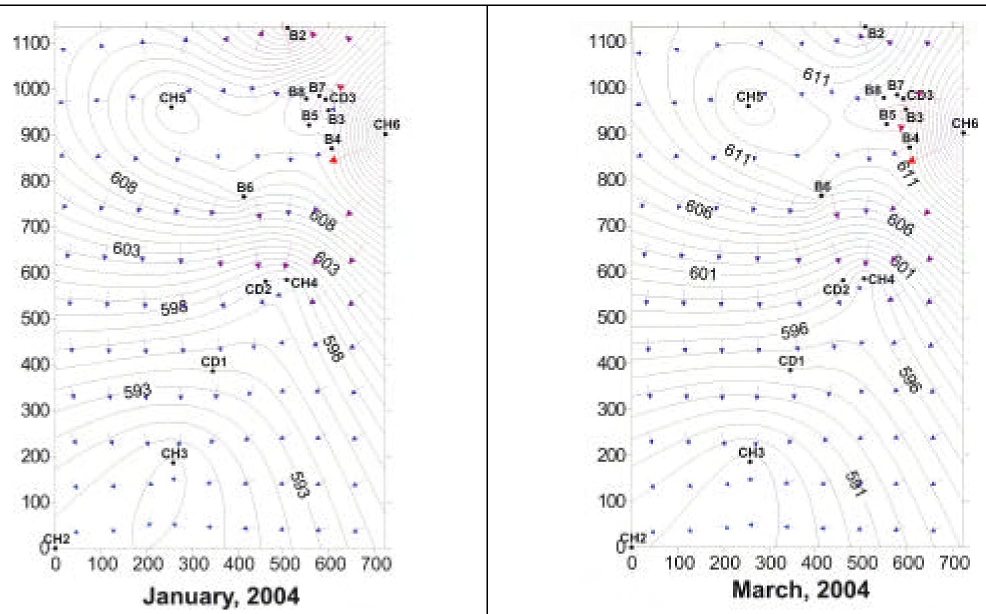
It was impossible to drill a borehole at the centre of the stream, to measure the water level under the stream channel. However, experience from areas in the Deccan basalt clearly shows that groundwater flow across stream channels is rare and generally streams form a 'no-flow' boundary (Kulkarni, 1987; Pawar, 1995; Joseph, 1997). Hence, groundwater flow from either side of the stream gathers along the stream channel, only to flow in the southwesterly direction, downstream in this case.

Water levels in the Chikhalgaon aquifer, from January to March 2004 indicate a mound in the vicinity of CD3 (Figure 46, B & C). Groundwater flow downstream of CD3 is similar to what would be expected in an otherwise natural profile. However, hydraulic gradients appear to be greater due to the creation of the local mound around CD3. *The development of a mound was initially thought to be an effect of the slow stabilisation of water level in BH2 after drilling, rather than regional flow to BH2 from the area near CD3. However, the cross section (Figure 46A) clearly shows that there is a distinct high developed in BH7, although the geometry of contours in Figure 47B is a result of both these factors together.*

Borehole BH2 continued to recover/stabilise after drilling, until the monsoon, i.e. June 2004. The mound was less pronounced in March 2004 (Figure 46 C) and was not as pronounced as earlier. Both the contour maps clearly show the groundwater discharge areas downstream of CD3, especially near CD2.



A



B

C

Figure 46: Cross section across stream section using water levels (Jan-Mar 2004) from observation boreholes and water table contour maps (borehole and dug well data) for January and March 2004. *Values, wherever not indicated, are in* m.

<u>April and May 2004</u>

The water table profile envisaged from the cross section of observation boreholes illustrates that the water level in the Chikhalgaon aquifer lay much below the position of the stream, with BH7 still showing a high as compared to the other observation boreholes, offsetting the natural groundwater flow profile towards the stream, in the portion west of CD3. On the other hand, groundwater flow on the eastern flank of the stream maintains a profile parallel to the surface topography, but with a very gentle hydraulic gradient towards the stream. Water levels for most part of this period remained static in BH8, perhaps due to groundwater flowing towards this borehole from the area around CD3 and BH7.

The effect of the mound developed at BH7 was still apparent in the water table contour map (Figure 47B). The explanation provided for this geometry is pretty much the same as explained in the earlier Figure (Figure 46B & C). The hydraulic gradients decreased in May, although the geometry of the water table contours still remained similar to that for January-March, with a groundwater discharge area in proximity to CD2 downstream.

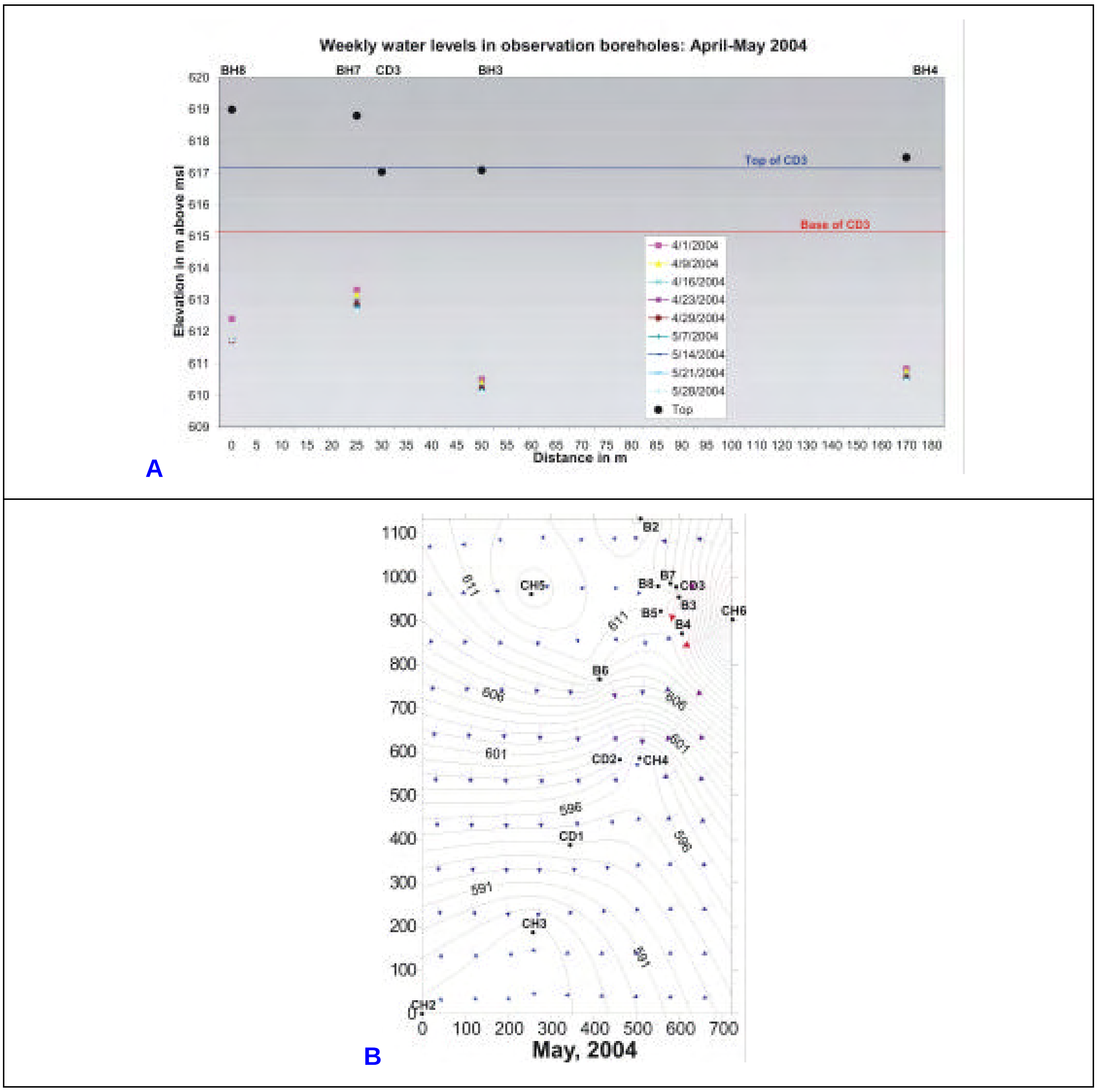


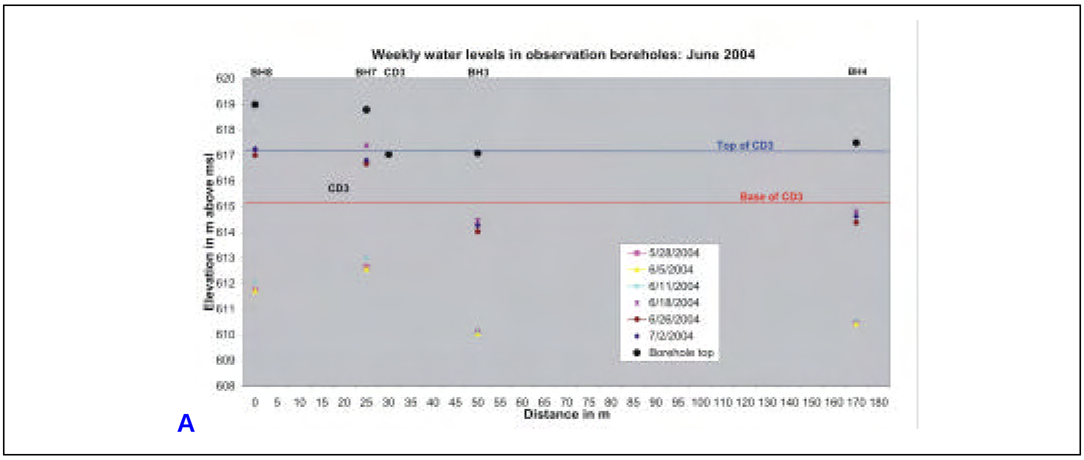
Figure 47: Cross section across stream section using water levels (April & May 2004) from observation boreholes and water table contour maps (borehole and dug well data) for May 2004 (the plot for April 2004 closely approximates to that in May 2004 and hence is not given separately here). ***Values, wherever not indicated, are in*** **m.**

June 2004

The structure CD3 filled up between 11 and 18 June 2004. The water levels in all boreholes also showed a quick response to the rainfall between these two dates (Figure 48A). The water level in BH8 rose by 5.07 between these two dates. Water levels in BH7, BH3 and BH4 rose by 4.4, 4.35 and 4.27 m respectively. Assuming a specific yield of 0.005, this implied that infiltration around BH8 during this period was about 26 mm, whereas that in the remaining 3 boreholes was between 21 and 22 mm, assuming an area of 1 km^2.

Although the net rise in water level in BH8 is greater than that in BH7, the water level in the latter rose to a significantly higher level than any of the boreholes, indicating that it may have been influenced more by infiltration from CD3. Also, considering the hydraulic gradient between CD3 and BH3, infiltration towards BH3 from the structure also seems quite possible. *What is quite clear is the first infiltration and recharge is quite a rapid event (less than 7 days), where most of the infiltration results into effective recharge to the underlying aquifer, bringing water levels close to ground level on the western flank of CD3, but levels on the eastern flank remain well below the base of CD3, i.e. below the bed level of the stream, implying that some degree of infiltration (most of this resulting in recharge to the shallow aquifer, the rise in water levels indicating addition to the aquifer storage), i.e. about 22 mm occurs to the Chikhalgaon aquifer during this period.* ***Of this, some 10 mm may actually be the addition to the aquifer storage considering that a rise of about 2 m in BH7 water level would bring it on par with the bed level in the stream (CD3). This implies an addition of about 10 mm considering an area of about 1 km2, not an unrealistic estimate of recharge surrounding the structure. Further rise in water levels would mean infiltration, most of which would leave the system as base flow to downstream areas.***

Figure 49B shows that a mound now actually develops at BH3, just after the main rain spell in June (i.e. 18 June 2004), but with the overall hydraulic gradient showing that groundwater flow occurs towards the stream, and in effect, towards the structure, i.e. CD3, clearly indicating the local effect of artificial recharge from the structure. *Hence, one can safely assume that the artificial recharge, at the most, equals infiltration around the CD3, i.e. it is equal to or less than 22 mm.* The recharge area around BH2 is also evident in the Figure. As mentioned earlier, the natural infiltration in this area, during this period was about 58 mm, definitely greater than that around the structure. Regionally, the groundwater flow is directed from the watershed boundaries (coherent with the aquifer boundaries) towards the stream, which is the groundwater discharge boundary. The discharge is apparent in the water table contour map from just downstream of CD3, with CD2 downstream, clearly marking a prominent groundwater discharge zone.



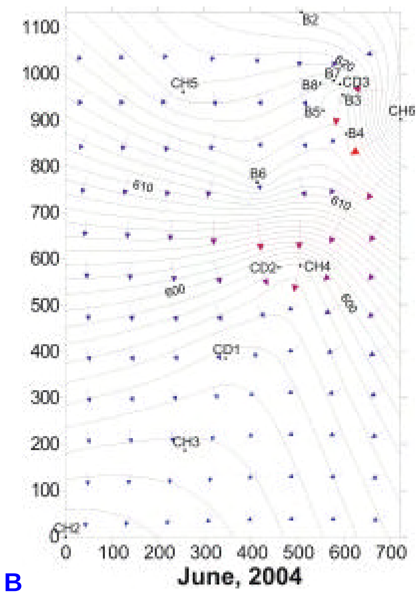


Figure 48: Cross section across stream section using water levels just at the beginning of the monsoon season (June 2004) from observation boreholes and water table contour maps (borehole and dug well data) for June 2004. *Values, wherever not indicated are in m.*

July-August 2004

Sections for July and August show some contrast (Figure 49A & B). Rainfall in July 2004 was comparatively lesser than that in June or August. Also, rainfall was in the form of low-intensity showers. The cross section for July 2004 indicates that water levels in BH7 and BH8 remained close to the stage in CD3, whereas water levels in BH3 and BH7 remained near the base of CD3, i.e. just below the stream bed level. In August, there was virtually no water level fluctuation in BH8, BH3 and BH4, implying no significant addition to the aquifer storage. However, BH7 showed a rise and then a fall in water level, within 1 m, the most significant observation being that the water level close to CD3 had dropped below the stage in CD3 by the end of August, creating a potential for infiltration from CD2, particularly on the western flank, during this period. However, the magnitude of such infiltration was not expected to be quite small and addition to aquifer storage not in measurable quantity. Water levels in BH3 and BH4 rose by less than 0.5 m in July, with water levels in BH8 remaining virtually static. Only BH7 showed a net water level rise of about 0.8 m, implying a very small amount of infiltration, i.e. less than 5 mm (assuming a specific yield of 0.005).

Figure 49C & D show how the hydraulic gradients steepened slightly in July, after the June spell of rain (Figure 48), but again become gentler in August after the heavy spell of rains (end July-early August 2004). The local effect of infiltration from CD3 is evident, especially in the August map (Figure 49D), with a small mound indicated around BH3. However, as mentioned above, the magnitude of recharge from CD3 to the Chikhalgaon aquifer is likely to be quite small during this period, with the overall picture of water table contours indicating groundwater flow towards the stream, including in the portion adjacent to CD3.

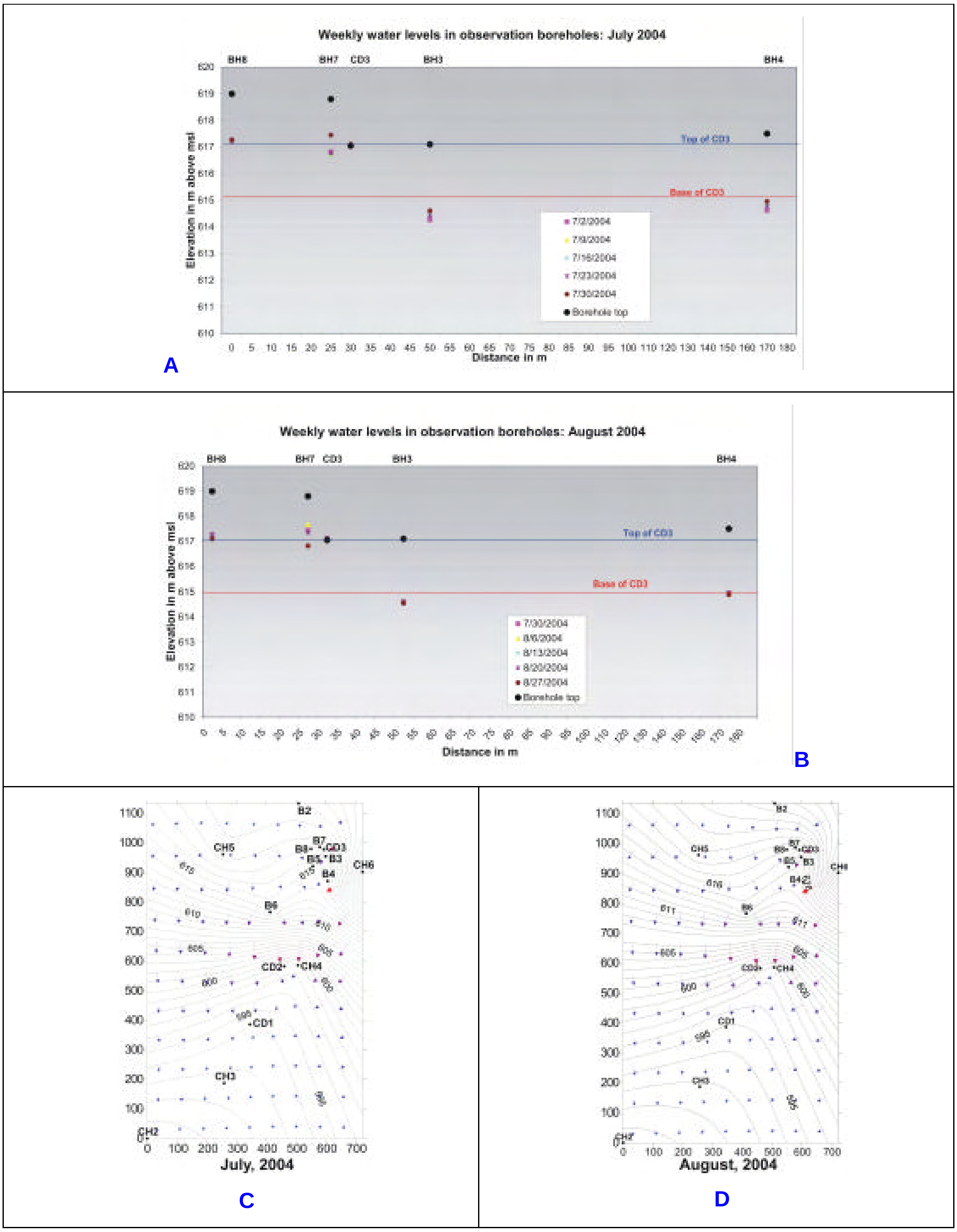


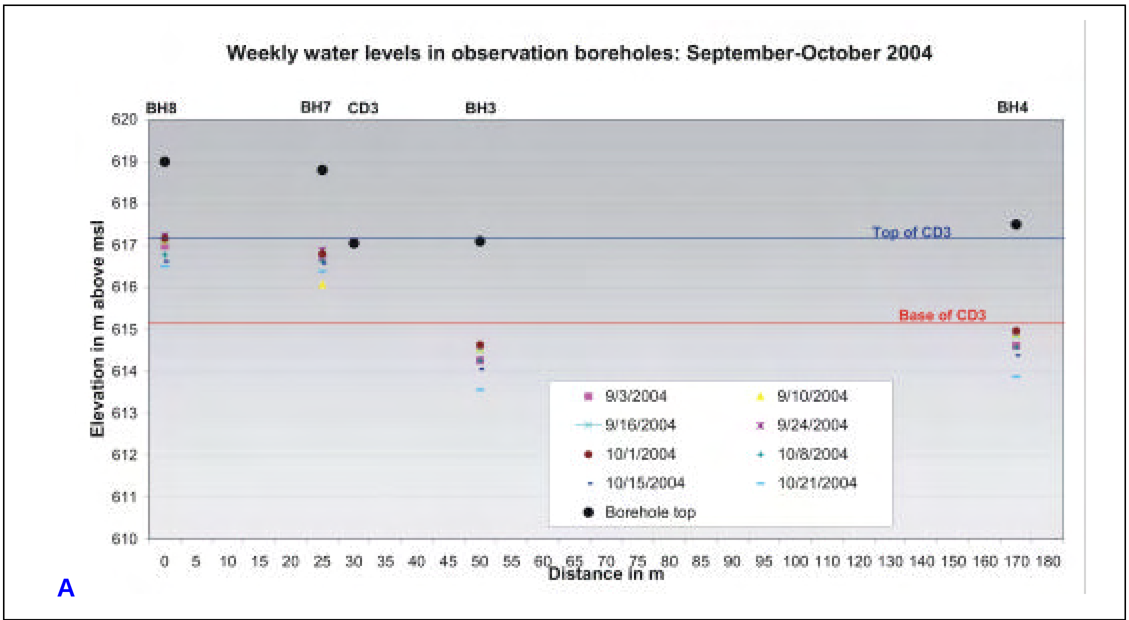
Figure 49: Cross section across stream section using water levels from observation boreholes in July and August 2004. Water table contour maps (borehole and dug well data) illustrate the picture for these two months. *Values, wherever not indicated are in m.*

September-October 2004

Sections for September and October 2004 show that levels in September rose and dropped in response to an early spell of good rain and then a decreased rainfall respectively (Figure 50A). Again, there was rain at the end of September and water levels in all the four observation boreholes peaked on 1 October 2004. Most significantly, water levels in BH7, during this period, were below those in BH8 and the stage in CD3, implying groundwater flow from both these directions towards BH7. Water levels in BH3 and BH4 remained near the base of the structure, although in early October, the water level in BH4 rose to a level slightly above the base of CD3. However, the groundwater gradient remained towards the stream on the eastern flank of the structure.

The net rise in the water levels in BH3 and BH4 was more than 1 m. whereas in BH7 and BH8, it was 0.7 to 0.8 m. Again, assuming a specific yield of 0.005, the infiltration was about 4 to 5.5 mm, part of which may have been derived from rainfall. However, considering that water levels in all the four boreholes (except for short periods in BH8) remained below the stage in CD3, a large proportion of this infiltration may be assumed to have resulted from CD3. *Considering this factor, one can surmise that the infiltration from CD3 during this period, was only about 4 mm, most of which would be lost as baseflow downstream (calculated over an area of 1 km^2).*

Figure 50B & C clearly indicate the dominance of groundwater flow towards the stream. Whatever local effects of infiltration from CD3 are not very clearly apparent in the water table contour maps.



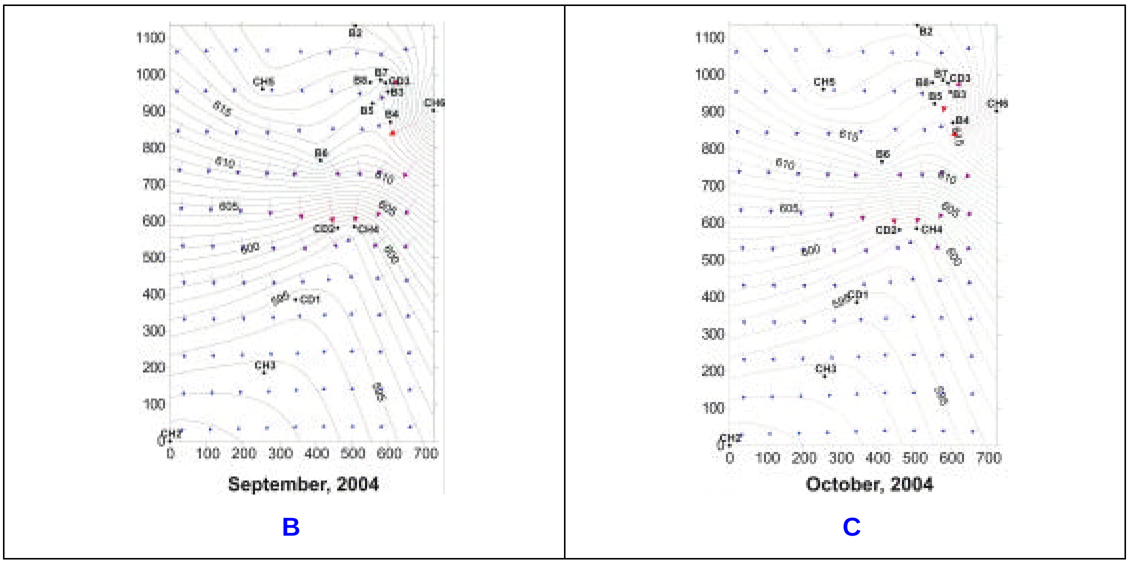


Figure 50: Cross section across stream section using water levels from observation boreholes in September and October 2004. Water table contour maps (borehole and dug well data) for these two months. *Values, wherever not indicated are in m.*

<u>November-December 2004</u>

The structure CD3 stopped overflowing on 11 November, after which there was a continuous water level decline in the structure, for which a detailed water balance has been developed later in this Chapter. CD3 dried up completely in the first week of January 2005. Figure 51A shows that water levels in BH8 declined more rapidly as compared to those in BH7, BH3 and BH4. The hydraulic gradient from the CD3 stage was towards all these three boreholes. However, BH7 also seemed to receive water from BH8, in addition to that from the structure. Water levels in BH8 and BH7 were within a range of 1 m from the declining stage in CD3. On the other hand, water levels in BH3 and BH4 dropped to below the base of the stream and hence, technically, some gradient from CD3 towards BH3 and BH4 could be expected during this period.

Assuming that the water level decline in BH8 is due to natural factors and outside the influence of CD3, and using the decline in BH7 as a net effect of natural decline and recharge from CD3, the total difference in decline in water levels in these two boreholes was estimated to be 0.35 m. This was, therefore assumed to equal the addition of water to BH7 from CD3.

Again using a specific yield of 0.005, this equals 1.75 mm of water added as artificial recharge to the Chikhalgaon aquifer. Similarly, netting off the water level declines in BH3 and BH4 versus that in BH8, the value estimated is 2.5 mm of addition to the aquifer from the structure.

The value of 1.75 nearly equals the value estimated for infiltration from the structure to the aquifer, using the dry season water balance, developed later in this Chapter. Figure 51B & C clearly indicate the dominance of groundwater flow towards the stream, even in the vicinity of CD3. Whatever local effects of infiltration from CD3 are not very clearly apparent in the water table contour maps except for a slight mound around BH3. Local infiltration resulting in recharge of about 2.00 mm occurred from CD3 to the adjoining portions of the underlying Chikhalgaon aquifer during this period. The discharge of groundwater in the vicinity of CD2 is, however, quite clear.

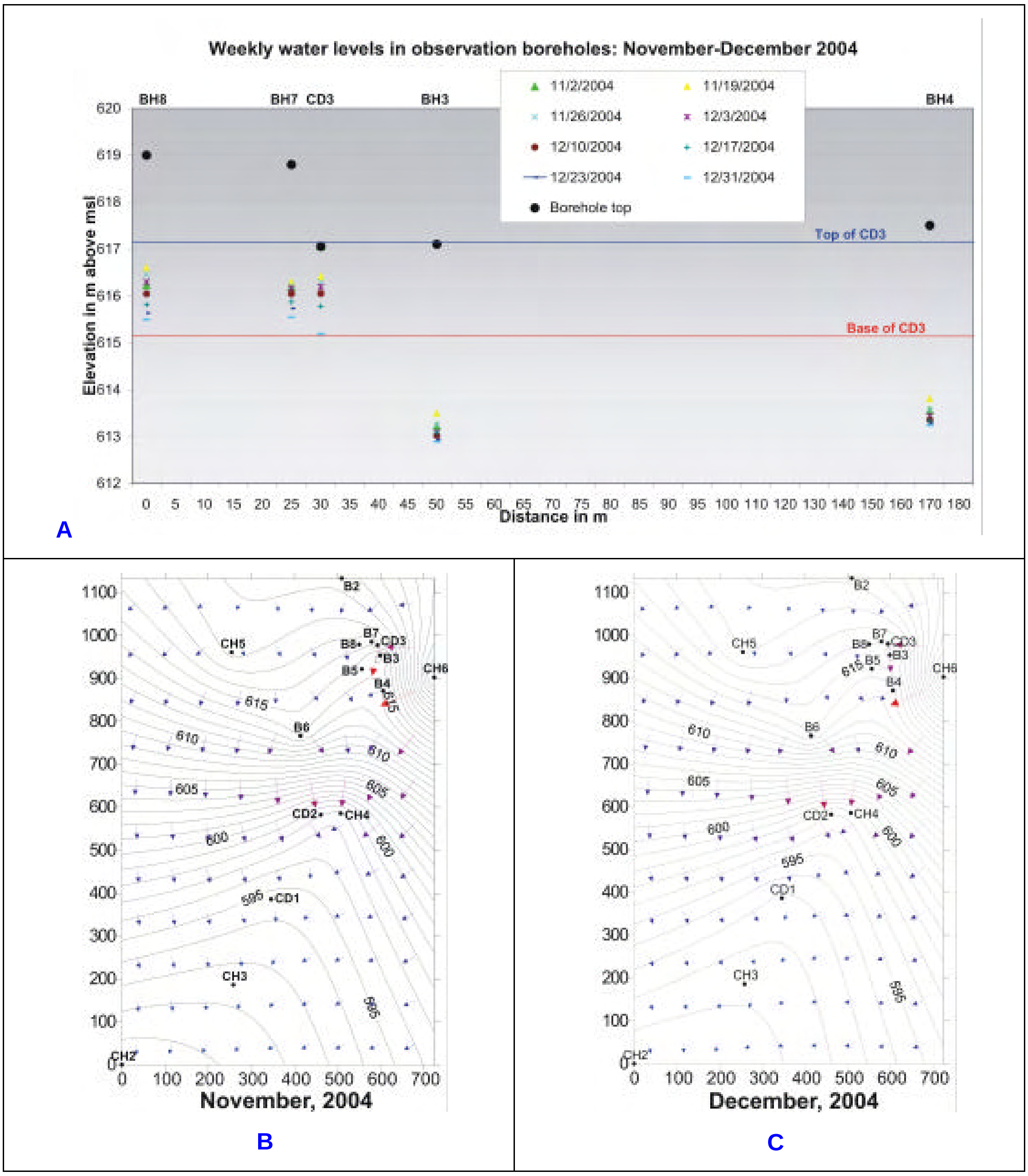


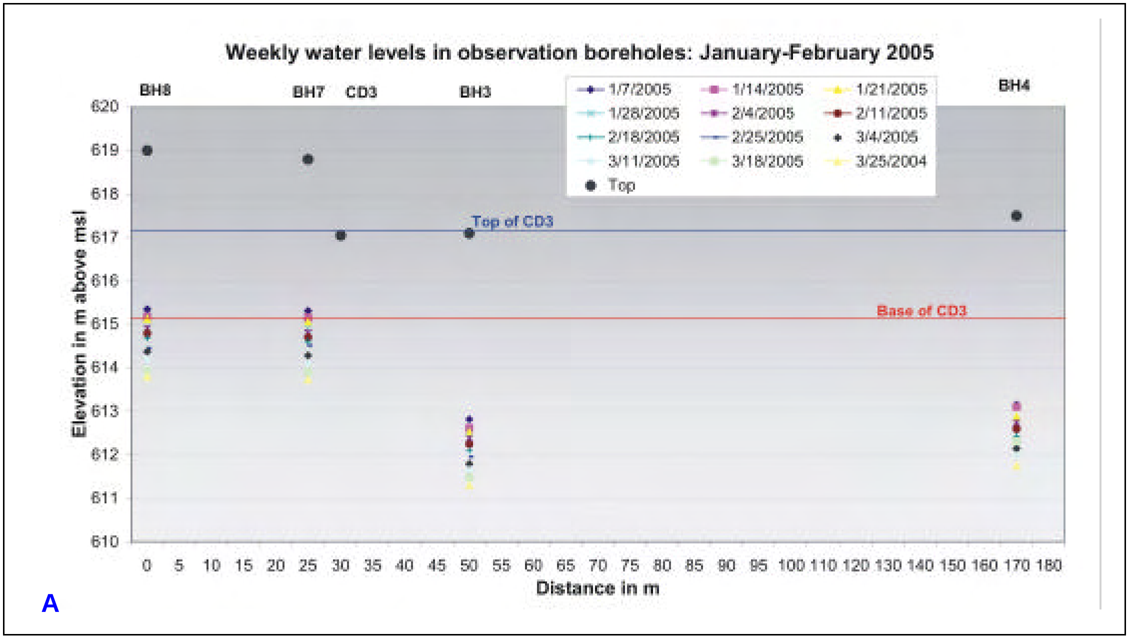
Figure 51: Cross section (A) across stream section using water levels from observation boreholes in November and December 2004. Water table contour maps (borehole and dug well data) for these two months are presented as B and C. This period coincides with the period over which CD3 ran dry. *Values, wherever not indicated are in m.*

January-February 2005

There was no water in CD3 after the first week of January 2005. The water levels in the boreholes between January and March 2005 clearly indicate that the hydraulic gradients on either side of CD3 are very gentle as water levels throughout the Chikhalgaon aquifer drop as a consequence of natural groundwater discharge, i.e. base flows towards the downstream portions of the aquifer, i.e. towards CD2 (Figure 52A). However, water levels to the west of CD3 (BH7 & BH8) remained close to or just below the base of CD3, i.e. near the stream bed. Water levels, in BH3 and BH4, on the other hand, were 2 to 3.5 m below the stream bed level.

Water levels in all four boreholes dropped by nearly the same magnitude, despite their locations (1.4 to 1.55 m) over a period of 77 days. There was no water in CD3, and therefore, no artificial infiltration/recharge. However, considering a drop of about 1.5 m across the aquifer in this portion, with the average specific yield (0.005), some 7.5 mm of water was discharged downstream from the aquifer.

Figure 52B clearly indicates the dominance of groundwater flow towards the stream, even in the vicinity of CD3 during this period. Although a local mound is indicated in the vicinity of the structure, the general groundwater flow is towards the stream. Although it is not distinct in water table contour maps, the hydraulic gradients decrease towards March, indicating a drop and a levelling off of water levels across the Chikhagaon aquifer. CD2 dried up in March, but the groundwater discharge zone remained prominent in and around the location of CD2.



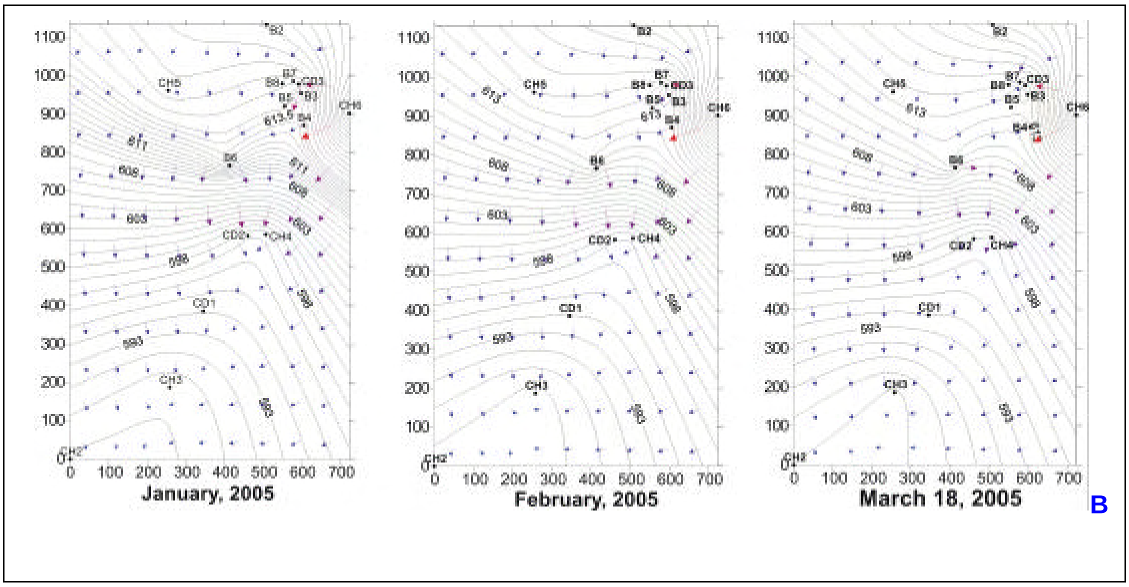


Figure 52: Cross section (A) across stream section using water levels from observation boreholes from January to March 2005. Water table contour maps (borehole and dug well data) for these three months are given in (B). There was no water in CD3 during this period. *Values, wherever not indicated are in m.*

Table 18 consolidates the observations and inferences on the estimates of artificial recharge during the period June 2004 to December 2004, the period over which the structure was effective in infiltrating water into the Chikhalgaon aquifer.

Table 18: Infiltration events from CD3

Period of event	**Rainfall in mm**	**Estimated infiltration from structure in mm (rounded off)**	**Natural infiltration, estimated from water level behaviour in BH2, in mm**
June 2004	391.5	22 *(10 mm as effective recharge)*	58
July 2004	288.5	5	12
August 2004	896		15
September-October 2004	211	4	21
November-December 2004	52 (only in November)	2 *(all 2 mm as effective recharge)*	-
TOTAL (in mm)		**33** ***(12 mm as effective recharge)***	**105**

Hence, using a combination of water level data and water table contours, the total infiltration from CD3 was estimated to be 33 mm (over an area of 1 km^2 mainly covering the aquifer surface area of the Chikhalgaon aquifer). Of this, some 12 mm can be considered to be the effective addition of water from CD3 to the aquifer. The natural infiltration (using data from BH2) was estimated to be 105 mm, out of which, the first spell of 58 mm results into effective recharge to the aquifer. Considering that later spells may contribute limited amounts of water to effective recharge, based on close observations summarised in Table 18, the natural recharge to the Chikhalgaon aquifer can be estimated to be some 80 mm, some 4% of the annual rainfall. The infiltration (105 mm), on the other hand, is about 6% of the annual rainfall. Hence, more than 50 mm of base flow is generated from this area, although in the lower portions of the Chikhalgaon watershed, it is expected to be somewhat greater in magnitude and may actually approach or even exceed the amount of recharge.

4.2.4 Water balance for CD3

The water balance for CD3 was calculated over two periods:

1. Post-monsoon (dry season) period between October and December 2003 and between October and January 2004.
2. Monsoon (wet season) period between June and October 2004, i.e. during the period of overflow from CD3.

Check dam CD3 in different stages of monitoring shows overflow during the monsoon season (left), water level decline after the monsoon season (middle) and running dry in winter (right). ***The photographs show the monitoring set-up including a staff gauge and the stilling well with the data logger (in the box, right hand photograph).***

4.2.4.1 Dry season water balance (period of negligible or no inflow and no overflow for CD3)

The equation of water balance for the dry season can be written as:

$$\nabla S_d = E + I + L_e + B_f \qquad \text{(i)}$$

where,

∇S_d= loss of water from CD3, measured as fall in water level in CD3 and computed as depletion of water level over individual time steps (refer Table…), in mm, during the dry period (i.e. period of no overflow on CD3)

E= evaporation in mm estimated on the basis of dry season evaporation from open pan for this year (2004) and using evaporation values of data from Karmoli weather station (for last year, i.e. 2003)

I= Infiltration in mm

L_e= Leakage from CD3 in mm

B_f= Base flow contribution to the check dam, found to be negligible, both in 2003 and 2004

Infiltration was thus estimated by the following equation, derived from eqn (i)

$$I = \nabla S - E - L_e \qquad \text{(ii)}$$

(a) October to December 2003

Table 19 below summarises the data for the water level decay in CD3 after the overflow had stopped October 2003. The irregular shape of CD3 implies that each time step with its respective water level drop signifies a certain volume loss from the check dam. The volume loss for each time step has further been reduced to the height of water column lost over the average surface area representing two consecutive times, i.e. over each time step for which the water level decline was measured.

Table 19: Water level decline in CD3 (October to December 2003)

Start date	**End date**	**Water level decline in m**	**Number of days for wl decline**	**Water level decline in mm/day**	**Volume loss in m3 over each time step** ***(average surface area of water spread for the time step is given in parentheses, in m^2)***	**Loss of water from CD3 in mm over each time step (volume loss/average area of water spread between two consecutive water levels)**
CD3 overflowing before 2 Oct 03	2 Oct 03	*wl close to the top of the dam wall, just after cessation of flow over CD3.*				

2 Oct 03	9 Oct 03	*Some rise in wl due to late rains (25.2 mm on 28/9 and 11.5 mm on 29/9 recorded at Karmoli)*			-46.47	-40.00
9 Oct 03	18 Oct 03	0.2	9	22.2	222.48 *(1113)*	199.89
18 Oct 03	28 Oct 03	0.27	10	27	263.21 *(976)*	269.73
28 Oct 03	10 Nov 03	0.05	13	3.84*	44.29 *(885)*	50.00
10 Nov 03	20 Nov 03	0.265	10	26.5	209.74 *(792)*	264.56
20 Nov 03	21 Nov 03	0.095	1	95	65.68 *(692)*	94.98
21 Nov 03	29 Nov 03	0.29	8	36.25	169.00 *(585)*	288.99
29 Nov 03	11 Dec 03	0.75	12	62.5	159.60 *(263)*	607.04
11 Dec 03	15 Dec 03	0.05	4	12.5	1.12 *(22)*	49.87

* Rainfall event between 28 October and 10 November 2003, may have caused a reduction in the decline. Despite the net decline during this period, there was some addition of water to the check dam

Hence, the total loss from CD3, over the dry period of 2003 was 1785 mm over a period of 63 days. In the absence of the AWS at Chikhalgaon during this period (the AWS was installed in November 2003 and became functional only in mid-December), the nearest evaporation data available was from Karmoli weather station. The cumulated evaporation of this period for Karmoli weather station was 315 mm (an average of 5 mm/day). The early part of the water level decline in CD3, i.e. until the end of October indicated some leakage. This was estimated to be about 200 mm. Substituting these values in equation (ii), we get infiltration as

I= 1270 mm.

This implies that 1.27 m of water column from CD3 infiltrates into the subsurface. This is equivalent to some 880 m^3 of water from the total (bank full) volume of 1236 m^3. This equals 1.62 mm of water considering the catchment area of CD3, i.e. 0.7861 m^3.

(b) November 2004 to January 2005

Table 20 below summarises the data for the water level decay in CD3 after the overflow had stopped in November 2004. The irregular shape of CD3 implies that each time step with its respective water level drop signifies a certain volume loss from the check dam, as mentioned above. Moreover, the volume configuration in CD3 had changed since the previous year, after GOMUKH's desilting of the structure in April 2004. The volume loss for each time step has, as in the previous section, further been reduced to the height of water column lost over the average surface area representing two consecutive times, i.e. over each time step for which the water level decline was measured.

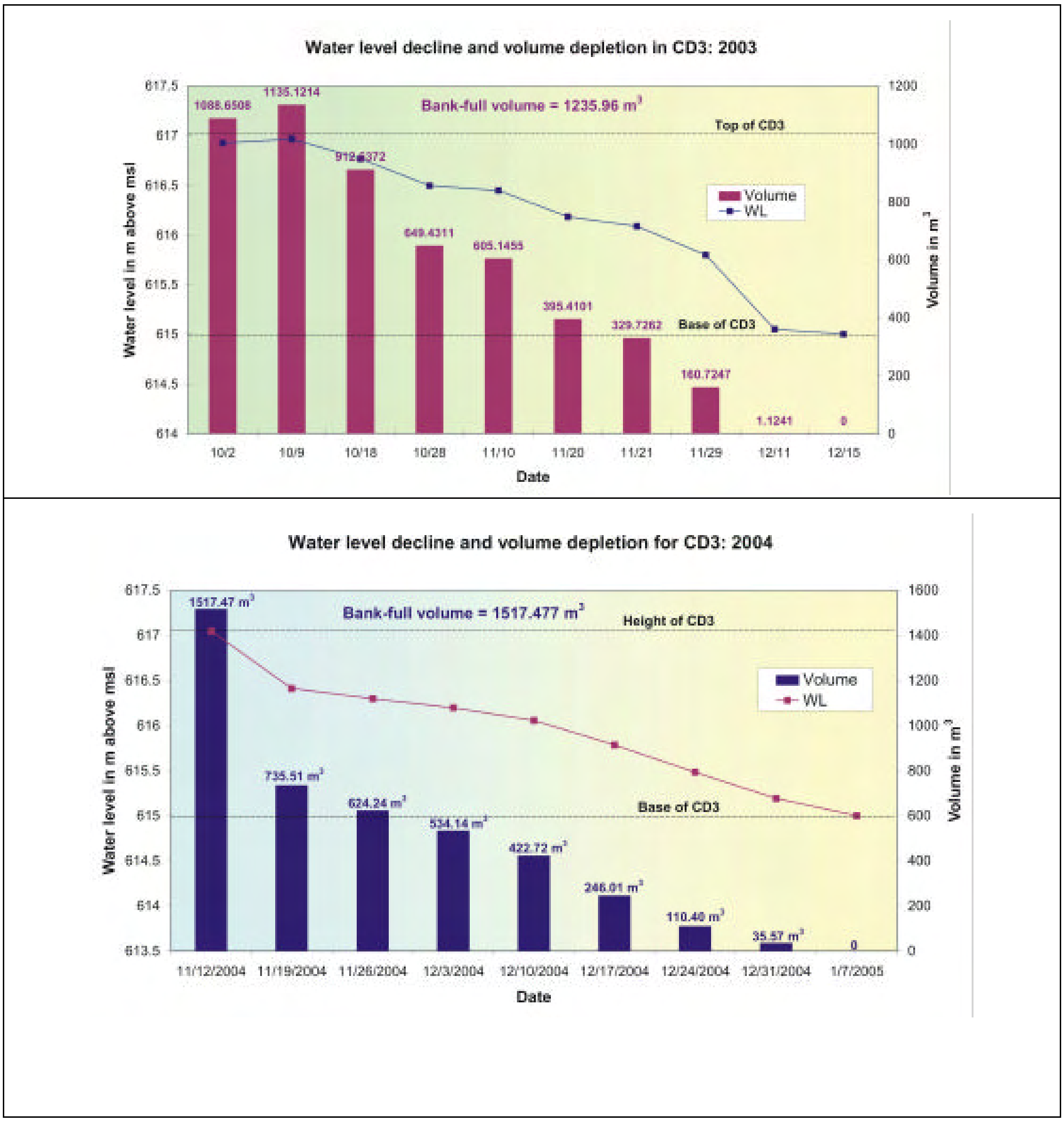
Table 20: Water level decline in CD3 (November and December 2004)

Start date	End date	Water level decline in m	Number of days for wl decline	Water level decline in mm/day	Volume loss in m3 over each time step *(average surface area of water spread for the time step is given in parentheses, in m^2)*	Loss of water from CD3 in mm over each time step (volume loss/average area of water spread between two consecutive water levels)
12 Nov 04	19 Nov 04	0.636	7	90.82	781.96 *(1237)*	632.27
19 Nov 04	26 Nov 04	0.115	7	16.37	111.27 *(968)*	114.97
26 Nov 04	3 Dec 04	0.101	7	14.46	90.10 *(892)*	100.97
3 Dec 04	10 Dec 04	0.139	7	19.94	111.42 *(802)*	138.9
10 Dec 04	17 Dec 04	0.272	7	38.88	176.71 *(652)*	270.98
17 Dec 04	24 Dec 04	0.303	7	43.27	135.61 *(451)*	300.33
24 Dec 04	31 Dec 04	0.289	7	41.28	74.84 *(264)*	283.89
31 Dec 04	7 Jan 04	0.416	7	59.39	35.57 *(90)*	396.63

Hence, the total loss from CD3, over the dry period of 2004-05 was 2271 mm over a period of 56 days. The cumulated evaporation during this period from the AWS data was 196 mm (an average of 3.5 mm/day). There was a leakage of about 50 mm, during the first 7 days of this decline, after which the leak was completely sealed with clay. Substituting these values in equation (ii), we get infiltration

I= 2025 mm.

This implies that 2.025 m of water column from CD3 infiltrates into the subsurface. This is equivalent to some 1352 m^3 of water from the total (bank full) volume of 1517 m^3. This equals 1.72 mm of water considering the catchment area of CD3, i.e. 0.7861 m^3. Figure 54 illustrates the how the water level in CD3 declined during the two dry seasons of monitoring under the AGRAR project.



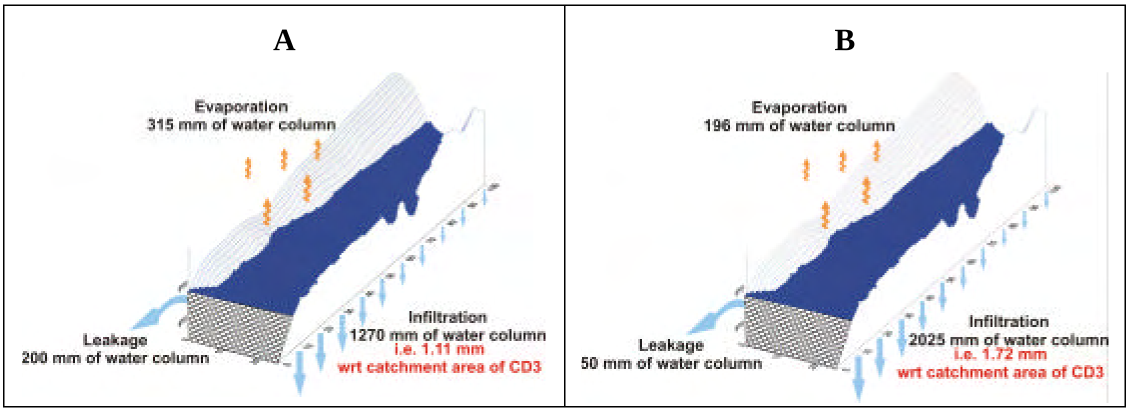


Figure 53: Water balances for the periods of dry season decay in CD3 during October-December 2003 (A) and November 2004 – December 2005 (B)

4.2.4.2 Wet season water balance (period of oveflow for CD3) – *June to Nov 2004*

The equation of water balance for the wet season, (period of overflow on CD3) can be written as:

$In = Out + S_t \pm \nabla S_w$ or

$\pm \nabla S_w = In - Out - S_t$ (iii)

where,

- $\pm \nabla S_w$ = *loss or gain of water from CD3, measured as a difference between inflow and overflow, in* m^3
- *In= Inflow into CD3, measured over rectangular weirs constructed at inlet to CD3, measured as 2320788* m^3*, i.e. 2952 mm*
- *Out= Total overflow from CD3 (including flood discharges), measured using staff gauge and continuous water level data, measured as 2025595* m^3*, i.e. 2577 mm*
- S_t = *Storage capacity of CD3, which in this case remains topped up for a period of 124 days after the first fill (due to the initial inflow), measured as 1529.82* m^3 *, i.e. 1.946 mm*

Substituting these values in equation (ii), we have,

$\nabla S_w = 293663\ m^3$

It may be noted that the inflow (2952 mm) and overflow (2577 mm) exceed the total annual rainfall (1860 mm) for the Chikhalgaon watershed considerably. This overestimation could be due to either the water channelised from areas outside the Chikhalgaon catchment during the cultivation of paddy and running off paddy fields into the mainstream or due to overestimated flows using empirical equations for flow over the inflow and overflow weirs. Nevertheless, considering both options (and a commonality factor to the errors for both weirs), the difference should closely approximate the loss between the inflow and overflow from the structure. The calculations imply that there is loss of 293663 m^3 of water from CD3. This implies some 373 mm considering that the catchment area for CD3 is 0.7861 km^2. This loss of water from CD3 during the monsoon can further be qualified on the basis of the equation:

$$\pm \nabla S_w = E + I + L$$

where

- *E= evaporation in mm, in excess of rainfall, computed from AWS data for Chikhalgaon*
- *I= Infiltration in mm*
- *L= Leakage from CD3, estimated to be balancing leakage into CD3 from adjoining fields, both estimated to be negligible in quantities as compared to inflow and overflow volumes computed above.*

Hence, the above equation reduces to

$$\pm \nabla S_w = E + I \qquad \text{(iv)}$$

Net evaporation computed during the 124 days of overflow on CD3 (*74 days when daily evaporation exceeded daily rainfall, using the Penman-Monteith equation)=* 361 mm.

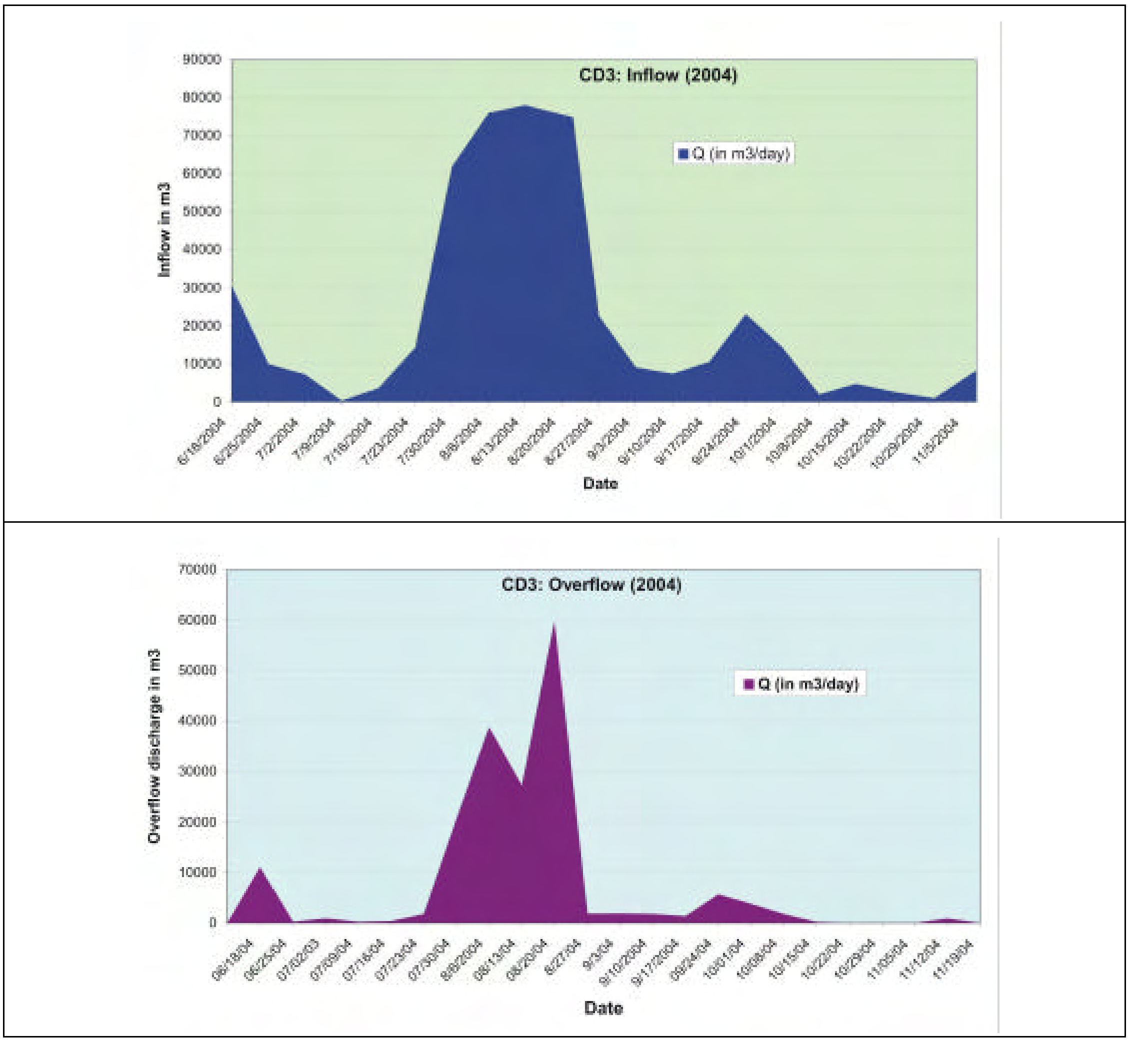
Mechanical and electronic problems with the pan in the AWS constrained continuous recording of data during this period. However, comparison between earlier data (December 2003 to June 2004) from the pan and using the Penman-Monteith equation yielded a factor of 0.6 to obtain pan values from the equation. Using this factor, the net evaporation for the period of overflow on CD3= 217 mm.

Hence, substituting values of ∇S_w and E in equation (iii), infiltration

$$I = 156 \text{ mm}$$

Considering infiltration during the wet and dry seasons in the year 2004, i.e. the total period when CD3 holds water, the total volume of artificially infiltrated water from this structure is nearly 158 mm of water, estimated to the base of the catchment area of CD3, i.e. 0.7861 km^2. This implies that 8.8% of the annual rainfall for 2004 infiltrated from CD3 to the underlying aquifer. However, considering that the specific yield of the aquifer is low (0.005), the maximum storage that the Chikhalgaon aquifer can hold is about 100 mm, considering an aquifer thickness of 20 m. A large part of this infiltration could be lost as base flow contributions to the lower portions of the watershed. The infiltration value of 156 mm implies that 293664 m^3 of water infiltrated from CD3. Surely, this seems a disproportionately large volume for recharge, considering the low specific yield of the aquifer. Figure 55 shows the flow into and out of CD3 during the wet season (2004).

The total effective recharge to the aquifer is estimated to be some 33 mm, implying that some 120 mm of infiltration from CD3 may have been lost downstream as baseflow during the wet season. However, these estimates (wet season) are not very precise, considering that they are based upon inflows and overflows measured over weirs, where runoff magnitudes are quite high and may yield 'low confidence' values.



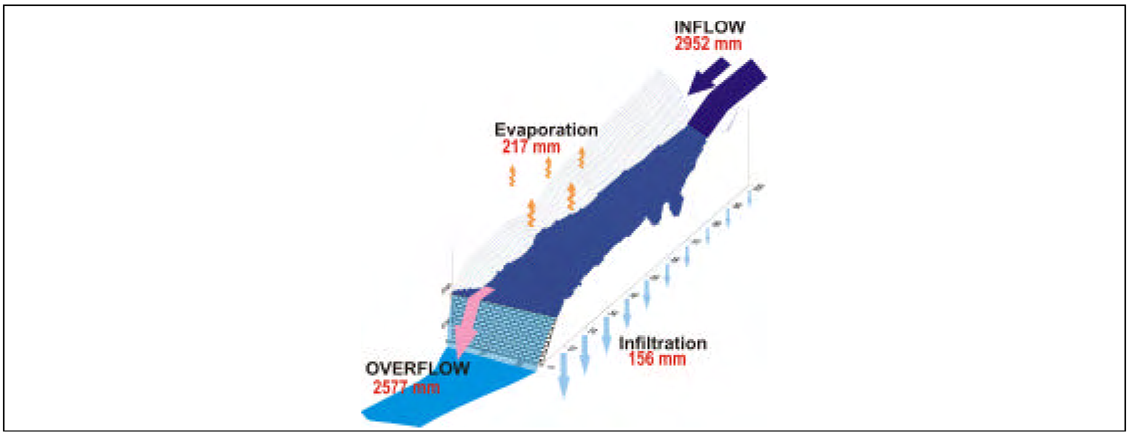


Figure 54: Wet season (2004) water balance for CD3, including hydrographs for the inflow and overflow during the monsoon season 2004.

4.2.5 Water balance for structures CD1 an CD2

Measurements of overflow (monsoon season 2004) and water level decline (dry periods of 2003 and 2004) were made in check dams CD1 and CD2, located downstream from CD3. Base flows were observed in the stream courses near the inlet to CD2. Base flow emergence was noticed in the locality adjoining the observation boreholes BH6 and BH6a and this seemed to increase in the immediate vicinity of CD2. The water table contour plots also indicated a groundwater discharge zone in the vicinity of CD2. On the other hand, flows into CD1 were observed (and were estimated a couple of times) to be similar to the overflows from CD2. This laid down the logic to estimate the dry and wet season water balances for these two structures.

Dry season water balance for CD1 and CD2

Dry season water balances for CD1 and CD2 were estimated using equation (i), as done for CD3. However, one minor change made to this equation was the inclusion of pumping from these structures. Both CD1 and CD2 were pumped during the dry seasons of 2003 and 2004. CD3, on the other hand was neither pumped in 2003 nor in 2004. The water level declines for CD1 and CD2 for the two monitoring periods are shown in Figure 55. *The catchment areas used for CD2 and CD1 are 1.5977 km^2 and 1.7157 km^2 respectively.*

Check dam CD2 overflowing during the monsoon season (left) and drying up in early summer (right). The photograph on the right also shows dug well CH4.

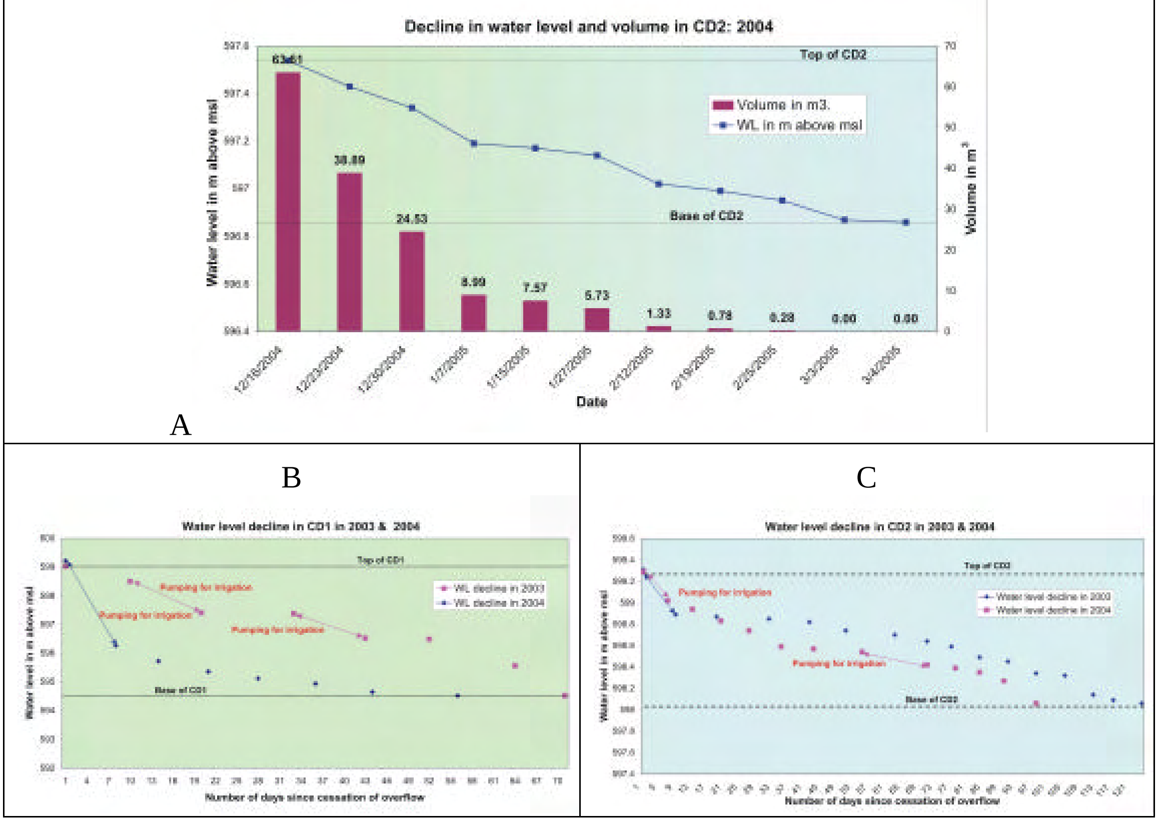


Figure 55: Water level and volume decline in CD2 (A). Water level declines in CD1 (B) and CD2 (C) for 2003-04 and 2004-05, with periods when pumped for irrigation.

Hence the equation for the dry season water balances for these two structures can be rewritten as:

$$\nabla S_d = E + I + Q_p + L_e + B_{f\,(out)} - B_{f\,(in)} \qquad \text{(v)}$$

where,

∇S_d*= loss of water from the check dam, measured as fall in water level in the check dam, in mm, during the dry period (i.e. period of no overflow)*

E= evaporation in mm estimated on the basis of dry season evaporation from open pan for this year (2004) and using evaporation values of data from Karmoli weather station (for last year, i.e. 2003)

I= Infiltration in mm

L_e*= Leakage in mm*

Q_p*= Pumping from check dam, estimated in mm using water levels, volumes and surface areas of water spread on dates of pumping, as well as the amount of water pumped on these dates*

$B_{f(out)}$*= Base flow leaving the check dam, apparent in the form of flows downstream*

$B_{f\,(in)}$*= Base flow contribution into the check dam adds to the structure (hence, negative in the equation)*

(a) October 2003 onwards

CD2

CD2 held water until 19 February 2004, i.e. for a period of 124 days during the dry season. The water level in CD2 declined by 1.27 m over this period, i.e. a loss of 1270 mm. In the absence of the AWS at Chikhalgaon during this period (the AWS was installed in November 2003 and became functional only in mid-December), the nearest evaporation data available was from Karmoli weather station. The cumulated evaporation of this period for Karmoli weather station was 315 mm (an average of 5 mm/day). Waterfrom CD2 was pumped only once, at the beginning of the dry season, just after flows over the check dam ceased. This pumping was estimated to account for 400 mm. Leakage and seepage were found to be very nominal in case of CD2, measuring some 100 mm.

Substituting these values, which were estimated on the basis of direct measurements, equation (v) can be rewritten as:

$$I + B_{f\,(out)} - B_{f\,(in)} = 455$$

Water table contour data clearly indicated that CD2 is located in a groundwater discharge zone, where the water level lies close to the ground surface in and around the structure. Infiltration in such areas is expected to be negligible. However, it was difficult to precisely separate base flows into and out of CD2. ***Nevertheless, it was clear that 455 mm of the water column, that equals less than 0.3 mm of water with regard to the catchment area of CD2 may actually be lost as local infiltration leading to base flows further downstream. This can, therefore be considered as a close approximation of base flows generated in the Chikhalgaon watershed during the dry season.*** The water level decline graph indicates that as the dry season progresses, the base flows out of CD2 are greater in proportion to base flows into it.

<u>CD1</u>

The total loss from CD1 over the dry period of 2003 was 4500 mm over a period of 63 days. As mentioned above (CD2), the evaporation data from Karmoli weather station was used and it totalled some 315 mm (an average of 5 mm/day) for this period. Seepage, emerging as stream flows downstream cannot be easily separated from leakage, but together both were estimated to be some 600 mm.

A farmer irrigating horse gram crop, in the neighbouring fields, pumped water from CD1 on 18 Oct 2003, 10 Nov 2003 and 29 Dec 2003. Pumping from CD1 was estimated to equal 2890 mm, forming the major component of the loss of water from CD1. However, CD1 lies in a groundwater discharge zone and there is evidence of base flows observed over a period of at least a month beginning from the date of water level decline in CD1. This flow is essentially in the form of trickles and cannot be measured on a V-notch, i.e. less than 25 mm over a period of some 20 days, i.e. some 500 mm of the water column in the structure.

Substituting these values in equation (v), we get

I= 195 mm.

This implies that very little water (about 4%) of the total storage infiltrated into the ground, and in all likelihood (based on field observations and water table contour maps) discharged to the surface again as base flows. Considering the catchment area of CD3, this equals less than 1 mm of water. Hence, apart from pumping, the most significant loss from the storage of CD1 was in the form of evaporation and leakages.

(b) December 2004 onwards

<u>CD2</u>

CD2 held water until 3 March 2005, i.e. for a period of 74 days during the dry season. The water level in CD2 declined by 1.27 m over this period, i.e. a loss of 1270 mm. The cumulated evaporation during this period (using AWS data) was 297 mm (an average of 4 mm/day). Water from CD2 was pumped once during this period, i.e. 1 Jan 2005. This pumping was estimated to account for about 145 mm of the water column in CD2. Leakage and seepage were found to be very nominal in case of CD2, measuring some 100 mm.

Substituting these values, which were estimated on the basis of direct measurements, equation (v) can be rewritten as:

$$I + B_{f\,(out)} - B_{f\,(in)} = 728$$

Like in 2003, water table contour data clearly indicated that CD2 is located in a groundwater discharge zone, characterised by active base flows. In 2004-05, therefore, ***it was clear that this 728 mm of the water column in the structure, accounted for a significant component of base flows in the vicinity of CD2 during the dry season of 2003-2004. This equals less than 0.5 mm of water with respect to the catchment area of CD2. This can, therefore be considered as a close approximation of base flows generated in the Chikhalgaon watershed during the dry season of 2004.*** The water level decline graph indicates that as the dry season progresses, the base flows out of CD2 are greater in proportion to base flows into it.

<u>CD1</u>

The total loss from CD1 over the dry period of 2004 was 3440 mm over a period of 43 days. As mentioned above (CD2), the evaporation data from Karmoli weather station was used and it totalled some 297 mm (AWS data) for this period. Seepage, emerging as stream flows downstream cannot be easily separated from leakage, but together both were estimated to be some 600 mm.

A farmer irrigating horse gram crop, in the neighbouring fields, pumped water from CD1 on 18 Oct 2003, 10 Nov 2003 and 29 Dec 2003. Pumping from CD1 was estimated to be only about 220 mm. However, CD1 lies in a groundwater discharge zone and there is evidence of base flows observed over a period of at least a month beginning from the date of water level decline in CD1. This flow is essentially in the form of trickles and could not be measured on a V-notch, i.e. less than 25 mm over a period of some 20 days. Hence, it would in all likelihood measure about 500 mm.

Substituting these values in equation (v), we get

$$I = 1823 \text{ mm.}$$

This clearly shows that a large component of water from the structure may have infiltrated into the ground from CD1, but without any monitoring points close to the structure, and the evidence of a groundwater discharge zone in all downstream portions of CD2, meant that the infiltration was converted to base flows downstream. This coverts to some 1.06 mm of water with respect to the catchment area of CD1.

2) <u>Wet season water balance (period of oveflow for CD1 and CD2)</u>

Although detailed measurements of inflows into CD1 and CD2 were not possible, some initial measurement at the inlets to the two structures implied that CD2 gained water in addition to overflows from CD3. This additional water was generated from a larger catchment area of CD2 as well as through base flows emerging at the inlet of CD2. On the other hand, inflow to CD1 was not found to be significantly different from the overflow from CD2. The hydrographs for the volumes of overflow/outflows from CD1 and CD2 during the wet periods of 2003 and 2004 are shown in Figure 56.

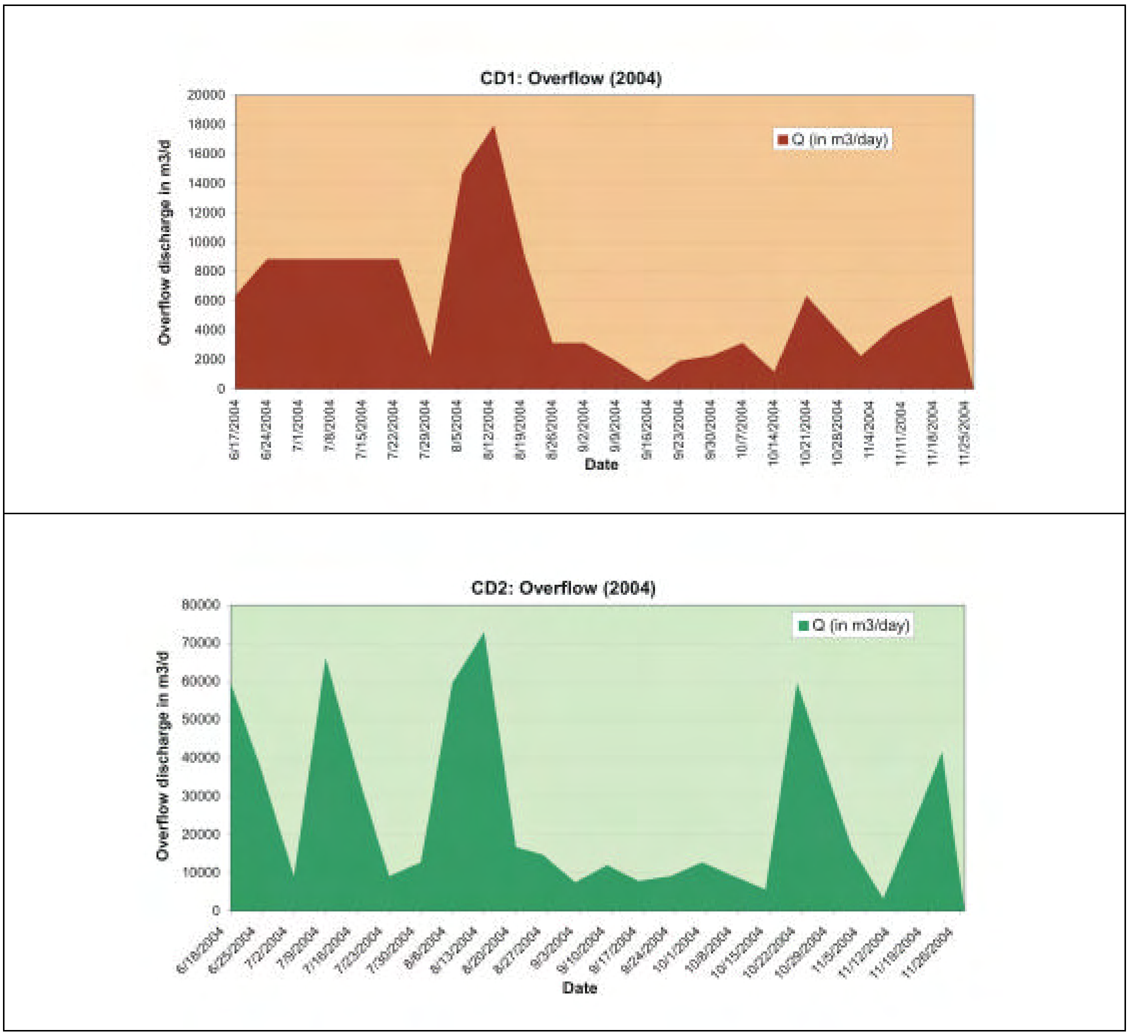


Figure 56: Hydrographs for overflows from CD1 and CD2 during the wet season of 2004

Therefore, although the inflow to CD2 was not measured directly, the overflows were measured. Inflow, for the sake of calculation was assumed to be equal to the overflow from CD3. Using equation (iii), the water balance for the wet season for CD2 was estimated on the basis of the following data:

- In= Inflow into CD2, assumed as the overflow from CD3, *measured as 2025595 m^3*

Out= Total overflow from CD2 (including flood discharges), measured using a staff gauge, *measured as 4551733 m^3*

- S_t= Storage capacity of CD2, which in this case remained topped up for a period of 163 days after the first fill, *measured as 582.89 m^3*

Substituting these values in equation (iii), the loss from or gain to the water in CD2 is therefore

$\bigtriangledown S_w$= -2525556 m^3

This implies that the overflow from CD2 is in excess of the inflow by 2526138 m^3, implying that CD2 gains water. This gain is essentially a combination of the additional runoff generated from the larger catchment area of CD2 (in excess of the CD3 catchment). Considering the catchment area of 1.5977 km^2 for CD2, this volume implies some 1580 mm of water added to CD2. This water includes base flow contributions as well as addition of surface water flowing from fields adjacent to the structure, especially after heavy spells of rainfall. Therefore, separating base flows from the runoff component was difficult. As mentioned earlier, the estimation of flows over the weir was found to be somewhat higher than the annual rainfall.

CD1, the earthen check dam, located downstream from CD2, received virtually all the overflow from CD2, although minor base flow contribution was expected in this portion of the stream. Nevertheless, inflow to CD1 was assumed to be the same as the overflow from CD2. The overflow from CD1 was measured on the spillway/waste weir that acted like a rectangular weir for measurement. This discharge lasted for a period equalling that for CD2, i.e. 163 days.

Using equation (iii) gain, the water balance for the wet season for was estimated for CD1 on the basis of the following data:

- In= Inflow into CD1, assumed as the overflow from CD2, *measured as 4551733 m^3*
- Out= Total overflow from CD2 (including flood discharges), measured using a

staff gauge, *measured as 4126474* m^3

- S_t= Storage capacity of CD2, which in this case remained topped up for a period of 163 days after the first fill, *measured as 2070.29* m^3

Substituting these values in equation (iii), the loss from or gain to the water in CD2 is therefore

∇S_w= 423189 m^3

This implies that there is loss of 423189 m^3 of water from CD1. This implies some 246 mm considering that the catchment area for CD1 is 1.7157 km^2. This loss of water from CD1 during the monsoon can further be qualified on the basis of the equation:

$\pm\nabla S_w = E + I + L$

where

- *E= evaporation in mm, in excess of rainfall, computed from AWS data for Chikhalgaon*
- *I= Infiltration in mm*
- *L= Leakage from CD3, estimated to be balancing leakage into CD3 from adjoining fields, both estimated to be negligible in quantities as compared to inflow and overflow volumes computed above.*

Hence, the above equation reduces to

$\pm\nabla S_w = E + I$ (iv)

Net evaporation computed during the 163 days of overflow on CD1 (*129 days when daily evaporation exceeded daily rainfall, using the Penman-Monteith equation)*= 630 mm.

Mechanical and electronic problems with the pan in the AWS constrained continuous recording of data during this period. However, comparison between earlier data (December 2003 to June 2004) from the pan and using the Penman-Monteith equation yielded a factor of 0.6 to obtain pan values from the equation. Using this factor, the net evaporation for the period of overflow on CD1= 378 mm, which exceeds the loss of 246 mm estimated above, implying that a significant proportion of the difference between inflow and outflow from CD1 is accounted for by evaporation rather than infiltration. Again, water table contours clearly indicate that there is likely to be a little or no infiltration to groundwater from CD1.

4.2 WATERSHED SCALE RESULTS

Chikhalgaon watershed was the focus of studies on the watershed scale, with the other five watersheds used for comparison. This section discusses the salient observations regarding Chikhalgaon watershed and subsequently attempts to compare observations from all five watersheds.

4.2.1 Chikhalgaon watershed

In addition to the three structures discussed in the earlier section, Chikhalgaon watershed included discharges in the form of springs on the upper slopes. Groundwater pumping is even more limited in these upper portions as compared to that from the Chikhalgaon aquifer. Monitoring of these structures, weather data, hydrology and hydrogeology of the microwatershed, especially groundwater resources in basalt aquifers in upstream and downstream portions to the check dams, formed the basis for developing a water balance for this microwatershed.

The detailed methodology and monitoring processes have been described in Kulkarni et al, 2003 and in Chapter 3 of this report. Presented here, in brief is the development of results into a broad water balance on the scale of the microwatershed, the typical unit used in planning and implementation of watershed development programmes, not only in Maharashtra but in other parts of India as well.

The water balance for the Chikhalgaon watershed was developed on the basis of the equation:

$$R = S_R + E_t + M_s + I + P \qquad \text{(v)}$$

where,

R= Rainfall in mm, measured at the weather station in Chikhalgaon

S_R= Surface runoff, measured at places, but essentially computed as the unknown component along with evapotranspiration E_t

E_t= Evapotranspiration (currently clubbed with surface runoff), also including evaporation from surface water bodies like the check dam

M_s= Soil moisture in mm

I= Infiltration in mm, estimated on the basis of water balances from the check dam as well as from hydrogeological observations within the watershed

P= Pumping (mainly from surface water), but also in the form of negligible amounts from groundwater, reduced to mm over the watershed area

Estimating various components of evaporation including direct evaporation from surface water bodies and transpiration losses from vegetation in an area are difficult to estimate due to a variety of reasons (*Sutcliffe, 2004*). Estimating evapotranspiration, therefore provides an enormous challenge, especially given the absence of local level information. Evapotranspiration, in Chikhalgaon, was estimated using a combination of methods, for which data from the AWS, cropping pattern and different empirical formulae were used.

Actual evapotranspiration was estimated using a simulation called WaSim (version 1.8.12), which is a training package for irrigation drainage and salinity developed by HR Wallingford and Cranfield University, with support from DFID (Hess and Counsell, 2000). At the same time, estimates of potential evapotranspiration using methods of Haude (1952) and Priestley-Taylor (1982) on a monthly basis, along with monthly rainfall and other weather parameters, from the Chikhalgaon AWS were used in these estimations.

Haude's method (1952) involves estimation of monthly potential evapotranspiration using the equation:

$$ET_{pot} = x * P_{14}(1- F_{14}/100) \quad \ldots$$

Where,

ET_{pot} = Monthly potential evapotranspiration in mm

x = Monthly coefficients (ranging from 0.26 for October-February to 0.39 for April-May)

P_{14} = Saturation humidity at 2 pm as a function of air temperature

F_{14} = Relative humidity in percentage

The monthly potential evapotranspiration calculated by Priestly-Taylor (1982) Method is based on data pertaining to solar radiation and temperature using the equation

$$E_u = 0.00128 (RnI/58.3)*(d/ d+?) \quad \ldots$$

Where,

Eu = Daily potential evapotranspiration ($MJm^{-2}d^{-1}$)

*RnI = daily net solar radiation, calculated as daily solar radiation * (1-A),*
{where A = albedo (0-1.0); A = 0.23(1-C_f) + (As*C_f) and C_f = e(-0.000029C) where C_f = soil cover index (0-1.0) As = soil albedo and C = sum of above ground biomass and plant residue(kg/ha)}*

$d = 5304/(T_k)^2*e^{[21.25-5304/T_k]}$, where T_k = Daily average air temperature in degrees Kelvin

*? = psychrometric constant = 6.6*10-4 P_B where P_B is barometric pressure (Kpa) and P_B= 101 – (0.0115*h_e) + (5.44*10^{-7} he^2), where h_e is elevation in m of the site*

The actual monthly evapotranspiration was simulated through WaSim which enables simulations of the soil/water/salinity relationships in response to different strategies and environmental scenarios. The simulation algorithm adopts a mass-balance approach calculating results from unit area of land. WaSim runs on a daily time-step using actual rainfall and uses WaSimET which calculates reference evapotranspiration from daily climate data using the Penman-Monteith method (Monteith, 1980).

The simulation was run using following data sets: soil, drainage, climate, crop and irrigation. Normally single layered soils are assumed. On simulation, results are presented in the form of tables as well as charts that can be transferred to excel sheets.

The results from the three methods are presented simply as a single chart showing different estimates through a period of one year, presented as cumulated monthly values (Figure 57).

The actual evapotranspiration during this period was 470 mm, based on WinSim estimates. Actual evaporation from open surface water bodies (based on pan data and the water balance for CD3) for one year is some 220 mm implying a total of 690 mm.

As mentioned earlier, the other challenge was to estimate baseflow, given the sporadicity and complexity of data pertaining to direct measurement of baseflows. The dry season component of base flows was quite small. Estimates from water balance indicate flows equalling some 2-3 mm. The water level decline in wells close to the stream (CH4) is within 1 m over the period in which water flows into CD2, and using the specific yield of the Chikhalgaon aquifer (0.005 from pumping test data), the dry season baseflow is only about 3.5 mm. At the same time, a large component of the infiltration (both natural and artificial) is returned to the surface as baseflow contribution during the wet season.

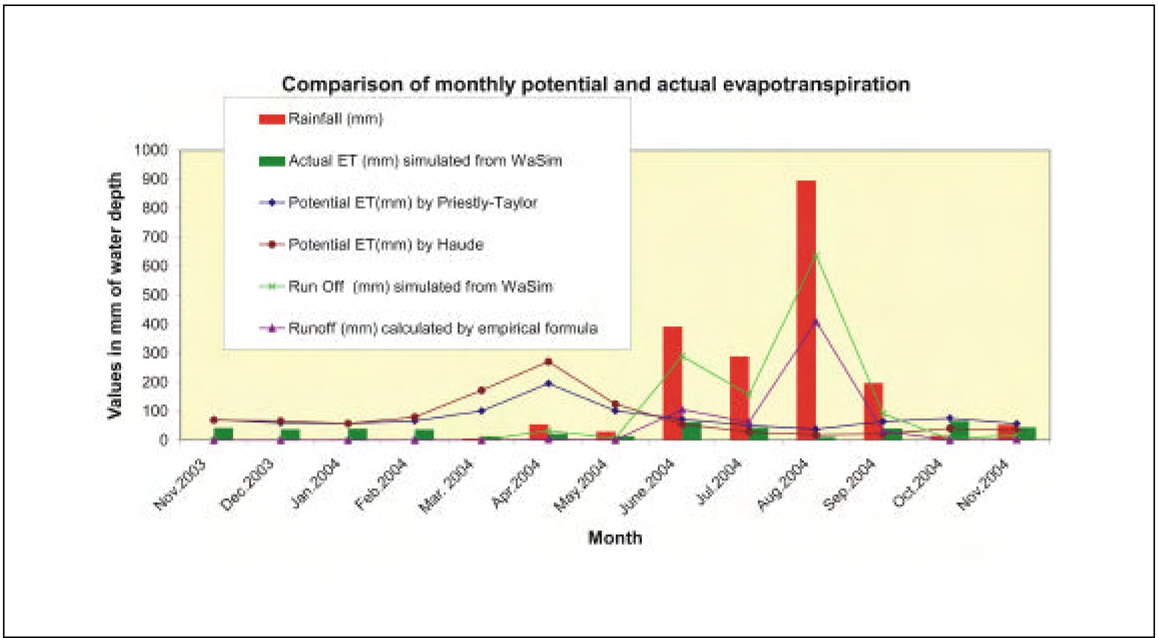


Figure 57: Comparison of evapotranspiration estimated by three methods

Summarising estimates from the above calculations, the total infiltration at various locales in the Chikhalgaon watershed is about 195 mm. Of these only about 75 mm results in effective recharge to the shallow aquifers, at various locales within the 7 basalt units exposed in the watershed (based on the detailed water balance in Chikhalgaon being extrapolated to these units). Some 20 mm maybe estimated as deeper infiltration, recharging deeper basalt aquifers. This implies that some 100 mm is the quantity of water that flows back to the streams as baseflow contribution from groundwater.

The water balance for the Chikhalgaon watershed can therefore be expressed on the basis of measured and estimated parameters. The runoff here is actually derived as the value obtained after subtracting all other parameters from the total annual rainfall. The water balance is presented in Table 21 below.

Table 21: Water balance for Chikhalgaon watershed

Component	**Quantity**	**Proportion to rainfall**
Rainfall	1860 mm	100%
Soil moisture	50 mm	2.69%
Infiltration (Effective recharge)	*195 mm* (75 mm)	10.48% (4%)
Recharge to deeper aquifers	20 mm	1.07%
Pumping (surface and groundwater)	100 mm	5.37%
Evapotranspiration	690 mm	37.09%
Base flow	100 mm	5.37%
Surface runoff	825 mm	45.70%

Surface runoff forms the single largest component of the water balance in the Chikhalgaon watershed, constituting nearly half of the rainfall received. The infiltration, which is about 200 mm on the scale of the watershed, is a sum total of natural and artificial infiltration to the set of five aquifers exposed as a layered sequence of horizontal basalt units over the microwatershed area. This infiltration is about 10.5% of the annual rainfall and is in agreement with the value of infiltration studies in basalt aquifers from other areas (Athavale and Rangarajan, 1990; Sukhija et al, 1996). However, recharge to shallow and deep aquifers, and the baseflows (both of which are a consequence of this infiltration) are almost equal in this water balance.

Surface runoff in the Chikhalgaon stream between CD3 and CD2

4.2.2 Other watersheds

Bhalgudi and Hadashi watersheds are similar to the Chikhalgaon watershed in the sense that they have watershed structures located along the drainage in the form of check dams, as against Nandgaon and Nanegaon, which don't. The water budget for Chikhalgaon watershed would be similar to the water budget for Bhalgudi but would be significantly different from that of the Hadashi watershed. The water level hydrograph for structures in Bhalgudi and Hadashi are plotted alongside those for check dams in Chikhalgaon (Figure 58).

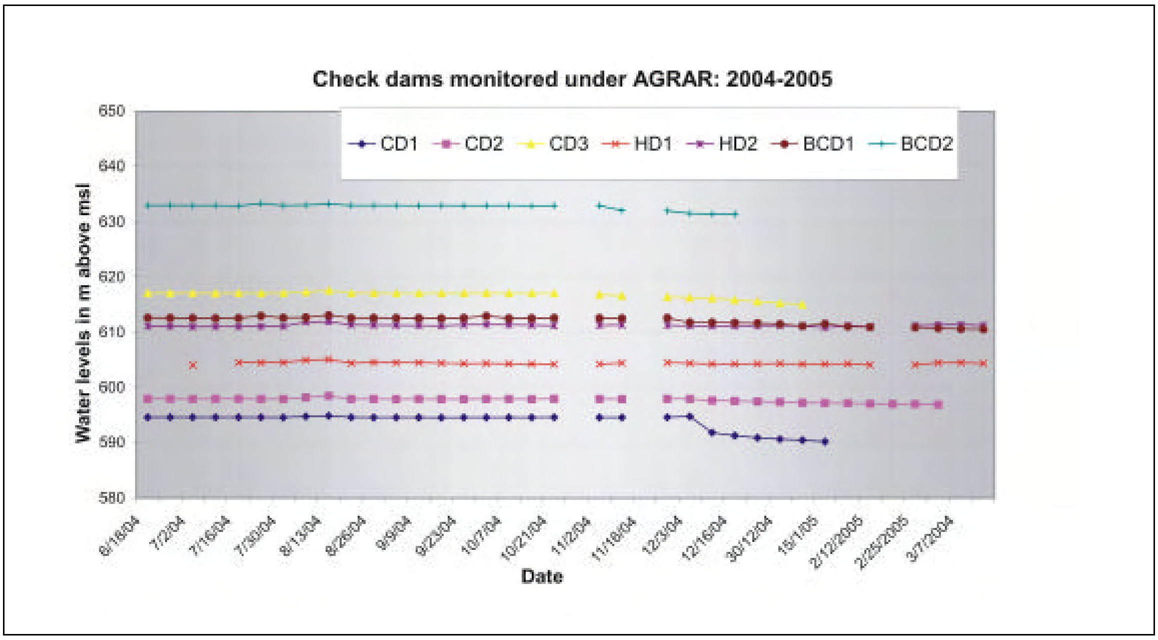


Figure 58: Comparison of stages in check dams monitored under the AGRAR project for the period 2004-2005

The check dams in Hadashi receive large components of discharges from the minor irrigation tank in Hadashi (MIT, Hadashi 2), thereby holding water throughout the year. The other check dams receive no surface flows from structures upstream during the dry season, clearly illustrating the significant contribution from base flows into CD2 and BCD1 through an extended period of water storage, all other factors being consistent across the area.

There are no artificial recharge structures in Nandgaon and Nanegaon, implying that there is no artificial recharge at these sites. Given this assumption, the base flow estimates for these two catchments would be affected because part of the base flow in Chikhalgaon is an effect of infiltration leading to prolonged base flows to the Chikhalgaon stream. This, although not quantified, was qualified through the observation that flows in the Chikhalgaon stream (downstream of CD3) lasted longer than those in stream channels in Nandgaon and Nanegaon.

The impact of artificial recharge, therefore would not significantly affect the water balance of non-project watersheds like Nandgaon and Nanegaon except for the fact that artificially recharged water would largely be adjusted as a part of the runoff rather than the baseflow, the infiltration component from structures converting to baseflow absent in these two areas.

A generalised water balance, based on limited measurements, for Nandgaon (which is adjacent to the Chikhalgaon watershed) is presented as Table 22.

Table 22: Water balance for a non-project watershed (Nandgaon)

Component	**Quantity**	**Proportion to rainfall**
Rainfall	1860 mm	100%
Soil moisture	50 mm	2.69%
Infiltration (Effective recharge)	*100 mm* (50 mm)	10.48% (2.7%)
Pumping (surface and groundwater)	100 mm	5.37%
Evapotranspiration	690 mm	37.09%
Base flow	50 mm	2.68 %
Surface runoff	920 mm	49.46 %

The watershed budgets for the two cases (project versus non-project) clearly bring out the differences in the relationship between runoff-recharge-artificial recharge. And, although this relationship between the two watersheds (Chikhalgaon, a project watershed versus Nandgaon, a non-project watershed) is quite subtle as compared to the overall water balances, artificial recharge and baseflow behaviour are clearly different in these two areas. Hence, even though the Chikhalgaon aquifer (and its counterpart in Nandgaon) retain a fair degree of saturation throughout the year, the artificial recharge structure in the former watershed has meant prolonged base flows to streams. Runoff (during the wet season) and evaportranspiration (during the dry season) are the large and common components of the water balance across project and non-project areas.

4.3 SATELLITE SITES AND RIVER BASIN

Various data sets from the satellite sites, along with the detailed studies in Chikhalgaon, provided some indicators of water resources in Kolwan valley/Walki river basin.

4.3.1 Rainfall data

As mentioned in Chapters 2 and 3, rainfall data from 10 different rain gauge stations was collected. Data from all rain gauging stations has been updated till March 2005. Rainfall data from the 8 rain gauge stations has been presented in Table 23. Two additional data sets were also obtained for Kolwan village, one from a Public Works Department (PWD) station and the other from a rain gauging station installed by Groundwater Surveys and Development Agency (GSDA), both State Government Agencies. Surprisingly, there is a significant difference for the three stations, located within 300 m from each other.

Differences were also noticed in the pattern of rainfall, e.g. smaller spells are apparent in the eastern portions (Nanegaon, Chikhalgaon and Chale stations), especially at the beginning and the end of the monsoon season. The following table indicates the rainfall data for the five AGRAR rain gauge stations as well as the three Government weather stations.

Table 23: Rainfall for the last monsoon for rain gauge stations in Kolwan valley (May 2004 to November 2004)

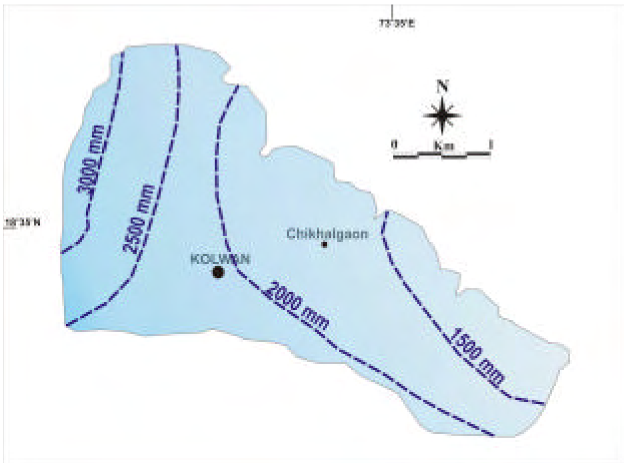
AGRAR RAIN GAUGE STATION		OTHER RAIN GAUGE STATIONS	
Rain gauge station	**Rainfall in mm.**	**Rain gauge station**	**Rainfall in mm.**
Chale	1725.6	Hadashi (MID)	2926
Chikhalgaon	1860	Karmoli (MID)	1930.7
Kashig	2054.1	Kolwan (PWD)	2241.1
Kolwan	2019.36	Kolwan (GSDA)	2312
Nanegaon	1940.2	Walen (MID)	3076

MID= Minor Irrigation Department; PWD= Public Works Department; GSDA= Groundwater Surveys and Development Agency (all agencies under State Government of Maharashtra)

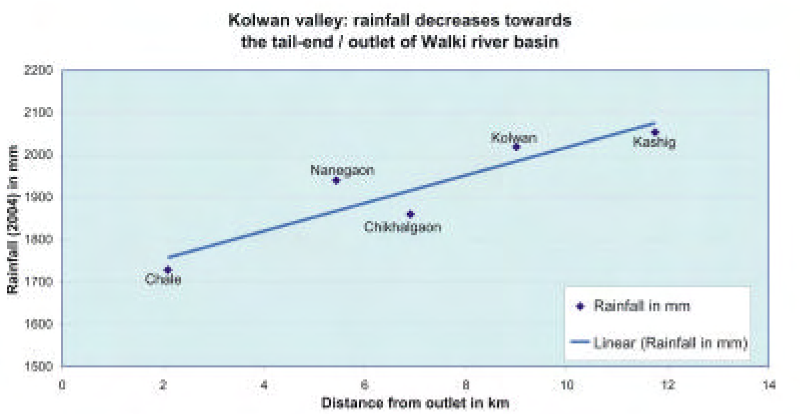
The annual rainfall decreases towards the tail end of the river basin, with a near linear relationship between rainfall and distance to outlet (Figure 59A). However, this graph is based on limited data only from AGRAR rain gauge stations and fitting limited data to a standard equation to predict rainfall distribution based on a single station may be too premature as of now. However, with ongoing monitoring, this will be possible. A line fitted to these data (Figure 59B*)* gives a regression equation:

$$y = 32.926x + 1688.9$$

where, x is the distance of the station from the river basin outlet in km and y is the annual rainfall at the corresponding station in mm



A



B

Figure 59: Isohyets show that rainfall in Kolwan valley decreases towards the west and northwest (A). Rainfall, almost linearly decreases in proximity to the river basin outlet (B).

The monthly maxima in 2004, for all rain gauge stations, were recorded in the month of August (Figure 60). It was observed that it rained nearly 1000 mm in the month of August alone, across the Kolwan valley, which is nearly half the average rainfall for the valley for all rain gauging stations. The monthly average for the AGRAR rain gauge stations was estimated as 314 mm. Although it rained as much as 143.2 mm in one day (1st August in Kashig), the daily average for all the five AGRAR rain gauge stations was only 10.77 mm. This trend clearly shows the spatial and intra-annual variability of rainfall in the study area.

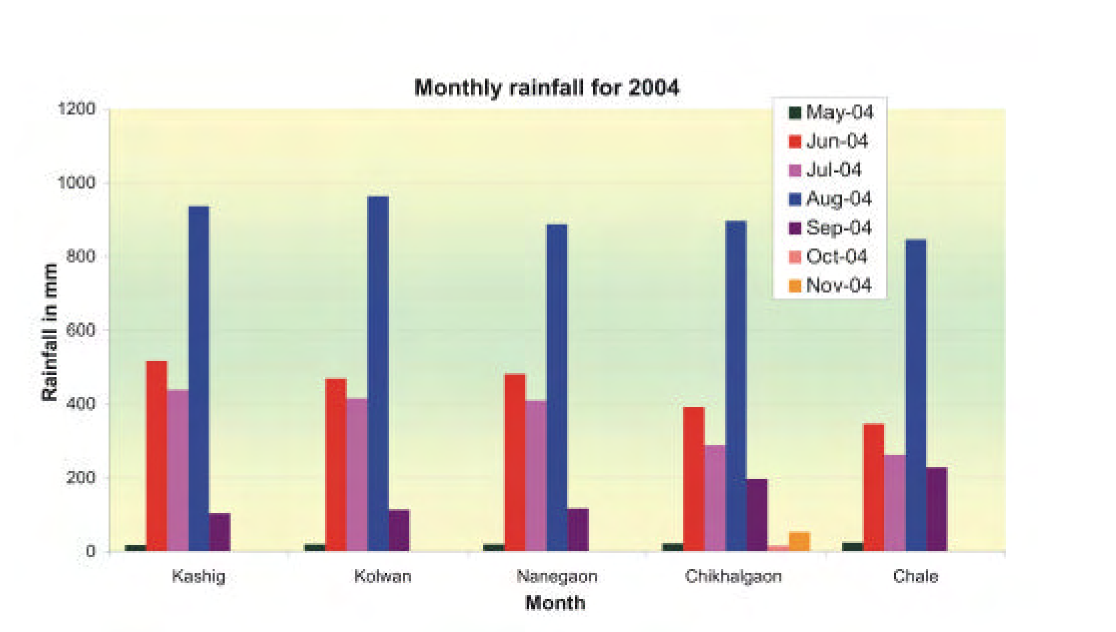


Figure 60: Monthly rainfall for AGRAR rain gauging stations for the year 2004.

There is a general decrease in rainfall from the west to the northeast (Figure 59A) In the portion of the Kolwan valley, east of Chikhalgaon, rainfall decreases from the southwest to the northeast. The net decrease in rainfall from the west (Walen) to the east (Chale), during the monsoon season of 2004, was found to be 1351 mm. The difference between the Kashig and Chale stations (AGRAR) is only 324 mm. In fact, a comparison between the 3 rain gauges at Kolwan (located within a radius of 500 m and within an elevation interval of 10 m from each other) indicates a difference of 293 mm. One reason for this difference could be because the design of the GSDA station is not a standard design, implying lower confidence limits to this data. The PWD station, although a standard design, maybe affected by human interference due to its location behind the school. Both these rain gauges were found to be overestimating rainfall by 10 to 15% as compared to the AGRAR rain gauge station at Kolwan, for which installation and calibration standards of the IMD were strictly adhered to.

4.4.2 Evaporation

Evaporation is not easy to measure directly (Sutcliffe, 2004). Despite data from four pan evaporimeters and the indirect measurement using other parameters from the AWS, estimating real-time evaporation proved to be the greatest challenge in Kolwan valley. However, difficulties in operating pans were essentially overcome through the network of stations, which backed each other up, during periods when one or the other instrument had problems. The common difficulty in all stations, however, was during the monsoon, when direct measurement over long spells was simply ‘washed out’ by heavy spells of rainfall. Nevertheless, information from these five stations provided enough data to estimate the seasonal variability as well as values specific to the major infiltration period after the monsoon.

The four pan evaporimeters (Bhalgudi, Chikhalgaon AWS, and Chale– installed under AGRAR; and Karmoli– Irrigation department) yielded data indicating that measured evaporation was as high as 10mm/day in April and as low as 0.5mm/day during the monsoon season. The rate of evaporation during the summer was found to vary between 7 to 10mm/day. In winter, the period of coincidence with the water level decay in the recharge structure, evaporation varied from 3 to 5mm/day. In the monsoon season it was found to vary between 0.5 mm to 3mm/day, depending upon how long a dry spell would last in order to enable measurement.

Evaporation data from pan evaporimeters at Bhalgudi (upstream) and Chale (downstream) indicated that the daily average evaporation rose in Bhalgudi from January to May-end 2004. It was lowest on 19 Jan (1 mm/d) and highest on 23 April (12 mm/d). However, the values in Bhalgudi until May 2004 were somewhat erratic and probably included some degree of measurement error.

In Chale, there was a progressive increase in daily evaporation from Feb to mid-May 2004. It dropped somewhat after mid-May. It reached peak during the period end-March to early-May (9 to 11 mm/d). The lowest, 3 mm/d, was recorded on 2 Feb 2004 and the highest, 12 mm/d, 2004 on 23 April. In Chikhalgaon, there was a progressive increase in daily evaporation from early Feb to end-April 2004. Evaporation was lowest on 30 Dec 2003 (3.1 mm/d) and was maximum on 23 Apr 2004 (11.7 mm/d). The average evaporation in Chikhalgaon works out to 6.2 mm/d (dry season average).

Daily averages calculated on a monthly basis for three evaporimeters in Kolwan valley show that although there is some difference in the average values across stations, the seasonal trend is consistent for all the stations (Figure 61).

In addition to the AGRAR sites, evaporation data was obtained from the weather station of the Water Resources Division of the Irrigation Department, installed at Karmoli. A comparative plot for evaporation for three stations in the Kolwan valley for summer of 2004 (Figure 62) indicate that the average evaporation is in between 7 mm to 8 mm/day. The maximum evaporation was obtained at Chale (7.88 mm/day) and minimum was obtained at Karmoli (6.99 mm/day). The rate of evaporation was similar (7.28 mm/day) in Bhalgudi (not shown in Figure) and Chikhalgaon.

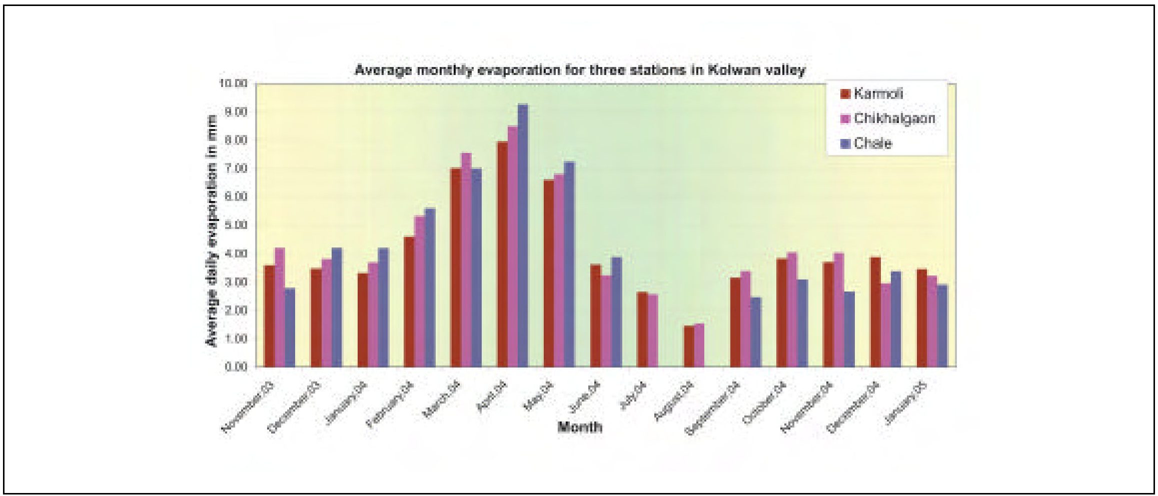


Figure 61: Average daily evaporation, for each month, for three stations in Kolwan valley (November 2003 to January 2005).

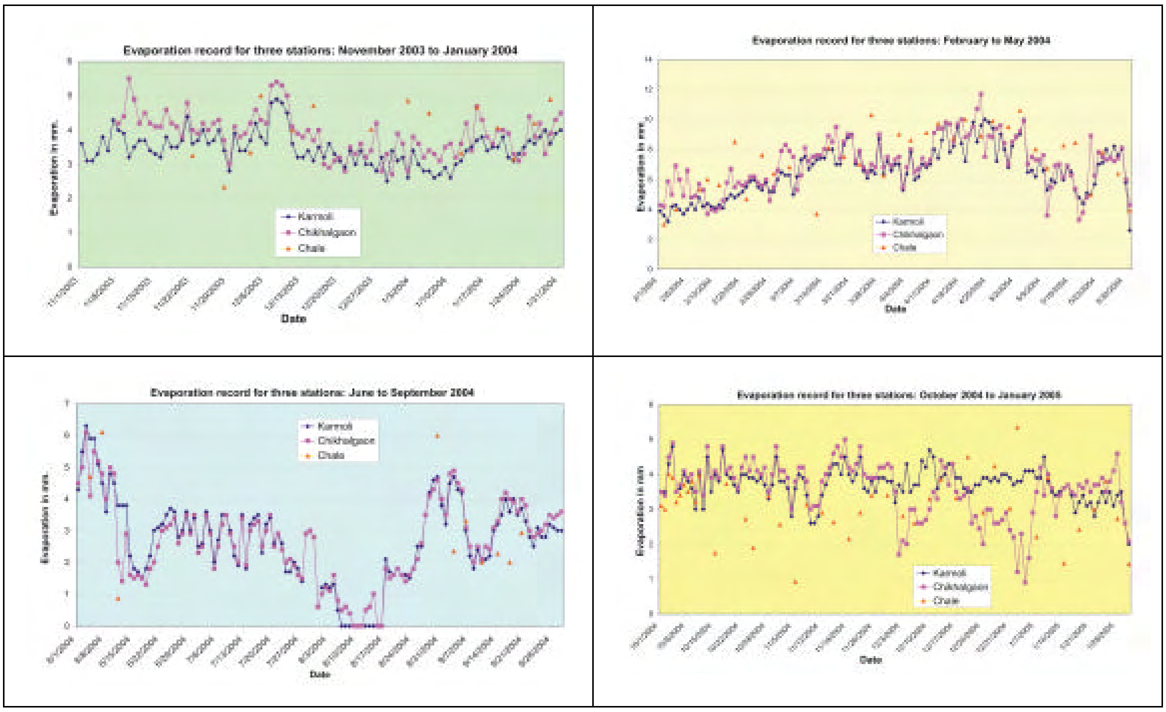


Figure 62: Comparative plot for evaporation for three stations in Kolwan valley for four different seasons

The difference in the seasonal values of evaporation across the river basin followed a common trend, i.e. values rose and dropped at the same times at all the four stations (Table 24). The temporal variations within a single station were significant though. Bhalgudi had an average rate of evaporation of 7.29 mm/day. However, during peak summer, i.e during mid April, the evaporation was as high as 12mm/day. In Chikhalgaon, during the same period the rate of evaporation was between 9mm/day to

12mm/day. In the other two stations the rate of evaporation was less than 10mm/day throughout summer except for one day in Chale where it was recorded to be 10.6mm/day.

Table 24: Summary of results for three pan evaporimeters in Kolwan valley

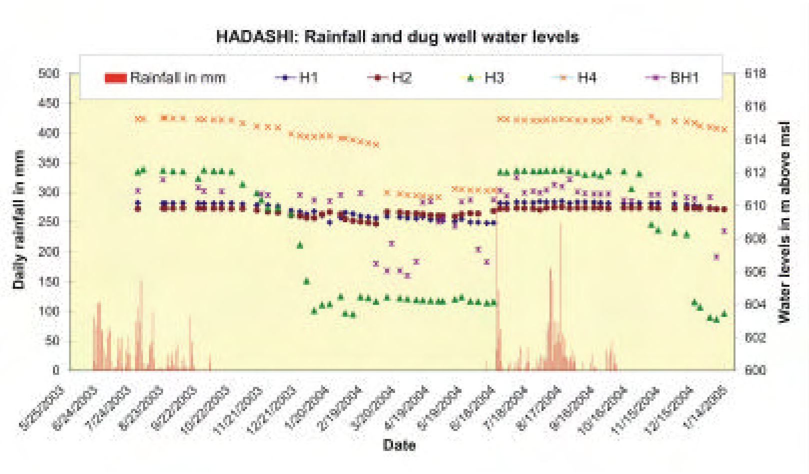
STATION	November 2003 – January 2004	February 2004 – May 2004	June – September 2004	October 2004 – January 2005
Chale	3.74	7.28	3.18 (limited data)	3.02
Chikhalgaon	3.91	7.05	2.68	3.57
Karmoli	3.47	6.54	2.72	3.72

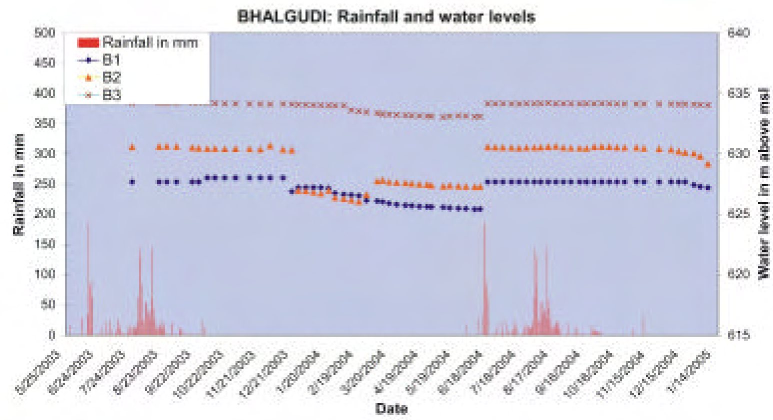
It is observed that the rate of evaporation dropped drastically after the occurrence of pre monsoon showers. This drop was more than 60%. The rate of evaporation during this period was between 2mm to 4mm/day.

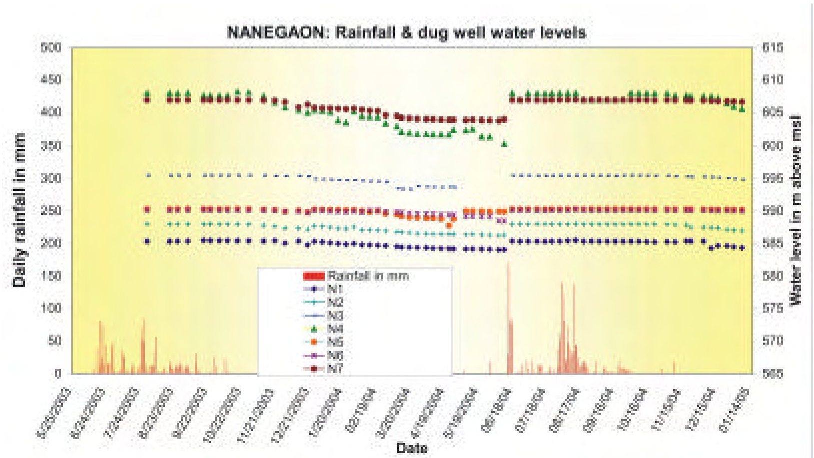
4.3.2 Groundwater

In Kolwan valley, not all the wells are pumped for irrigation. From the 30 dug wells, only about 10 are actually used for irrigation. Irrigation use from these wells is also not intensive. The water is used for one crop in winter. Hence, by and large, the well hydrographs for a great majority of wells show a trend of the natural response of groundwater to responses like infiltration from rainfall, discharge to base flows and some pumping. Figure 63 show the rainfall and dug well water levels for Nandgaon, Nanegaon, Bhalgudi and Hadashi.

Apart from dug wells and observation boreholes in Chikhagaon, dug wells in Nandgaon, Hadashi and Nanegaon were monitored on a weekly basis. In addition, three wells were monitored in Bhalgudi, since these were the only wells in the vicinity of the check dams studied there. The trend in most of these wells is similar to the trend in Chikhalgaon, wherein wells attain maximum levels in the first week of September. Although there is no quantitative water level data preceding July 2003, the current year data and qualitative observations from last year (June 2004) show that the initial rapid rise in water levels in wells (and therefore in the shallow basalt aquifer) is caused as a response to two steps in the first rainfall (as explained in section 4.4.2.3, earlier in this Chapter).


HADASHI: Rainfall and dug well water levels
Rainfall in mm
H1
H2
H3
H4
BH1
Daily rainfall in mm
Water levels in m above msl
Date


BHALGUDI: Rainfall and water levels
Rainfall in mm
B1
B2
B3
Rainfall in mm
Water level in m above msl
Date


NANEGAON: Rainfall & dug well water levels
Rainfall in mm
N1
N2
N3
N4
N5
N6
N7
Daily rainfall in mm
Water level in m above msl
Date

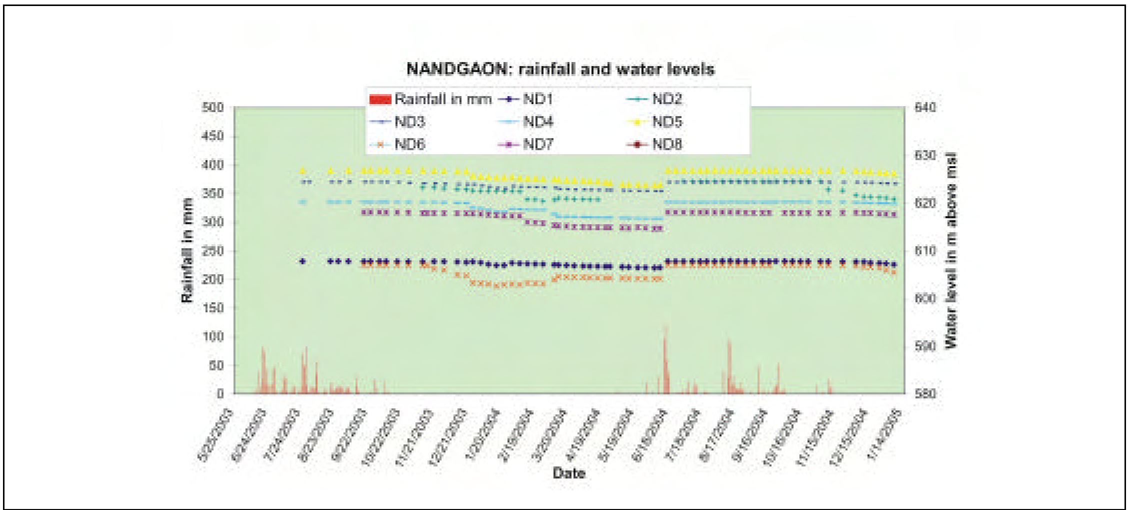


Figure 63: Dug well hydrographs for Hadashi (A), Bhalgudi (B), Nandgaon (C) and Nanegaon (D)

Hydrographs from the four other villages included study of water levels in dug wells in the 'project' villages (similar to Chikhalgaon) of Hadashi and Bhalgudi along with stage changes in the check dams in these two villages and well water levels in 'non-project' villages of Nandgaon and Nanegaon (Figure 63). The hydrographs reveal some similarities and differences in hydrographs across project and non-project villages, especially with respect to recharge. These salient features of this comparison are listed below.

1. *The first 50 mm rain accounted for soil moisture deficits and did not affect a significant rise in well water levels, both in project and non-project villages. Water levels in dug wells remained at a minimum even after the first spells of rain (cumulating to about 50 mm), i.e. between late April 2004 and 6 June 2004.*
2. *Thereafter, water levels in all wells (in all three watersheds) rose to near full-saturation after the first week of the heavy rain spell in June. Water levels in the respective aquifers attained full saturation, due to infiltration from about 200 mm of rainfall on the 13th and 14th June 2004.*
3. *Some dug wells, like H3 and H4 in Hadashi, N4 in Nanegaon and CH1 in Chikhalgaon are pumping wells. These wells are either pumped for irrigation or for water supply to the village (CH1). These hydrographs show changes in the water levels even over short durations, indicating effects of pumping, especially after the monsoon season (Figure 63A).*
4. *The hydrographs show that some wells are irrigation wells, while others are community wells. Fluctuating water levels during the dry season indicate pumping from wells. Gently sloping or flat hydrographs for dry seasons indicate wells that are either not pumped or are community wells from which only small quantities of water are extracted.*
5. *Wells in Hadashi (H1 and Bh1) respond to releases into check dam HD2 from the*

irrigation tank upstream. Both are non-pumping wells. Therefore, the fluctuations in both these wells, especially during the dry season is on account of releases from the irrigation tank filling up the structure and recharging the aquifer tapped by the wells nearby.

6. *Wells in Nandgaon and Nanegaon show normal well hydrographs, with fluctuation in water levels in some wells a result of pumping, especially during the dry season.*

Some specific observations pertaining to wells in each of the four areas are given below (please refer Figure 63).

4.3.2.1 Hadashi

Wells H1 and H4 are community drinking water wells. These wells achieved maximum water levels between mid and end August 2003, with water levels remaining fairly steady till 10 Oct 2003, after which they showed steady declines till the month of January 2004. The water level in H1 was abnormally low on 15 Jan 2004 and this can be attributed to excessive drawing out of water on 15 Jan, by school children (Hadashi) for watering plants. *This level, therefore, is not the static water levels but represents the water level after water was manually drawn from the well.* The water level in H4 dipped by nearly 3 m on 7 Mar 2004, when it was pumped to meet the water requirement for road construction. Water levels in both wells remained fairly steady during and after the monsoon period of 2004.

Wells H2 and H3 are private wells. Dug well H2 used to be an irrigation well before lift irrigation schemes came to Hadashi. It is not used anymore and is kept idle except for manual drawing of water be buckets, once in a while. The water level in this well gradually declined over the dry period (after October 2003). Between 1 Jan 2003 and 15 Jan 2003 and then again, between 26 Feb 2004 and 7 Mar 2004, the water level in the well rose by more than 0.5 m. These two episodes were monitored and it was found that the well was recharged by irrigation return flow from the adjoining sugarcane field, irrigated using surface water from the river, during these two periods.

Return flow from irrigated sugarcane (right, background) flooded open field (left) and caused some water level rise in dug well H2

Well H4 belongs to a private entrepreneur owning property over some 200 hectares. The water from H4 is used to irrigate a large plantation of horticultural species that forms a part of this estate, which houses a large temple as well as other infrastructure. The well was pumped even in the month of September (18 Sept 2003) and also after this year's monsoon, i.e. from October 2004. The well showed a steep decline after 18 Oct 2003 until early Jan 2004, when water in the well approached its base. The well was pumped every day during this period. Thereafter, the well was only pumped intermittently and the water level lay close to the base of the well. Even recently, the well was virtually pumped every day after October 2004 and its water level is presently close to its base.

An unused borehole, Bh1 in Hadashi was monitored along with the dug wells. The water level in the borehole shows a fluctuating pattern and appears to be controlled by changes in the flow of the adjacent stream as well as the pumping of H7 and another pumping borehole nearby.

4.3.2.2 Bhalgudi

Well B1 is located within a stream channel and the stream flow interferes with its water level, during much of the monsoon. During this period, the actual water level may have been slightly above what is measurable because water from the stream mixes with well water. Well water seems to be discharging into the stream.

However, once the stream flow reduces considerably, water levels in the well appear more normal (after 2 Oct 2003). The well was pumped in December 2003 and shows a gradual depletion thereafter. The water level in B1 has remained very steady after this years monsoon, i.e. after June 2004. Well B2 is pumped from 25 Dec 2003 until 26 Feb 2004 for rabi irrigation. B3 is not pumped but its proximity to B2 may be causing some effect on its water level, especially after 12 Feb 2004.

Well (BH1) and runoff in the Bhalgudi stream mix during the rainy season.

4.3.2.3 Nandgaon

In Nandagon, wells can be classified as under:

1. ND1, ND5, ND6 and ND7 are irrigation wells.
2. ND2, ND3 and ND4 are used as community wells.

Wells ND1 and ND6 are at a lower elevation than the other wells. All wells except ND3, are pumped to some extent or the other. Most of the pumping is for irrigation during the rabi season (Dec 2003 to Feb 2004). ND4 was pumped in December 2003 to supply water to irrigation labourers who had camped in the village for cutting of sugarcane. It was again pumped in February to supply water for the 'village fair'.

4.3.2.4 Nanegaon

Wells N1, N2 and N3 (located in the upper portions) are non-pumping wells and therefore show steady water levels throughout the year. N3 may have been pumped between Feb and Mar 2003, but there was no direct evidence to indicate the drop in the well water level during this period and the rise thereafter.

Wells N4 and N7 (at upper elevations) are pumping wells. The N4 hydrograph indicates that some of the water levels recorded are, in fact, pumping water levels. This well was pumping even during the late monsoon period (September-October 2003) for providing protective irrigation to rainfed crops. The hydrograph also showed abrupt rise in water levels on 18 Oct 03, 29 Jan 04 and 26 Mar 04. These abnormal water level episodes in the well can be attributed to local recharge from return irrigation flows from adjacent sugarcane fields to the well. N4 was also pumped in August 2004, hence an abnormality in the hydrograph between 12 Aug and 20 Sept 2004.

N7, on the other hand, showed a steady decline in the water level due to pumping until 26 Feb 04 when pumping for irrigation ceased. The water level in the well remained fairly steady in the summer, thereafter.

Wells N5 and N6 are located in the lower portions of the Nanegaon microwatershed and tap a different aquifer. The water levels in these wells showed a steady decline until February and March 2003 respectively, when there was a sudden drop, indicating that the farmers pumped wells to provide protective irrigation to an otherwise 'surface water lift' irrigated sugarcane crop. Surface water irrigation from the river is allowed only for 8 months, beginning June. Hence, some wells are pumped to provide irrigation to such crops, especially in the months of March, April and May.

4.3.3 Water balance

Rainfall data from 8 rain-gauging stations was collected in the Kolwan valley, in addition to some measurement of river flows. Data similar to that from Chikhalgaon watershed was collected from four other watersheds to obtain a representation of hydrological and hydrogeological conditions within the river basin (Kulkarni et al, 2003;

Kulkarni et al, in press). The water balance developed here is based on data from the five study watersheds and also from a few monitoring points on the river. It is a generalized water balance, only indicating the relative amounts of the various components. Table 25 summarises the main components of this water balance, defined through the equation below.

$$R = S_R + E_t + M_s + I + P \pm \nabla S_I \qquad \text{(vi)}$$

where,
R= Rainfall in mm, measured at the weather station in Chikhalgaon
S_R= Surface runoff, measured at places, but essentially computed as the unknown component along with evapotranspiration E_t
E_t= Evapotranspiration (currently clubbed with surface runoff), also including evaporation from surface water bodies like the check dam
M_s= Soil moisture in mm
I= Infiltration in mm, estimated on the basis of water balances from the check dam as well as from hydrogeological studies within the watershed
P= Pumping (mainly from surface water), but also in the form of negligible amounts from groundwater, reduced to mm over the watershed area
∇S_I= Input to storages of minor irrigation tanks, that occasionally release water into the river…

Infiltration here includes infiltration from natural and artificial sources (based on the other scales of study). However, working on a river basin scale often requires generalizations. For instance, in this case, infiltration at various levels where favourable conditions exist have been assumed on the basis of direct measurements made at a few specific locations. The infiltration of 200 mm, which is more than 10% of the rainfall is slightly higher than that estimated for larger river basins of peninsular India (Athavale and Rangarajan, 1990).

Table 25: Water budget for Walki river basin

Component	*Quantity*	*Proportion to rainfall*
Rainfall (average from 7 stations)	1920 mm	100%
Soil moisture	50 mm	2.6%
Infiltration of rainwater to the subsurface	200 mm	10.41%
Pumping (mainly from rivers)	100 mm	5.2%
Surface runoff and evapotranspiration (including baseflow)	1470 mm	76.56%
Average annual input to minor irrigation tank storages	110 mm	5.73%

The average annual input to the minor irrigation tank storages is 100 mm, the loss from these tanks being releases to the river, which are picked downstream after forming a part of the river flow. Part of this input is lost directly to evaporation. As mentioned for the water balance on a microwatershed scale, it will eventually be possible to separate runoff and evapotranspiration. Nevertheless, surface runoff would still remain the largest component of the water balance in the Walki river basin (or Kolwan valley).

4.4 HYDROCHEMICAL CHARACTERISTICS

Relatively little is known about the hydrochemistry of the Deccan Basalts. The main aim of collecting samples for this study was therefore to begin to understand the fundamental hydrochemical characteristics of groundwater in the Kolwan Valley, whilst investigating the potential impact of recharge on the groundwater quality. The results have provided an insight into the potential controls and geochemical processes, which determine and modify the groundwater chemistry in the study area.

In the Kolwan valley, 73 samples were collected between November 2003 and June 2005. Most of the sites sampled were from the Chikhalgaon and Hadashi catchments of the Kolwan valley. Grab samples were collected from 10 boreholes, 5 dug wells, 2 rivers, 3 check dams, 2 springs and 1 irrigation tank (Figure 64), whenever possible, up to three times a year. Most samples, therefore, were from shallow groundwater and surface water. Sampling dates were chosen to coincide with pre-monsoon (May/June) post-monsoon (November), and post-irrigation of the Rabi crop (February). Onsite measurements were collected for pH and specific electrical conductance (SEC), and whenever possible, samples were filtered and stored in new plastic bottles. Following discussions with the laboratory it was decided not to acidify samples for preservation, but to complete the analysis, within 1-2 days of collection (Table 26).

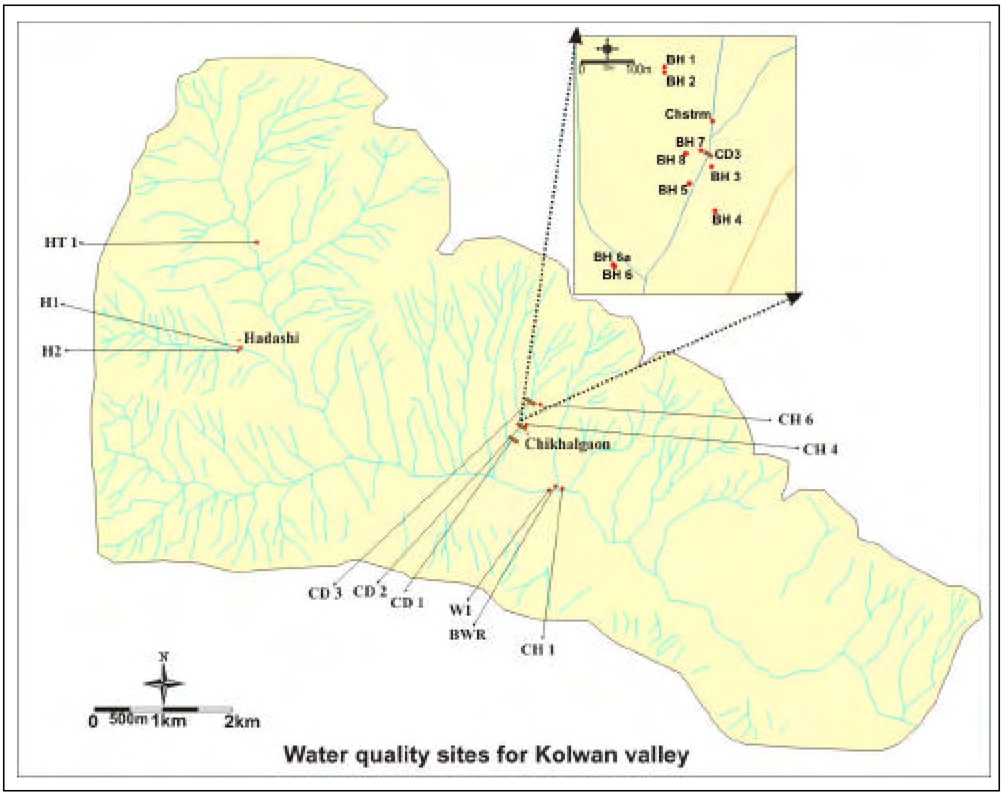


Figure 64: Map of Kolwan valley, including all water quality sampling points.

Table 26: Summary of sampling dates and procedures for water quality sampling

Date	Who sampled	Analyses	Filtration	Acidification
16 May 2003	BGS & Acwadam	BGS	YES (0.45 µm)	YES
22 Nov 2003	BGS & Acwadam	Polytest, Pune	YES (0.45 µm)	YES
2 Feb 2004	Acwadam	Polytest, Pune	NO	NO
7 June 2004	Acwadam	Polytest, Pune	NO	NO
25 Nov 2004	Acwadam	Polytest, Pune	YES (11µm)	NO
16 Feb 2005	Acwadam	Polytest, Pune	YES (11µm)	NO
30 May 2005	Acwadam	Polytest, Pune	YES (11µm)	NO

For consistency, this interpretation is based only on data analysed at the Polytest laboratories, Pune, between November 2003 and May 2005. A summary of the data is given in Table 27. Where data is below the detection limit of analysis, a concentration equal to half the detection limit was substituted for calculation of the statistics, and replaced with the detection limit in Table 27. The distribution of data is shown graphically on a Piper plot (Figure 65).

Table 27: Summary statistics of major and minor element concentrations in the Deccan Basalts of the Kolwan Valley

{NB: Highlighted results exceed the Maximum Admissible Concentration (MAC).}

Parameter	Units	Min	Max	Mean	Median	No.	MAC (India, Class A: Drinking Water)	MAC (EU; Drinking water)
pH		7.1	9.4	8.0	8.1	73	6.5-8.5	
SEC	µS/cm	160	500	319.2	324.5	64		
Ca	mg/l	3.6	52.8	34.8	38.4	73	200	250
Mg	mg/l	1.92	24	11.7	12.24	73	100	50
Na	mg/l	5.7	65	21.4	15	73		150
K	mg/l	0.2	20	2.3	1.2	73		12
Cl	mg/l	3.9	23.9	9.2	8	73	250	250
SO4	mg/l	0.21	23.92	5.4	3.93	73	400	250
HCO3	mg/l	72	258.64	174.3	183	64		
NO3	mg/l	<0.03	6.98	0.8	0.27	73	20	50
As	mg/l	<0.001	0.16	0.0	0	73	0.05	0.01
F	mg/l	<0.01	0.43	0.1	0.06	73	1.5	1.5
Fe	mg/l	<0.007	5.63	0.2	0.02	73	0.3	0.2
Mn	mg/l	<0.03	0.032	0.0	0.03	73	0.5	0.05

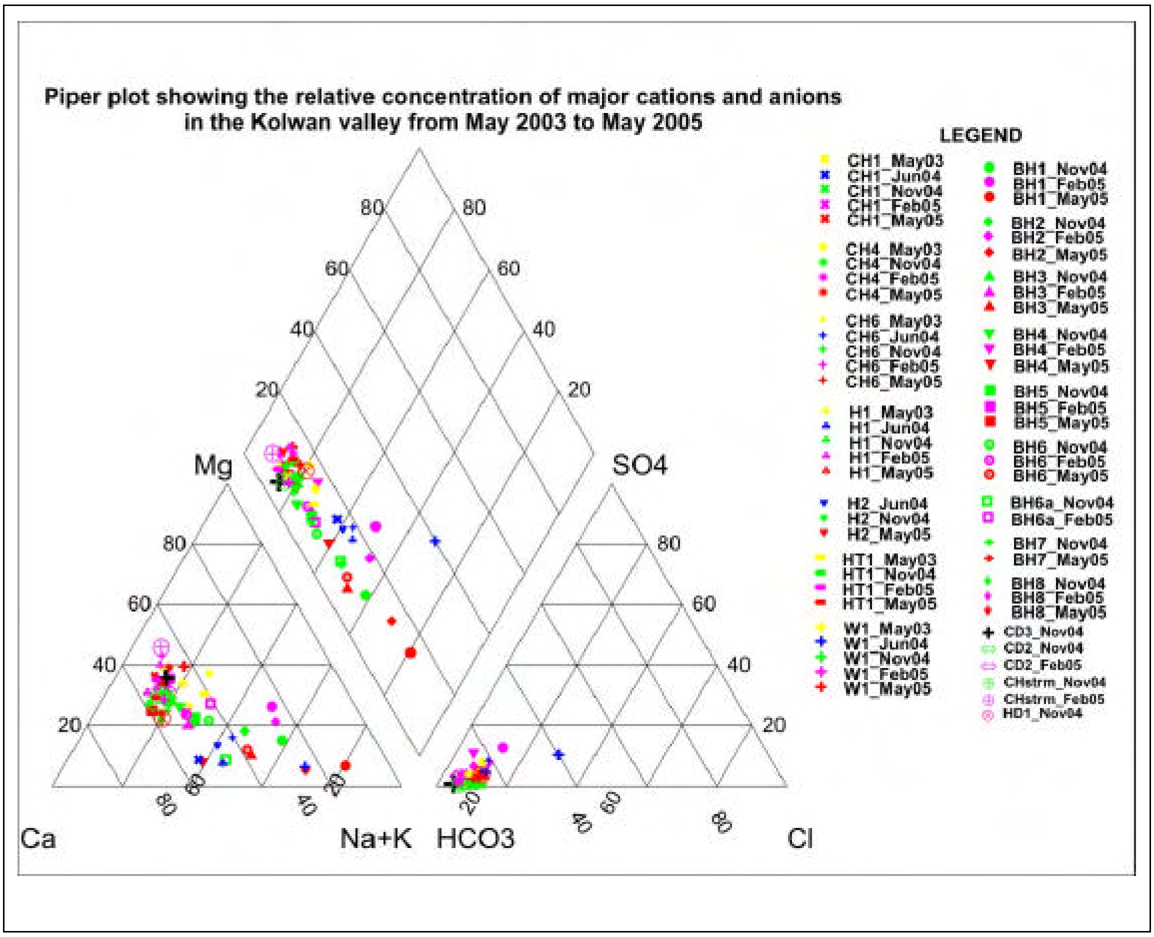


Figure 65: Piper plot showing the relative concentrations of major cations and anions in the Kolwan Valley Deccan Basalts, from May 2003 to May 2005.

4.4.1 Water types and physicochemical characteristics

Groundwater in the Kolwan Valley is relatively fresh with weak mineralization, as illustrated by the low SEC values (between 160 and 500 µS/cm). Values of pH were recorded as high as 9.4, in June 2004 at BH3, but are more typically between 7.1 and 8.5 with a median of value of 8.1, suggesting slightly alkaline water. Boreholes tend to demonstrate slightly higher values of SEC and pH compared to other sampled sources.

Waters in the Kolwan valley range from Ca-Mg-HCO_3 to Na-Ca-Mg-HCO_3 types (Figure 65). After the monsoon, in November 2004, water samples generally appear to demonstrate a fresher signature of Ca-Mg waters compared to samples collected later in the year, in February and May 2005, when both Mg and/or Na may increase in concentration (Figure 66).

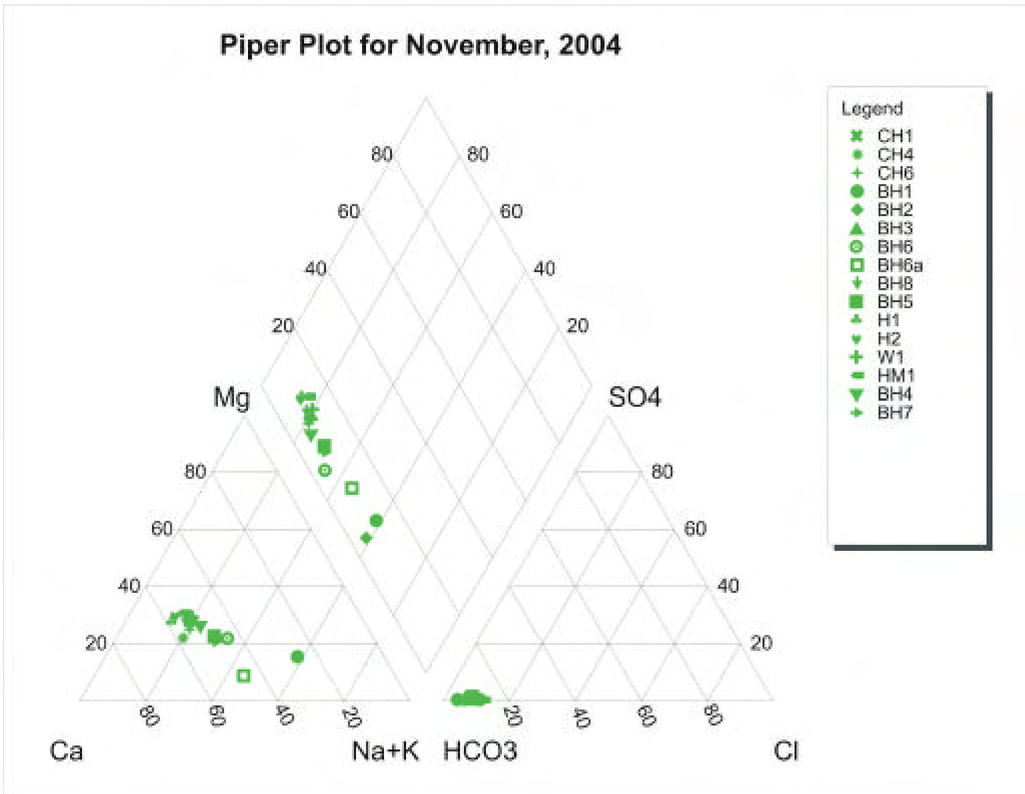


Figure 66(a) Piper plot for June, 2004

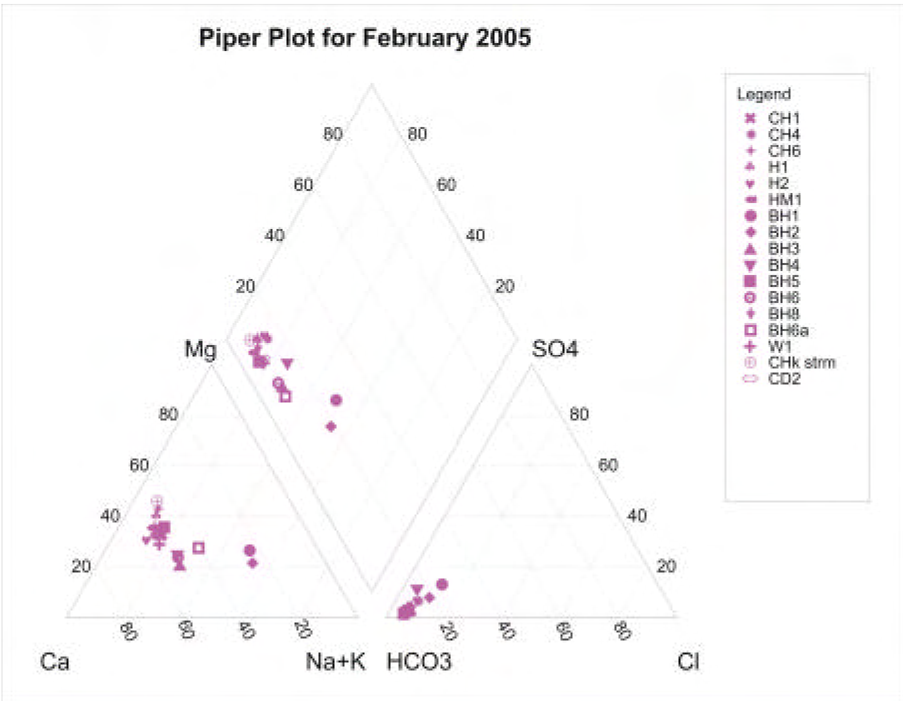


Figure 66(b): Piper plot for February, 2005

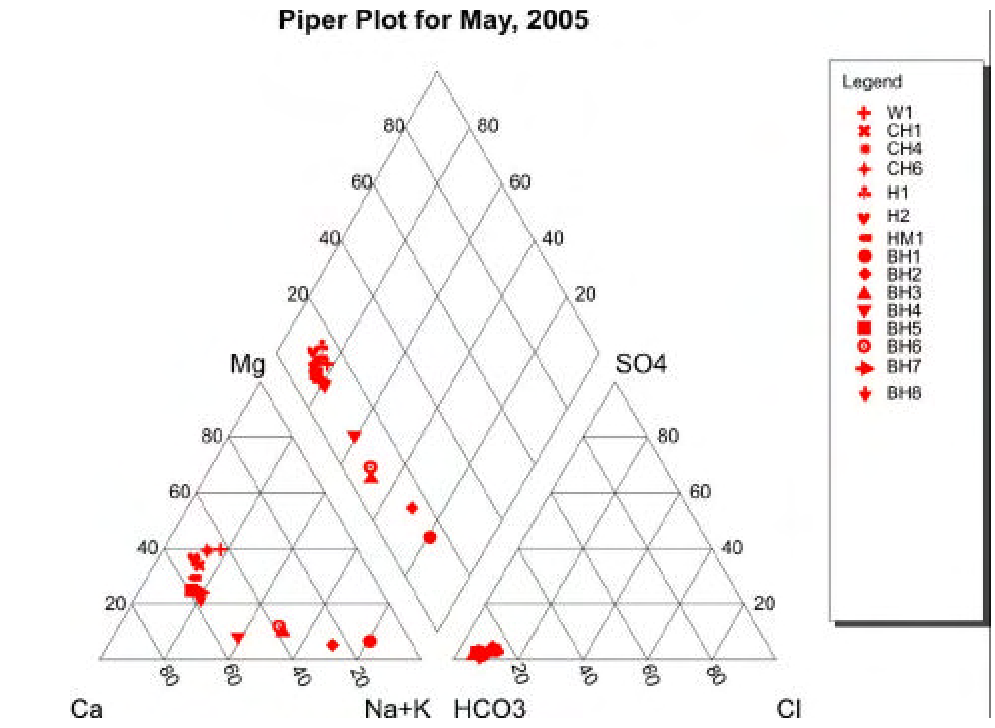


Figure 66(c): Piper plot for May, 2005

Figure 66: Piper plots showing the relative changes in concentration of major cations and anions in the Kolwan Valley. November 2004, February 2005 and May 2005.

No trend is visible in the anion ternary (Piper) plot (Figure 65), where all samples remain dominated by HCO_3. One exception to this is a Walki River sample (W1), which increases in both Na and Cl, in June 2004 (Figure 65). However, during the dry season the flow in the Walki River is influenced by periodic release of water from irrigation tanks upstream. This will impact the water chemistry results, and the sample in June 2004 represents particularly low flow in the river at the time of sampling.

4.4.2 Major and minor elements

Most major elements appear to demonstrate narrow ranges of concentrations at relatively low concentrations (Table 27). For example, the low median value of Cl (8 mg/l), suggests a short residence time of groundwater in the Kolwan valley and limited water-rock interaction. Bicarbonate (HCO_3) consistently dominates the anion concentrations, regardless of season or source, again supporting the suggestion that groundwater is relatively fresh.

However, some concentrations of elements are elevated, for example, the median value of Mg is relatively high (12.2 mg/l), suggesting that when water-rock interaction does take place, a high Mg source is available in the basalt aquifer. Trace elements can also illustrate a wide range of concentrations. Iron, in particular, shows extremely large variations to well above the MAC (Table 27), with a maximum concentration of 5.6 mg/l found at BH3. Arsenic also increased to a maximum of 1.6 mg/l in June 2004 at BH1, although remained low in future samples and at other sites. The high concentrations of Fe and As are believed to be due to entirely natural processes, for example, localised reducing conditions within the basalts. The majority of groundwater samples collected to date remain well below both the Indian environmental standards and the European drinking water limits. (Exceptions are discussed in *Section 4.2.7: Pollution Indicators*.)

4.4.3 Geochemical controls

The dominant geochemical processes, which influence groundwater chemistry include:

- mineral dissolution/ precipitation
- redox reactions
- ion exchange
- mixing with older formation waters

The potential influences of each of these processes are discussed, with particular focus on interpretation of temporal variations throughout the year and the impact of recharge on groundwater quality. Although results can vary each year, due to many different influences, this initial interpretation suggests that mineral dissolution/precipitation is probably the most important geochemical process influencing the groundwater chemistry in the Deccan Basalts of the Kolwan valley.

4.4.3.1 Mineral dissolution/ precipitation

Although most of the water samples are relatively fresh, mineral dissolution can be rapid and much of the water chemistry is established quickly. The dissolution of calcite in particular, is fast and although concentrations of Ca are relatively low (median 38 mg/l), cations are dominated by Ca and anions are dominated by HCO_3 (Figure 65).

Changes in relative cation concentrations can be identified between seasons (Figure 66). An increase in Ca is often followed by an increase in Mg, as seen in February 2005. Samples in the Kolwan Valley are particularly rich in Mg, reaching 24 mg/l in the Chikhalgaon stream, in February 2005. This suggests a rich source of Mg possibly from ferromagnesian minerals (hornblende, amphibole, or olivine) in the basalts.

All samples from the irrigation tank, check dams, dug wells, springs and even rivers, generally demonstrate a fresh water signature dominated by Ca-Mg. However, most borehole samples illustrate a further cation evolution from Ca-Mg towards Na-rich groundwater, as the dry season approaches, in May 2005 (Figure 66c). The source of Na could be from the weathering of plagioclase feldspars in the basalts. Na: Cl ratios are found as high as 9 in BH1 (June 2004), suggesting that water-rock interaction appears to be an important process, particularly in this 100 m deep borehole, which demonstrates Na-rich water throughout the year, even after the monsoon (November 2004). Sodium rich water also dominates in BH2 and concentrations appear to increase towards the dry season, in May 2005, in all boreholes, except BH5, BH6A and BH7. ***Of these, BH5 and BH7 have been found to be directly influenced by infiltration from CD3, resulting in artificial recharge to the underlying aquifer.*** Similarly, all boreholes illustrate higher concentrations of Na, in comparison to dug wells, the irrigation tank and rivers, except for BH5 and BH8 (Figure 67).

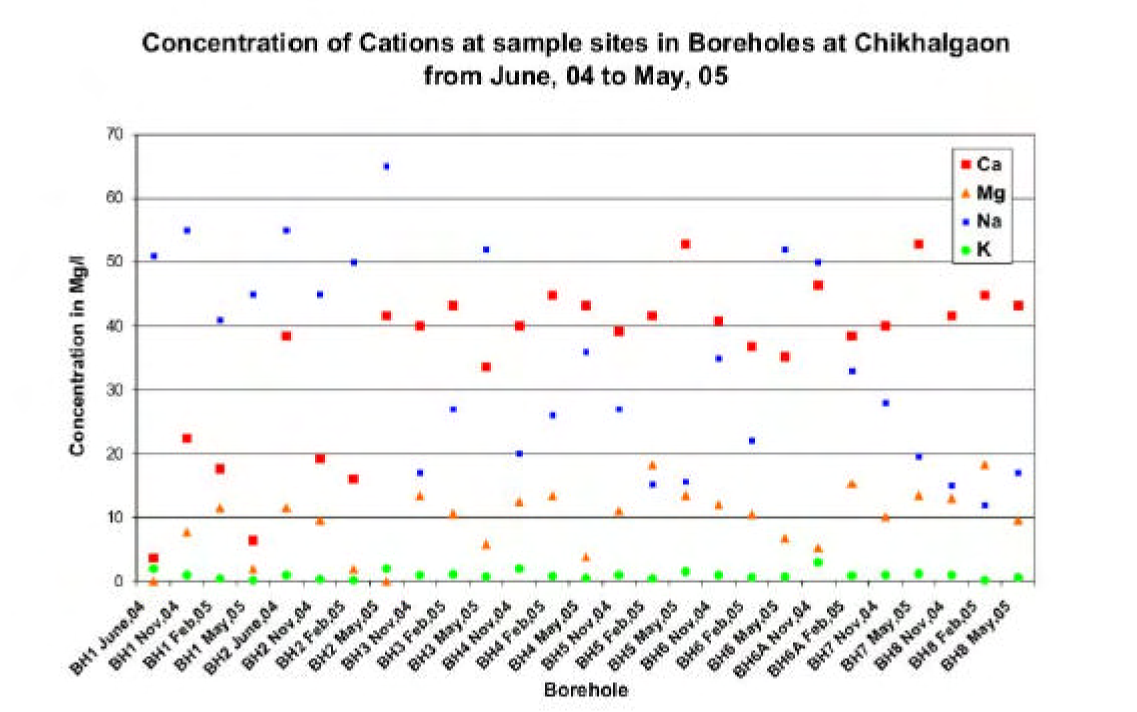
Cl and SO_4 concentrations are generally low, but increase slightly towards the end of the dry season, particularly in June 2004, and then appear to decrease after recharge. Between November 2004 and May 2005, a general trend of increasing SEC is illustrated in the boreholes, suggesting increasing water-rock interaction. F concentrations are low in November 2004 (median: 0.06 mg/l), but also appear to increase towards February and/or May 2005, suggesting an available source. With increasing water-rock interaction, F concentrations reach a maximum of 0.43 mg/l in May 2005 in BH1, and 0.42 mg/l in February 2005 at BH6A, but are also elevated at BH7, BH8 and CH4.

4.4.3.2 Redox reactions

Most of the water samples were collected from dug wells, irrigation tanks, or rivers, which are open to the atmosphere. Grab samples were collected from the boreholes and therefore most of the results illustrate oxygen rich water, as would be expected.

Increasing concentrations of Fe, As and Mn are indicative of reducing conditions. Despite the sampling limitations, Fe was found as high as 5.6 mg/l at BH3, and at elevated concentrations in BH4 and BH6 in February 2005, and at high levels at dug well CH6 and the Walki river, in June 2004. The reducing conditions required may be due to decaying organic matter in the unprotected sources, as elevated concentrations of NO_2-N were also recorded at CH6, by BGS, when sampling in May 2003.

Fe was also found to be elevated in BH1, where concentrations of As were also very high (0.16 mg/l) in June 2004, suggesting reducing conditions in the deeper aquifers tapped by the 100 m deep borehole, although this was only recorded once. Concentrations of Mn were consistently low, suggesting a lack of source in the area (Figure 69).



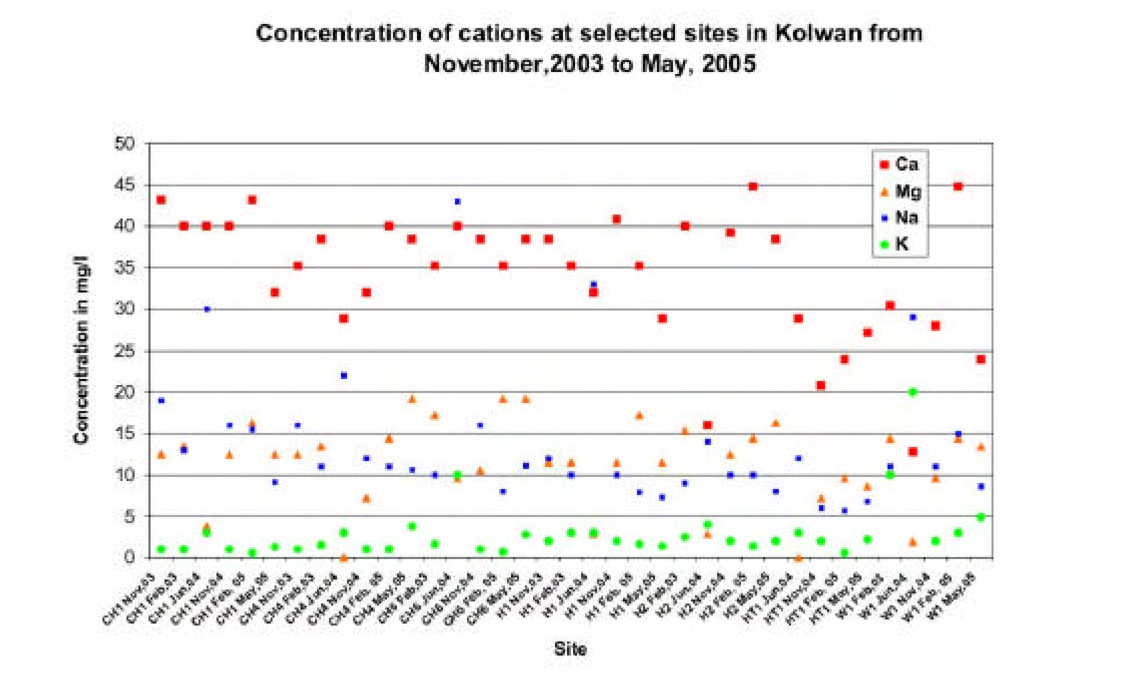


Figure 67: Concentrations of Cations at sample sites in the Kolwan Valley. November 2003 - June 2005.

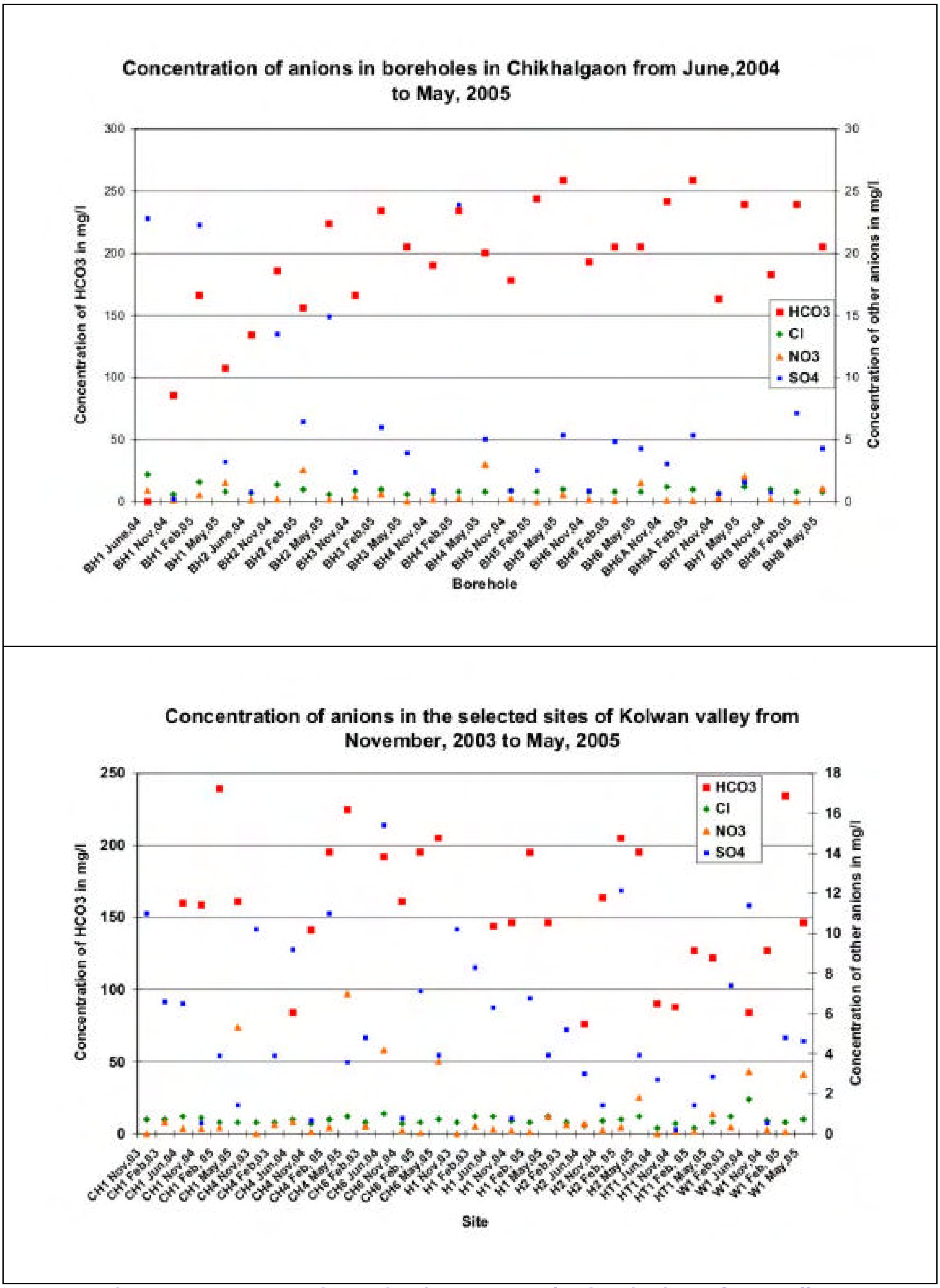


Figure 68: Concentrations of Anions at sample sites in the Kolwan Valley. November 2003 May 2005.

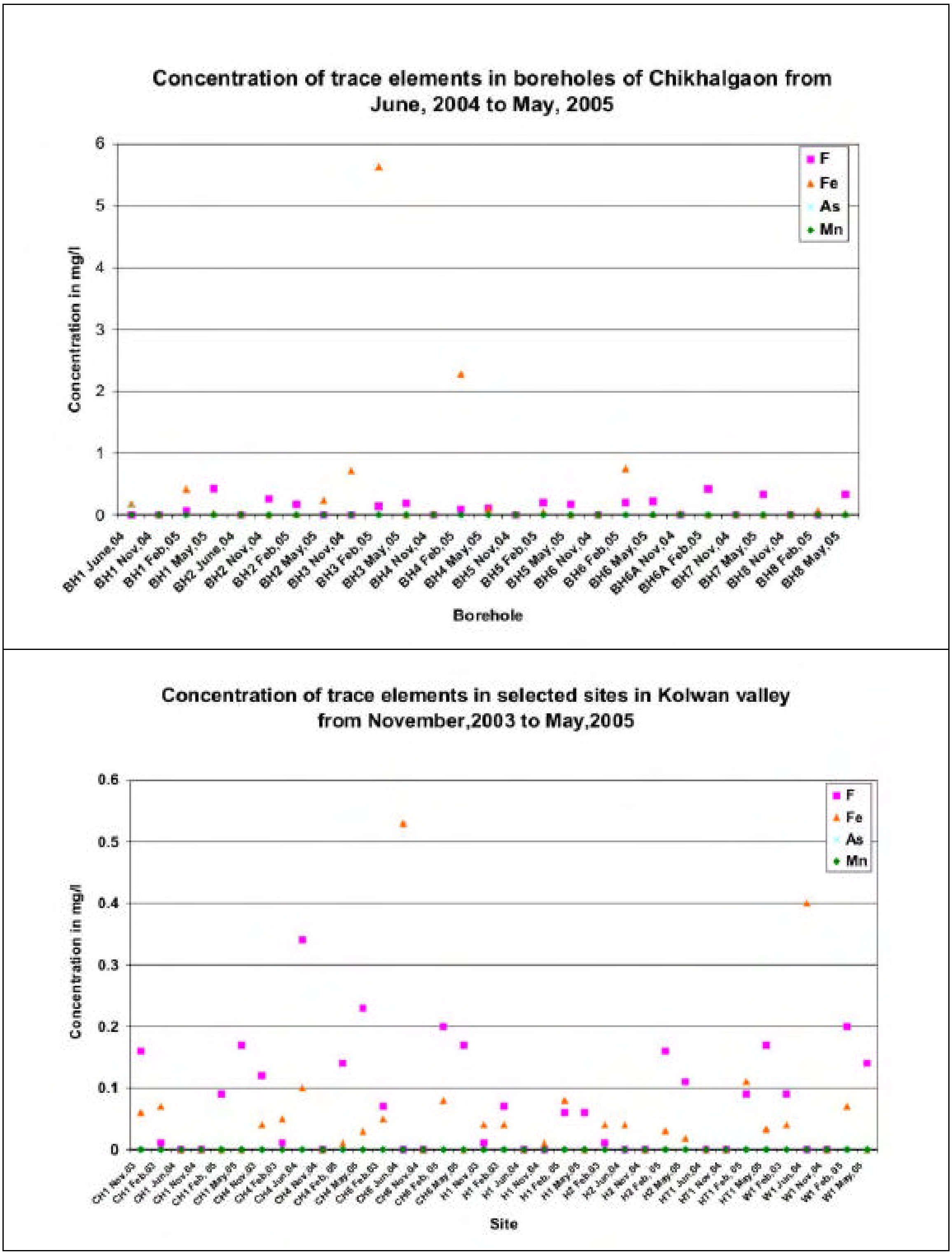


Figure 69: Concentrations of Trace elements at sample sites in the Kolwan Valley. November 2003 - June 2005.

4.4.3.3 Ion exchange

In groundwater, additional Na can be derived either from mineral weathering or via ion-exchange of Na on clay minerals for Ca or Mg. In June 2004, many of the samples (CH1, CH4, H1, H2, and W) appeared to follow a similar trend between Ca and Mg and this was frequently the opposite trend seen for Na and/or K concentrations, suggesting that ion-exchange may be an important process in the aquifer (Figure 67). However, in May 2005, Na and Ca often follow the same trend, suggesting that an increase in Na is more likely to be due to rock weathering. Some borehole samples (BHs 1, 2, 3, 4, 6, 7 and 8) suggest the possibility of cation exchange in May 2005, but more data is needed before it can be concluded that ion exchange is an important process in the Kolwan valley and results hitherto can be said to be only 'indicative' and not 'conclusive'.

4.4.3.4 Mixing with older formation water

Chloride is the best indicator of mixing with older formation waters as it behaves conservatively, but in general, concentrations are relatively low (median: 8 mg/l) suggesting that the aquifer has been well flushed of original formation waters. An increase in Na and Cl is seen at several sites (CH1, CH4, CH6 and H1) towards the end of the dry season in June 2004, and may suggest the presence of a more mineralized groundwater. However, the change in concentration is minimal and HCO_3 continues to dominate anion concentrations in the piper diagram, suggesting a young fresh water for most samples (Figure 68).

Only at two sites were Cl levels elevated to above 20 mg/l: the Walki River and BH 1 (Figure 68). The elevated levels in the Walki River in June 2004, are likely to be due to anthropogenic inputs, like fertiliser run-off, rather than mixing with formation waters. However, the concentration of 22 mg/l at BH 1 in June 2004, is more likely to be due to the presence of older formation waters, as the borehole is 100 m deep and has never been pumped.

4.4.4 Regional characteristics

These initial results confirm the heterogeneities of the Deccan basalts in the Kolwan valley and remind us that sampling is simply a picture of the water quality in a particular time and place. Significant variations can occur in water quality due to many influences, like: aquifer heterogeneity, vertical stratification of chemistry and/or minerals, distribution of recharge or leakage from overlying soil. The geochemical controls discussed previously will also provide a significant influence on the chemical variations present regionally in the Kolwan valley catchment.

Most of the results to date suggest isolated changes in concentrations of specific elements, which have been attributed to different hydrochemical controls. No significant differences have been identified between the groundwater chemistry of the Chikhalgaon and Hadashi catchments, but there does appear to be some localised differences in chemistry between the borehole sites in the Chikhalgaon catchment. Some boreholes

(BHs 1, 2, 3, 4, 6, & 6A) gradually increase relative concentrations of Na and decrease Ca and Mg, towards the end of the dry season, to illustrate a more mineralised groundwater in May 2005. In contrast, BHs 5, 7, & 8 remain Ca-Mg dominated in May 2005, demonstrating a greater similarity to the groundwater chemistry of dug wells, irrigation tank and river, and therefore suggesting a different type of groundwater in comparison to the other boreholes (Figure 66C).

4.4.5 Water quality and depth

In November 2004 all the boreholes drilled in the Chikhalgaon catchment were sampled for the first time. Some of the boreholes were drilled to different depths and therefore provided an opportunity to investigate changes in water quality with depth. The water quality varied significantly between boreholes, despite their close proximity (Figure 68). In particular, differences in chemistry were highlighted between BH1 (100 m deep) & BH2 (30 m deep), which are 10 m apart. Some differences were also noted between BH6 (30 m deep) and BH6A (9 m deep), which are only 1 m apart.

BH1 and BH2 are dominated by Na, with lower concentrations of Ca, and suggest an influence of water quality from BH1 on BH2. This is in contrast to BH6 and BH6A, which demonstrate different water types, despite their close proximity. BH6 has high levels of Fe (0.75 mg/l) in February 2005, while the maximum concentration of Fe at BH6A is 0.03 mg/l (November 2005). In contrast, BH6 has only half the concentration of F (0.2 mg/l) compared to BH6A (0.4 mg/l) in February 2005.

4.4.6 Hydrochemistry of recharge water

Rainfall samples were not collected within the AGRAR project. However, water samples were collected along Chikhalgaon stream and Walki River in November 2004. Sample points included Chikhalgaon stream (CHstm), recharge structures (CD2 and CD3) and the River Walki (Figure 64). Few changes in water quality were detected along the Chikhalgaon stream except at CD3 where an increase in Mg and SEC were identified, together with a decrease in Cl. The main changes, however, were seen at the River Walki, where concentrations of Ca, Na, CO_3 and HCO_3 decreased and K increased slightly, although change is expected here due to a greater contribution from other water sources.

The water in the Chikhalgaon stream is generally fresh and very similar to the quality of the ground waters sampled. Therefore, it is very difficult to identify the impact of recharge and the presence of the artificial recharge structures on groundwater quality.

4.4.7 Pollution indicators

Despite the fact that the majority of land in the Kolwan valley is used for agricultural purposes there is very little indication of agricultural pollution of water sources. This may be a result of efficient agricultural practice of planting different crops within one field and/or planting different crops in succession, which reduces the need for fertilizers and pesticides. Concentrations of NO_3 are generally low, with a median concentration of only 0.27 mg/l, although many sites increase in concentration at the end of the dry season (Figure 68). Some sites may be more vulnerable to potential fertilizer run-off, like dug well H2, which lies level with surrounding fields and is without protection.

The only sites where agricultural pollution is suggested are at the River Walki, and in the private borehole nearby (BWR), where concentrations of K reach 20 mg/l, in June 2004. This might be attributed to a denser cultivation of irrigated crops, like sugarcane, on both banks of the River Walki. Concentrations of Cl, NO_3, and SO_4 were also found to be elevated in the River Walki (W2), and at a dug well (CH6), again suggesting an impact from fertilizers. Sulphate concentrations appear very erratic at many sites, regardless of the season, which also suggests an anthropogenic influence of fertilizers (Figure 68).

4.5 COMPARISON OF RESULTS FROM RECHARGE SITES

Detailed monitoring in Chikhalgaon, using three check dams constructed in a sequence along a stream channel as well as the results from check dams in Hadashi and Bhalgudi helped in classifying these structures into three broad categories. The salient features of these three categories are summarized in Table 28.

Table 28: Characterisation of check dams based upon the role they play in the water resources of Kolwan valley

Check dams	Locations from case study sites	Water use	Comment
Check dams acting essentially as AR structures	CD3, BCD2(?)	Essentially recharge	Some of these structures, for instance CD3 could probably have been more effective further upstream (natural recharge area).
Check dams built in groundwater discharge zones, collecting base flow discharges in streams	CD2, CD1, BCD1	Informal and unstructured lifting of water	Need to check out whether there is a possibility of enhancing the storage to structures like CD2 through desilting or even increasing storages wherever possible and formalizing water use as in structures below.
Check dams that fall into either of the above category but more significantly harvest releases from larger MI Tanks upstream	HD1, HD2	Formal user groups	Structures like HD2 arguably act as both recharge and harvesting structures due to the inflow from the tanks above. Need to understand such cases in more detail for assessing how best to operate water user associations.

5. Results: Socio-economic aspects

As explained in the Chapter 3, a detailed socioeconomic survey was conducted in five villages in Kolwan valley. The emphasis of this survey was to study water resources (availability and management) in selected villages. Instead of a comprehensive impact assessment covering conventional methods and tools, the impact assessment under the AGRAR project was attempted on the basis of social and economic status of the villagers as well as on the basis of their living conditions. An attempt was made to study changes in the farming pattern, irrigation sources and availability of water resources. The villages in the Kolwan valley are medium sized villages with a population range of 500 to 1200 persons per village. There are different sources of water in these villages. An analysis of water resources and its impact on the livelihoods is attempted in this chapter. This chapter also includes some important stories (in boxes) that provide insights into water-related events in the Kolwan valley.

GOMUKH, the implementing agency for the watershed development programme in the Kolwan valley has been working in this area since 1996. Through a systematic approach, various schemes in the watershed development programme were implemented during subsequent years. A part of this programme was to construct recharge structures along streams in the three watersheds, namely, Chikhalgaon, Hadashi and Bhalgudi. The main purpose of these structures was to build water-impounding bodies, which would retain water after the monsoons. This would increase the soil moisture in the watershed, recharge underlying aquifer and irrigate lands, especially adjoining these structures. Watershed projects need to adopt a sustainable livelihoods approach of improving productivity and reducing poverty, even though such projects often present conflicting challenges (Batchelor et al, 2000). This was evident even in case of the Kolwan valley, clearly highlighting ‘trade-offs’ between the engineering and the social sides of GOMUKH’s interventions.

5.1. PATTERNS OF WATER USE

Different sources of water like the river, spring, wells and dams are accessed for water supply. People access water from these sources using pumps and diesel engines but even ‘manual’ access from sources is not uncommon. Tap-water is available in some villages in the valley. The details of the four main areas of water use are given below.

5.1.1. Drinking water and domestic use

Generally community tap-water is used for drinking and cooking purposes. This water, most commonly is sourced from dug wells. In Chikhalgaon, the gram panchayat has provided community tap water to the villagers. The water is pumped from the dug well (CH1) near the river and is stored in the overhead tank just upslope from the main village. The tank feeds some 14 odd community taps by gravity. Each community tap provides water to 15 to 18 households. The villagers pay Rs.150/- per annum per household to the Gram Panchayat as water tax. It was reported during informal discussions that, in most of the villages, the villagers pay Rs. 150/- to Rs.500/- as water tax, wherever such a drinking water facility is available. Spring water is an additional source reported in villages like Hadashi and Bhalgudi. In all the villages, dam and river water is used for bathing and washing clothes. The socio-economic survey conducted under AGRAR revealed that the water requirement per day in each of the five villages is fulfilled from different sources. In Chikhalgaon, 90% households use tap water for drinking and domestic purposes. Around 52% households use river water for washing and bathing. Almost 10% households use well water for their daily needs. Of course, there is clearly an overlap between these classes and since water is available in the river and wells perennially, access can tend to be somewhat flexible. Hence, villagers use more than one source of water to meet their water requirement, depending upon the availability. The proportion of population using various sources differs considerably from village to village (Table 29). Taps, hand pumps and wells (directly accessed) are used as the main drinking water sources. River and spring water are mainly used for washing, bathing and other domestic uses.

Table 29: Water sources available in study villages for meeting daily water requirement

(expressed as percentage of population)

Water requirement fulfilled by the source per day	Chikhalgaon	Hadashi	Bhalgudi	Nanegaon	Nandgaon
Tap water (groundwater based village scheme)	90	0	15	15	41
River	52	78	20	39	0
Well (private)	10	48	0	8	4
Spring (community)	3	15	37	0	49
Borewell (private; pumped)	0	3	5	1	0
Borehole (with handpump; mainly community)	0	7	0	22	0

Source: ACWADAM/GOMUKH socio-economic survey conducted in 2004

Ownership of groundwater sources like wells, in the Kolwan valley, is fragmented and is owned by different sections of the society. There are private wells and borewells along with community wells. Apart from the initiative of gram panchayats, some communities have also come together and have developed water supply schemes for their village or *bastis*. GOMUKH has also initiated some drinking water supply schemes in villages like Nandgaon and Bhalgudi, mainly by developing existing springs. Most of the schemes are running successfully.

Community effort of women from one of Hadashi's hamlets

Loyarewadi is one of the scattered habitations of Hadashi village. The total population of Loyarewadi is about 90. The women from this habitation came together and formed a group to construct a tank for drinking water supply, in 2001. Some 40% of the total cost was borne by the villagers and the remaining 60% cost was donated by an NGO. A tank of 5000 litre capacity was constructed in the hamlet. A 350 m pipeline was laid to lift water from a private well near the mainstream. The well-owner allows this pumping on a *gratis* basis. Water is lifted some 50 m upslope with a 3 HP electric motor. The well pumps water for 15 to 20 minutes every day. The water is chlorinated and stored in PVC tank adjoining which common taps have been provided. There are no individual household connections from the tank. *This scheme has solved the drinking water problem of some 25 odd families of Loyarewadi.*

Drinking water supply scheme of Loyarewadi

Pumping well for the scheme

<u>Bhalgudi spring tank</u>

GOMUKH constructed a number of spring tanks in Bhalgudi (and more recently, in some other villages of Kolwan valley). Such spring tanks supply water to villages and/or hamlets located in the upper slopes. Until some five years ago, Bhalgudi village used to face acute water scarcity during summer, with water being supplied through tankers. Today, drinking water supply schemes through such spring tanks ensure that the village has enough water throughout the year, making it a 'tanker-free' village.

Spring tank in Bhalgudi…

…feeds the water supply to hamlets downslope by gravity.

5.1.2 Irrigation

Almost 80% of the agriculture in the valley is rainfed, with paddy being the major crop. In the rabi season (post-monsoon period of irrigated cropping), dam and river water is used for irrigation purposes. There are some 100 odd lift irrigation schemes in the Walki river basin (including 8 from the Hadashi minor irrigation tank). Of these, 40 schemes lift water using diesel engines, while the remaining 60 are powered by electricity. The water is lifted from the river and is carried to farms by laying pipelines, as far as 3 km upstream in the village. Some farmers who own wells use this water for irrigation in preference to well water. GOMUKH has constructed 18 different structures like masonry and earthen check dams and

Kolhapur Type Weir[1] in the valley. The water in such check dams is available till until anywhere between nid-December to April. Farmers having land close to such structures, use this water for irrigation. There are no formal arrangements, for defining access to and allocation of this stored water. Where one village owns such structures but another owns surrounding land, this can lead to inter-village conflict over allocation of stored water (refer section 5.2.6).

There are 140 springs in the valley. These springs are used for irrigation by the farmers mainly in the upstream area, along the slopes of the hills. These farmers can cultivate only small patches of land from spring water. A few small farmers buy water from the rich farmers for crops like wheat and sugarcane. In case of wheat, the farmers pay Rs.60/- per hour of watering. The total water requirement for wheat is some 75 hours per acre. Hence, the farmer pays around Rs. 4500/- for water for an acre of wheat. The rate of water for sugarcane is Rs.3000/- per acre per year. The farmers who are selling water have installed 10 HP electric pumps on the river, with pumping provision for about 10 hours a day from November to the following May. There are 11 formal water users' societies (all on surface water) in the valley. A few farmers in the downstream area are using water from the some 7 bore wells present in the area, although this is a more recent trend from the last couple of years.

Kolhapur type weir (K-T weir)

Masonry check dam

Water from springs is diverted to small fields by gravity

Open dug wells are increasingly becoming sources of rabi season irrigation

Sources of irrigation in the Kolwan valley

[1] Kolhapur type weir is a masonry check dam having wooden or metal gates regulating flow in the stream or river.

5.1.3 Water for livestock and other uses

Most farmers have at least one bullock or a buffalo. A few farmers, however,have as many as 20 milking animals. The water requirement for livestock is fulfilled by a farmer's own water share (from an established source) or the river. In summer, almost all the animals use the water from the Walki river for drinking. In villages like Chikhalgaon and Bhalgudi, spring water is also used as a drinking water source for livestock.

In the Kolwan valley, there are not many water dependent, economic activities outside of agriculture. There are a few poultries, mainly in Chale and Nandgaon. Besides these, there is a large vegetable processing unit set up by GOMUKH in Chale. Water for these activities is lifted from the river and carried through pipelines laid to the units. There are small enterprises in the valley like eateries, grocery shops and rice mills. Some household water could be accounted for in such enterprises. In recent times, there plant nurseries are coming up in villages like Chikhalgaon and Bhalgudi. Water requirement for such nurseries (mostly feeding floriculture in other parts of Pune district) is fulfilled by lifting water from the river or some wells downstream, and then storing it in nearby tanks.

5.2 MANAGEMENT AND INSTITUTIONAL ARRANGEMENTS

In most of the villages there is an obvious lack of community involvement in the maintenance of structures. Generally there is a communication gap between implementing agencies and the villagers as to who should maintain the structure. Very often, individuals, play an active role either in mobilising maintenance efforts or doing it themselves every now and then, bridging this gap, thereby. Mr. Lahu Phale has been instrumental in various activities taking place in Chikhalgaon. In fact it was through his initiative that the land for the installation of the AGRAR, automatic weather station was made available. He was also keen to share the information obtained from the project with the villagers and so donated some money to purchase a computer in the village school for displaying weather and water resources related information. The computer was installed, with the remaining share for its purchase coming from GOMUKH and ACWADAM.

CD3 being desilted in 2004

Important role played by individuals

In Chikhalgaon Mr. Lahu Phale, *'Upsarpanch'* (deputy-head of the village, inset) is an enthusiastic person. He perceived the importance of maintenance of structures and desilted CD3 single handedly before the monsoons of 2004. The desilting of CD3 increased the storage capacity of the structure. Due to this, the checkdam had water till the first week of January 2005. During previous years the structure dried up by the second week of December, or even earlier. This has inspired him as well as a few other farmers, who were determined to desilt the other two structures as well, before the monsoons this year. By the time this was written, CD2 was desilted.

<u>'DEVRAI' in Chikhalgaon</u>

Sacred groves or *'Devrais'* are community-protected forests. Maintained by villagers, the Chikhalgaon *devrai* is located in the foothills of Chikhalgaon and admeasures some 80 acres. It is a natural forest with different varieties of flora and fauna. The villagers do not allow anybody to cut trees here and so the forest is retained in its natural state, including a perennial source of water in the form of springs.

'Devrai' as seen from Chikhalgaon village

Springs in the 'Devrai' are perennial

There are formal watershed committees in each of the five villages but their role appears to be very limited. They get actively involved in the initial stages of construction of check dams and farm ponds. But later on, their participation and involvement tends to decrease, especially during the maintenance of the structures. Involvement in formulating a formal agreement for water usage and sharing among the villagers is even less so. For the complete success of such projects, an increased and active role of the watershed committee is expected.

Before the implementation of watershed programme in the Kolwan valley, watershed associations and watershed committees were formed in each of the project villages. Watershed association *(Panlot sangh)* is a village level association where every farmer can become its member. The watershed committee *(Panlot samitee)* is elected by the villagers. The implementing agency selects the appropriate site after discussions with these two institutions. All the technical, social and economical aspects are considered before any structure is constructed. In some villages, the proposed beneficiaries are identified or user groups are formed. Some 10% of the total expenditure is to be contributed by the beneficiaries, either in the form of cash or as labour. The government pays rest of the money. The 10% amount paid by the beneficiaries is given to the watershed committee by the government for the maintenance of the structure. The implementing agency monitors the whole procedure during the project period. Once the project is over, the entire maintenance is handed over to the watershed association and watershed committee, in other words, to the village. It is the responsibility of the villagers to maintain the structure but this remains a grey area in the whole process.

In Chikhalgaon, for instance, a formal consent was taken from the Watershed Association and the Watershed Committee before constructing the recharge structures. But there were no water user groups formed, although beneficiaries were identified. The villagers paid their 10% share through labour contribution. GOMUKH was involved in the maintenance of the structure till the project period. Though the watershed association and the watershed committee are in existence, their participation in the process of follow-up and maintenance is very limited in Chikhalgaon.

5.3 WATER AND LIVELIHOOD ANALYSIS

Watershed development has improved livelihood opportunities for watershed communities though the degree of improvement varies from the spectacular to the 'now not very good' (Joy and Paranjape, 2004). The AGRAR project attempted to look into some of the aspects that contextualised water and livelihoods, especially from the artificial recharge angle, but also generally from the perspective of watershed development in Kolwan valley.

5.3.1. Changes in resource conditions

The river, along with some dug wells, remains the major source of irrigation. Over the last few years, there has not been a significant increase in the number of wells in the valley. However some farmers like Maruti Phale of Nandgaon, have invested money on deepening of wells. Around 30 percent farmers have reported that there is an increase in the water table during the last couple of years. These 30% farmers include all the farmers surveyed in the project and non-project villages. However, when one thinks about one to one survey in the project villages (like Chikhalgaon and Hadashi), more than 70% respondents have reported rise in the water table which is perceived by the farmers in the form of increase in irrigated crops and benefits to livestock. Farmers could take crops like horse gram and peas during the rabi season, on soil moisture without proper irrigation. There is enough fodder available for the livestock throughout the year. As far as non-project villages are concerned, though there are some indirect benefits availed by the villagers, the survey could not clearly identify these. It is difficult to say if it was only the rich farmers or farmers with large land holdings or farmers with wells located close to the structures that had benefited with increased water levels, especially considering the local effects from such structures and the multiple Act of factors that control livelihoods in the Kolwan valley (Chapter 4).

The wells and river have become perennial. One of the reasons for this perenniality is the increase in baseflow contribution to streams in project areas. At the same time, water is released from the minor irrigation tanks on the Walki river periodically, implying river flow throughout the year. Due to GOMUKH's initiative a few abandoned wells in the valley were deepened and constructed like the well in Harijan Basti of Chikhalgaon. This well has become a perennial source of water for the nearby houses and village livestock. There are total 17 check dams constructed in the valley and the farmers having lands adjacent to check dams are using this water for irrigation after the monsoon. River Walki, which used to get dry by the end of January, has become perennial and farmers have been able to take more than one crop annually.

This well, in the Harijan vasti of Chikhalgaon, was repaired to provide drinking water to the hamlet that is about 500 m east of Chikhalgaon village.

Check dam in Hadashi from which, lands along the river, are irrigated using diesel engines

Maruti Phale's well: Pre and post watershed scenarios

The well, CH2, belongs to Mr. Maruti Phale. It is located in the Chikhalgaon watershed, on the western flank where lands are registered under Nandgaon village. Maruti owns 5 to 6 acres of land in Nandgaon. He narrates that the well was shallow and narrow six years ago. It used to irrigate 1 acre of land then. Mr.Phale used to pump it for about three hours just after the rainy season, one and half hours between January and March. In April and May, he used the well only for household purposes, mainly as drinking water. The well was subsequently deepened (2 years ago) and properly constructed; this was subsequent to the construction of CD1, CD2 and CD3. Maruti spent around Rs. 90,000/- for excavation and construction of the well. Presently, he pumps water from the well for three hours from November onwards until the following summer (March). In April and May, he pumps it for one hour every day, to irrigate vegetables. He now grows rice, wheat and vegetables on his land throughout the year. He also grew sugarcane in the year 2003-2004.

Maruti Phale's well, now used for irrigation

The well was full to the brim in December 2003. Maruti Phale is ploughing his land to grow a rabi crop irrigated by well water.

5.3.2. Changes in access to and use of groundwater

Traditionally, river, dug wells and springs were the main source of irrigation in the valley. All these sources were not perennial and so the villagers faced severe water scarcity during summer. Women had to walk almost 5 km daily, to fetch water. There was not enough water for livestock, especially during the summer months of March, April and May; farmers could not even think of the second crop (rabi crop) until 1997-98. Agriculture was basically rainfed and the farmers had to sit idle during the summer months or look for opportunities to work outside Kolwan valley.

After the watershed interventions by agencies like GOMUKH, the situation has improved in the valley. During the late 1980s, the Irrigation dept. of Government of Maharashtra constructed three minor irrigation tanks in Hadashi and Walen. The area is a high rainfall area with the total rainfall of almost 2000 mm/year. The tanks could hold a significant amount of throughout the year, with dry season flows in the Walki river being releases from these tanks. The Walki river became the sole supply of ensured water during summer for domestic purpose and livestock.

Then in the late 1990s, GOMUKH began it active implementation of the Watershed Development Programme in Kolwan valley. Due to its efforts like construction of continuous contour trenching (CCT's), check dams and land treatment in the catchment area, the water table in the valley reportedly improved. The water level in the wells is reported to have risen by 1 to 3m after the watershed development programme, although there is no time series data record of water levels from the pre-watershed period. Some farmers could irrigate their lands using well water. Watershed development, spring development and the releases from tanks together contributed to an improved availability and access to water resource. Water became readily available for the farmers and their problem of availability of domestic water and the water for livestock has been solved to a large extent now. Table 30 indicates the change in the water sources in Chikhalgaon and Bhalgudi villages from 1996 to 2004. However, these changes cannot be compared with levels in the non-project villages, as no data are available for these prior to 2004.

Table no 30:Change in the water resources in Chikhalgaon and Bhalgudi

Type	Chikhalgaon		Bhalgudi	
	1996	2004	1996	2004
No. of wells	3	8	6	8
No. of Borewells	2	11	2	2
Water level in m.	6.3	4.8	7.9	6.4

Source: ERAPL report, 2004

The number of dug wells in all five study villages has gone up since 1996 (Figures 70 and 71). In Chikhalgaon and Bhalgudi there were 3 and 6 dug wells respectively in 1996. This number has gone up to 8 each in the two villages in 2004, indicating an increasing shift towards groundwater use. A few of these new wells are community wells like CH1, which is the main source of drinking water supply to the Chikhalgaon village. Almost all the remaining wells are privately owned irrigation wells. There is no increase in the number of bore wells in these villages. Apart from the observation boreholes in Chikhalgaon, only one new borewell has been drilled by farmers in Chikhalgaon.

At present, almost all the lands adjacent to the river are irrigated and the farmers take around three crops in a year. Some farmers have laid pipelines of about 3 km. and are irrigating their lands in areas away from the river. Due to accessibility of water, farmers having lands closer to river can take more than two crops a year improving their financial status. In the Kolwan valley, a direct correlation between rich/larger land holdings and proximity to the river is not apparent. Farmers with small and large land holdings have lands both in the upstream and downstream portions in the Chikhalgaon watershed.

Table no 31: Well water use in five villages

Village	Total no. of wells	Wells used for drinking water	Wells used for Irrigation
Chikhalgaon	8	2	5
Hadashi	4	2	2
Bhalgudi	3	1	1
Nandgaon	8	3	4
Nanegaon	7	2	5

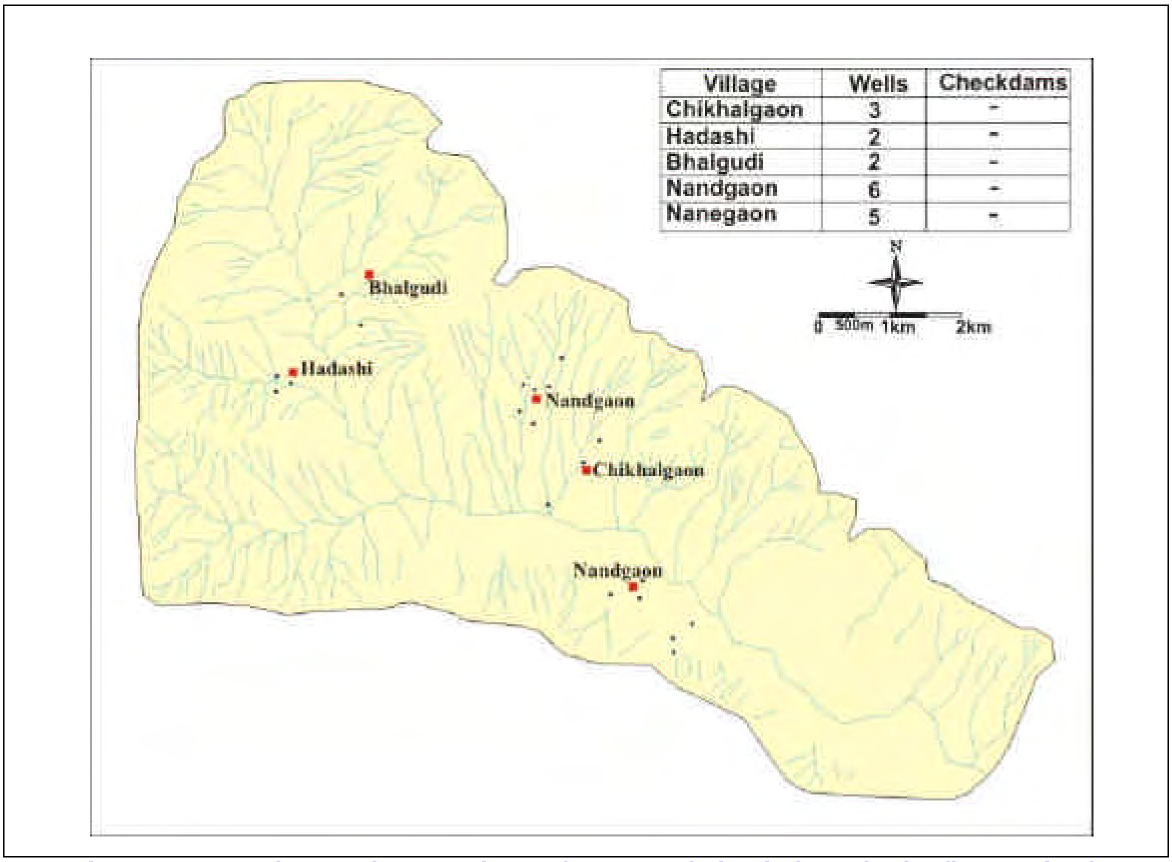


Figure 70: Map illustrating locations of wells and check dams in the five study villages (pre watershed development)

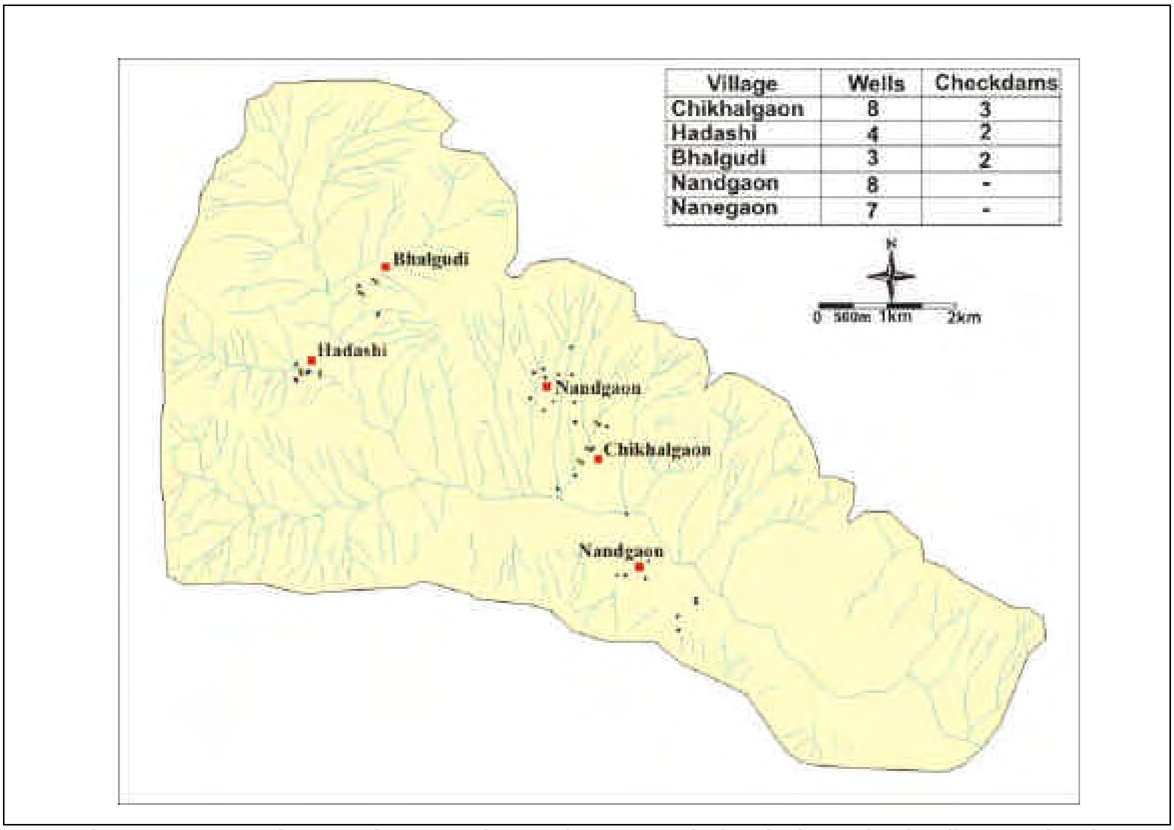
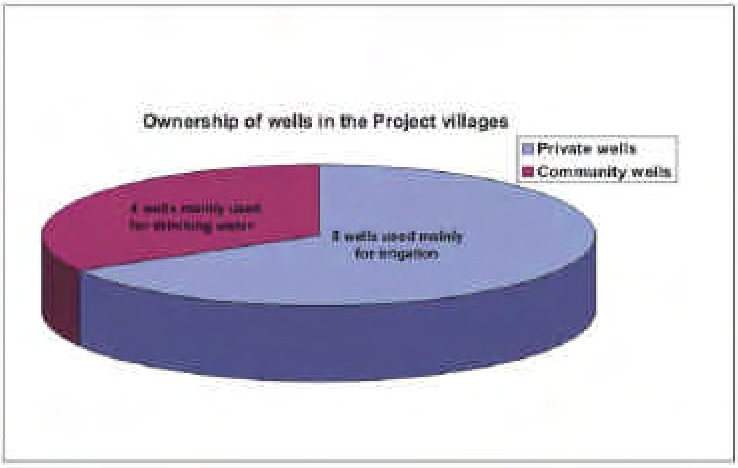


Figure 71: Map illustrating locations of wells and check dams in the five study villages (post watershed development)

Some rich farmers sell water to the poor farmers at some fixed rate depending upon the crop. About 15% to 20% farmers are involved in this practice. Some farmers have drilled boreholes and are using this water for orchids and vegetables, mainly in Nanegaon and Nandgaon (the non project villages). However, the number of farmers drilling boreholes in Kolwan valley is quite low. As the drinking and domestic water supply has become regular, villagers can now afford to use groundwater (springs and wells) for irrigation and livestock. Some farmers in Bhalgudi are irrigating their lands using spring water by gravity.

Table no 32: Table indicating the use of the structures for irrigation

Village	Total no. of structures	Water for irrigation	Water not used for irrigation
Chikhalgaon	3(CD1, CD2, CD3)	CD2 andCD3	CD3
Hadashi	2 (HD1 andHD2)	HD1 andHD2	--
Bhalgudi	2 (BCD1 and BCD2)	BCD1	BCD2



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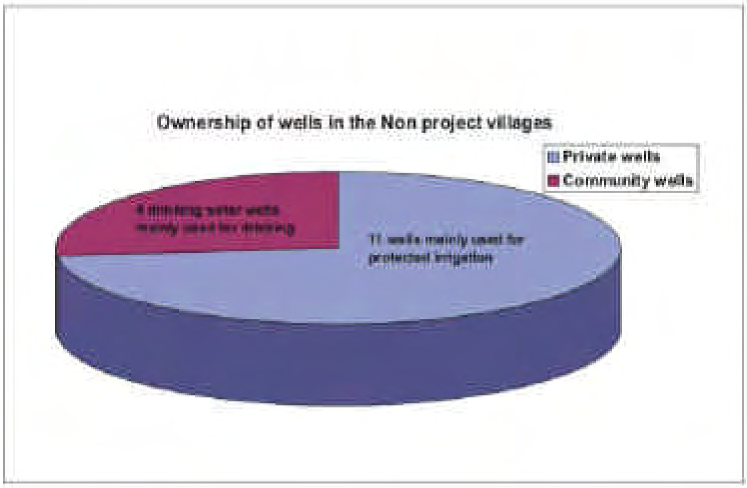

B

Figure 72: Ownership of wells and their usage in project (A) and non-project villages (B) in Kolwan

5.3.3 Changes in livelihood 'outcomes'

Due to the easy accessibility of water resources, there is a change in the social and economic condition of the farmers. There is an increase by 50% in farmers practicing rabi irrigation. Now farmers are taking more than one crop a year. Earlier paddy was the only crop taken during the monsoon. Crops like wheat, sorghum, sugarcane and vegetables are evident throughout the year. Approximately 12% respondents reported irrigation during the latest survey. This, in itself, is an increase of 10% as compared to the baseline survey. However, the extent of irrigation caused due to project must be more if one considers the crops taken. Some 36% reported growing wheat in the rabi season, almost the same percentage have started growing vegetables while 26% have shifted to sugarcane.

The presence of sugarcane on a large scale in the area itself indicates improved availability and access to water. As there is an increase in the soil moisture, a considerable number of farmers have reported usage of cultivable wasteland after the watershed work. The project, can be considered to be one of the factors in bringing about multi crop pattern in the valley. Looking at the variety of crops reported one feels that the extent of irrigation may be much more than the 12% reported by the farmers.

A large number of farmers have reported that livestock has benefited as there is ample water as well as green fodder available during the summer now. Around 22% farmers have reported an increase in milk production. There was no fixed source of water for livestock in the valley. Traditionally all the cattle used to drink water from the river Walki, whenever water was available in the river. Otherwise water was made available for the livestock through the domestic water fetched for the household purpose. Lately, river Walki has become perennial and other sources like dug wells and springs have water throughout the year so there is ample water available for the livestock. Some dug wells, like the one in the Harijan Basti of Chikhalgaon, is only used as the drinking water well for cattle. Springs in the upstream area of Bhalgudi and Hadashi are also used as the major sources of water for livestock.

Table 33: Change in cropping pattern and other sources in Chikhalgaon and Bhalgudi

Type	Chikhalgaon		Bhalgudi	
(Area in Hectares)	1996	2004	1996	2004
Horticulture	2	6	2	4
Vegetables	4	8	4	6
Wheat	6.10	12.50	5.50	13.50
Summer vegetables	--	6.10	--	8.30
Milk production (Lit/day)	125	250	150	180-200

Source: ERAPL report, 2004

The average household income shows an increment of Rs. 3000/- as compared to the baseline survey. However there are striking changes in the composition of income sources. Service income has increased by 5 to 22 percent. Number of families reporting livestock income has doubled. On the other hand the families depending on labour income have reduced to 13 percent from 40 percent at the time of baseline survey. Families reporting business income has also increased by 5 percent. The migration of farmers to the villages as agricultural labour has reduced considerably in the two villages. In Chikhalgaon and Bhalgudi, around 140 and 145 persons used to migrate to other places respectively for the search of work in 1996. At present the migration has come down to 65 and 62 in the two villages respectively.

A successful flower nursery in Chikhalgaon

Mr. Hiraman Waluj, started a rose nursery in Chikhalgaon in 2003 with an initial investment of Rs. 25,000. He owns land of about 1 acre. He has installed a 5 HP motor on the river Walki from where he pumps water once in two days and stores it in the tank near his nursery. The capacity of the tank is around 3000 litres. He waters his plants twice a day. There were some 30,000 saplings in the field in 2004-2005. He reports selling his plants at the rate of Rs.8/- per plant. Some large buyers buy 8000 to 9000 plants a month, with the bulk sale rate of Rs. 5/- per plant. His total expenditure on plants, for maintenance and packing, is some Rs.25,000/- per year. He reports an annual profit of Rs. 1,00,000/-. His entire family of five people is into this business and he hopes to expand this business further.

Mrs. Valuj with the rose saplings

Hiraman Waluj (right) near the makeshift tank used for storing the water for his rose nursery (Ongoing construction work of permanent tank can be seen in the background)

Rose nursery developed by the Walujs

5.4 IMPACT ASSESSMENT

Assessing impacts from watershed development projects is a great challenge. The hurdles encountered in effective impact assessment have recently been discussed in generic and specific reviews watershed development projects (Joy and Paranjape, 2004; Kerr, 2002). This section summarises some of the salient observations pertaining to impacts from watershed development, albeit keeping in mind that other factors (outside the watershed development project) also influence such outcomes and impacts.

5.4.1 Social change

Social environment remains unchanged and closely resembles with the situation at the time of baseline study. The caste composition of the area is characterized by the dominance of forward caste population in the overall population. This fact gets reflected in the baseline and the evaluation study as well.

The average family size has increased as compared to that at the time of baseline survey. This may be due to reverse migration that has taken place during the past few years due to employment opportunities created by implementation of the project.

It is observed that there is a significant change in the occupation pattern during the last 8 years. At the time of baseline survey, during 1996, 81% population was engaged in agriculture followed by 8% in service, 6% labour and 5% in business. Now during the evaluation study in 2004, it is observed that only 65% people are engaged in agriculture followed by 20% in service, 9% in business and 6% labour. There has been significant increase in the sectors like service and business. Due to proximity to the towns like Pune and Mumbai and good communication sources people prefer to work in these towns. Though agriculture seems to have gone down by 20%, there is no visible change in the valley. Many male members of the family are into service or business and female members of the family conduct a large proportion of agriculture-related activities. Figure 73 indicates the change in household occupation during the last decade.

Most of the farmers in the five villages are small to medium land-holding farmers with the average land holding of up to 1 to 2 hectares. There is no significant change in the size of land holdings from 1996 to 2004, even though there is significant change in the cropping pattern. There is an overall improvement in the economic conditions of the people. There is a considerable increase in the number of ‘pucca’[2] houses. (Figure 74)

Sanitation facilities in all villages are improving. In 1996, only 1%, 0% and 2% families had latrines in Bhalgudi, Chikhalgaon and Hadashi respectively. In 2004, 5%, 10% and 12% families in Bhalgudi, Chikhalgaon and Hadashi respectively have latrines. Besides these three villages, there were 7% and 20% latrines constructed in Nanegaon and Nandgaon respectively. More than 50% households have bathrooms in the houses.

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[2] Pucca house means walls of the house is made up of pucca material like burnt bricks, GI sheets, stone, cement concrete etc and roof is made up of lime concrete RBC or RCC sheet.

Katcha house means both walls and roof are made of katcha material like solid mud, unburnt bricks, wood and thatched roof.

Semi pucca houses are those which are neither katcha nor pucca.

**Definitions adopted from National Building Organisation, Government of India in consultation with RGI and NSSO.*

It is observed that there is an overall increase in household articles like TV, fans, cupboards, bicycles, two wheelers etc. The fact that villagers are able to spend on these goods which are not necessity articles indicates improved income and spending capacities. Table 34 indicates increase in assets in Chikhalgaon and Bhalgudi from 1996 to 2004.

The villagers in the five villages have also spent on purchase of land and livestock along with the repair or construction of houses. Table 35 indicates the details of the purchases in the last 10 years by the farmers.

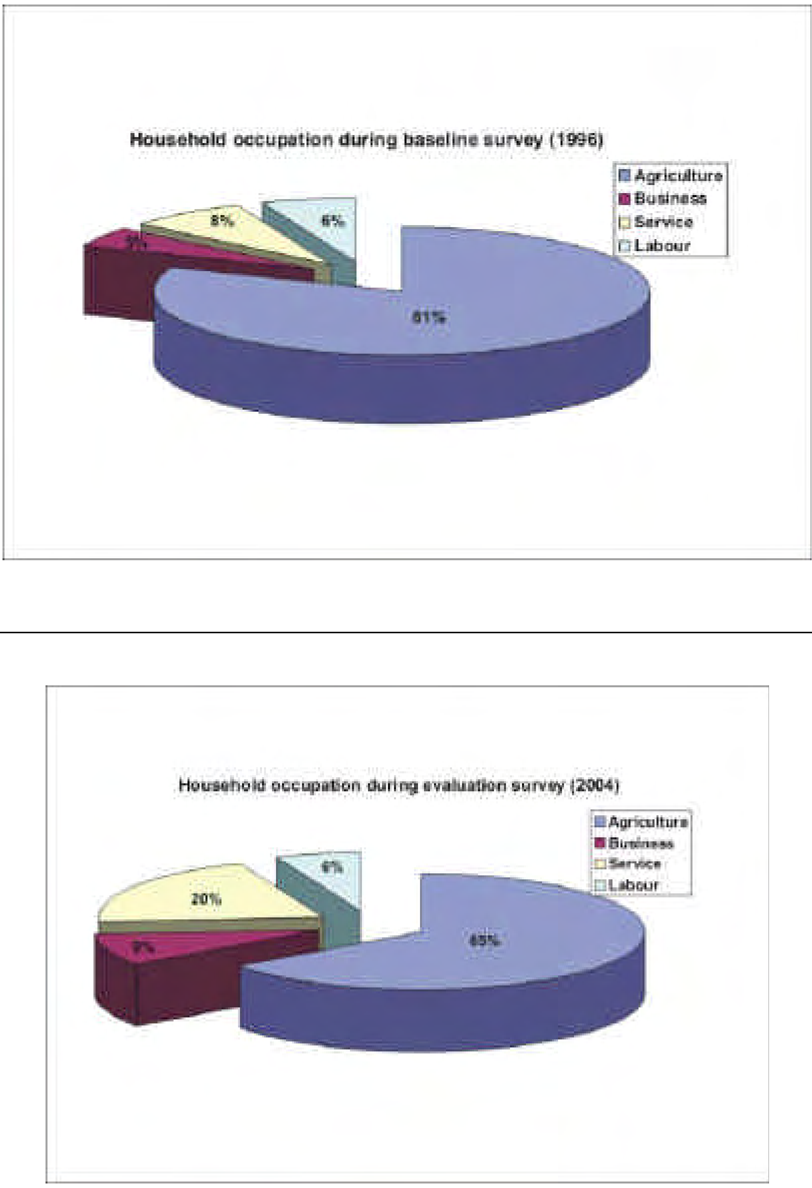


Figure 73: Change in the household occupation, 1996 to 2004 (Chikhalgaon)

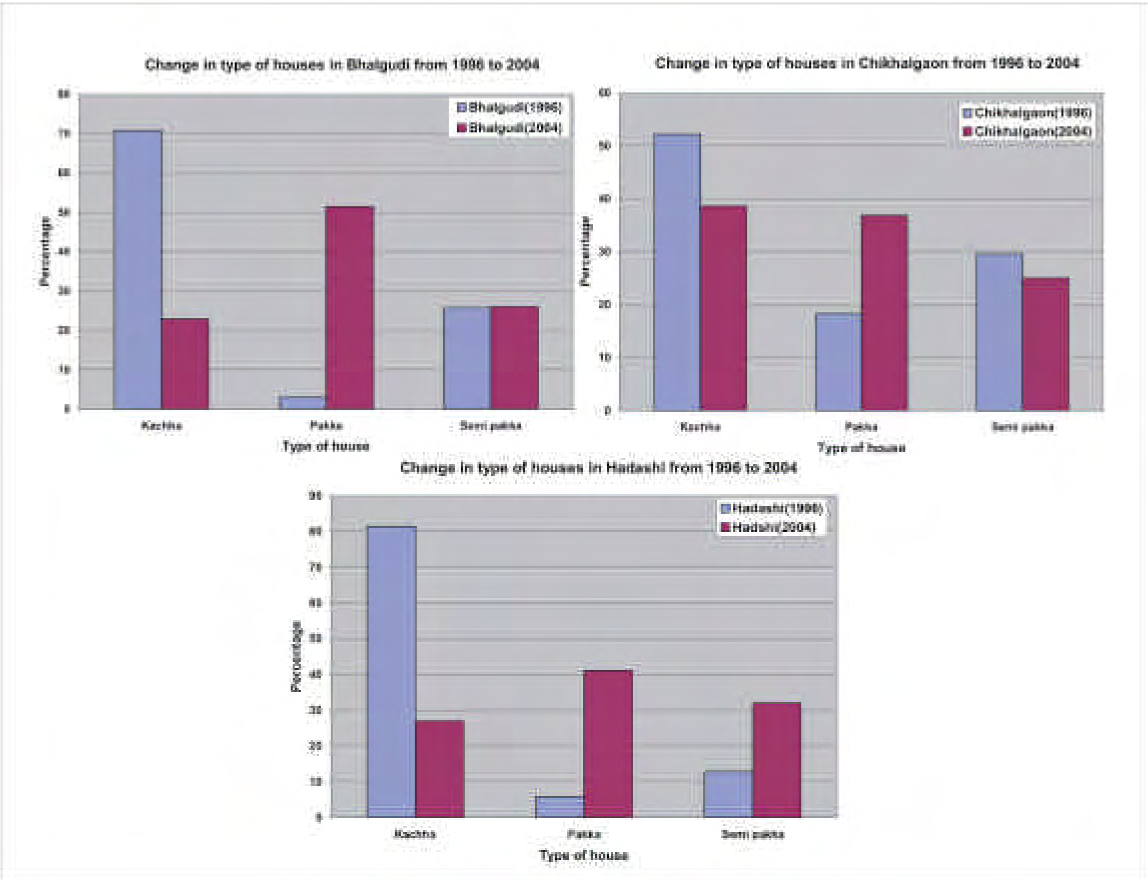


Figure 74: Increase in Pucca houses in Bhalgudi, Chikhalgaon and Hadashi

Table 34: Change in assets in Chikhalgaon and Bhalgudi

Type	Chikhalgaon		Bhalgudi	
(Number)	1996	2004	1996	2004
Tractors	1	2	2	3
Motorcycle	4	10	5	8
T.V sets	39	41	24	32
Farming equipments	--	9	--	11
Saving groups	--	5	--	2

Source: ERAPL report, 2004

Table 35: Details of purchase of assets in the last 10 years

	Bhalgudi	Chikhalgaon	Hadashi	Nanegaon	Nandgaon
Purchase of land (%)	6	2	3	4	2
Purchase of livestock(%)	0	33	17	11	0
Digging of wells(%)	0	4	0	4	2

Bore wells (%)	0	0	0	0	0
Construction of house/ repairs (%)	9	30	26	13	6

It is observed that the most of the farmers have spent on construction/repairs of the houses in the last 10 years. It seems to be the first priority among farmers as it is a necessity as well as a status symbol to have a pucca house(constructed house). Next, farmers have spent on purchase of livestock, mainly in Chikhalgaon, Hadashi and Nanegaon. In these three villages, fodder is readily available and the farmers have some milk co-operative societies from where milk is collected and taken to the market.

A few farmers have invested on purchase of land. Most of the land has been purchased by the outsiders, people other than the ones already residing in the village(with the exception of Chikhalgaon). Some farmers in Chikhalgaon, Nanegaon and Nandgaon have dug new wells. The success rate of boreholes in the valley is not so encouraging and so instead farmers prefer to invest in the construction and deepening of wells although a few borewells (4-5) were drilled in these five villages during this summer period of 2005.

5.4.2 Economic improvement

It is observed that the overall income of the household has gone up over the last 6 years (Figure 75). The average annual income in 1996 for Bhalgudi, Chikhalgaon and Hadashi was Rs.17220/-, Rs.19630/- and Rs.23831/- respectively. Incomes have gone up to Rs. 26860/-, Rs. 29712/- and Rs. 30984/- respectively (the official poverty line is Rs12,000/year). The average annual income for Nanegaon and Nandgaon was Rs. 64,210/- and Rs. 19,889/- respectively in 2004. Farmers in Nanegaon mainly take sugarcane as a cash crop, drawing irrigation water from the nearby river.[3] This is clearly reflected in the much higher average annual income of the village.

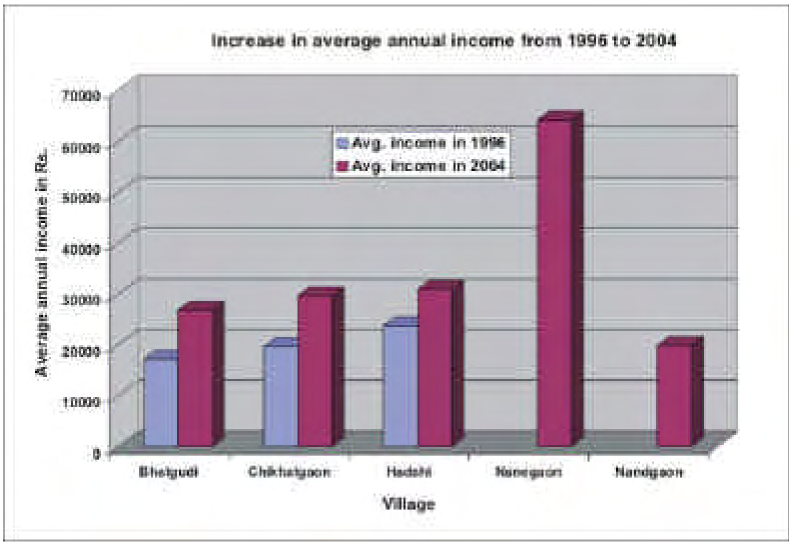


Figure 75: Increase in annual income in three villages from 1996 to 2004

[3] The growth of water-intensive sugarcane irrigation has concerned GOMUKH, who are now actively supporting organic vegetable production as a less water-intensive alternative.

There has been an increase in income groups in the three villages. In 1996, more than 50% households in Bhalgudi and Hadashi were in the income group of Rs. 12,000/- per annum. Around 90% households in these two villages were in the income group of less than Rs. 50,000/-per annum. In case of 2004, there has been a significant increase in the households having annual income of Rs. 12,000 to Rs. 24,000 and more in the three villages. In 1996, there were very few households having annual income of Rs. 50,000 and more. There were 0,6 and 3 households in Bhalgudi, Chikhalgaon and Hadashi respectively. Now the households having annual income of Rs 50,000 and more have gone up to 12, 20 and 20 in Bhalgudi, Chikhalgaon and Hadashi respectively. Table 36 indicates distribution of households according to different income groups.

5.4.3 Benefits to livestock

There have been significant benefits for the households possessing livestock. Hadashi has maximum number of livestock from amongst the villages in the valley. Table 37 indicates major benefits to livestock in the three 'project' villages. An increase in green fodder (available from February, with minimal irrigation requirement, until its harvest in April-May) and availability of water in summer are the two major benefits to the farmers in the three villages.

Table 37: Benefit to livestock in the three villages after the implementation of watershed programme (1996 – 2004) (As percentage reporting increase)

Benefit	Bhalgudi(%)	Chikhalgaon (%)	Hadashi(%)
Increase in milk production	6	9	22
Increase in green fodder	17	42	63
Increase in stall feeding	17	7	5
Possibility of cross breed animals	23	2	4
Ample water in summer for livestock	6	89	96

Source: ERAPL report, 2004

5.4.4 Change in cropping pattern

There is a significant change in the cropping pattern from 1998 to 2004. In 1998, paddy was the main kharif crop. Nearly 99% of this total paddy was grown during the monsoon. Around 2% farmers in the Kolwan valley grew jowar (sorghum) as a kharif crop. Some 1% farmers grew pulses but percentage of vegetables grown was negligible (GOMUKH, 1996). Some 60% farmers growing irrigated crops in 1998 were growing wheat. Some 19% grew pulses, 4% cultivated vegetables while only 1% grew jowar and 0.35% had sunflower. Cultivation of sugarcane was virtually absent in 1998 because of the absence of irrigation facilities.

It appears that in 2004, the cropping pattern in Chikhalgaon and Hadashi has changed significantly. There is no change in the kharif crop, with paddy being the most dominant crop grown in the rainy season. In Chikhalgaon, it was observed that, wheat, sugarcane and vegetables were the important crops grown during the rabi season. In 2004, vegetables (30% of the farmers) and sugarcane (35%) and wheat (44%) formed the rabi (irrigated) crops. This change can be attributed to the improved availability and access to water in the Kolwan valley in general and in the Walki river, in particular. A detailed survey of the irrigated cropping pattern is presented as a specific section at the end of this Chapter (Annexure 1).

In Hadashi too, there is no significant change in the kharif crop but there is a significant increase in vegetables and sugarcane, both irrigated, rabi crops. The percentage of wheat grown has reduced from 60% in 1998 to 54% in 2004. But the percentage of vegetables and sugarcane has gone up from 4% and 0% in 1998 to 51% and 29% respectively in 2004. There is also some decrease in the production of pulses in both the villages. It is also observed that crops like jowar and sunflower are not grown in the two villages anymore.

Table 38 summarises the change in the cropping pattern from 1998 to 2004. Data used for 1998 is the consolidated data from the 8 project villages of Kolwan valley (GOMUKH, 2000). Data used for Chikhalgaon and Hadashi is from the evaluation study conducted under the AGRAR project. The generalised crop calendars for pre and post watershed periods are presented as Tables 39 and 40.

Table 38: Change in cropping pattern in Kolwan valley

Percentage of farmers growing irrigated crops	Kolwan valley (1998)	Chikhalgaon (2004)	Hadashi (2004)
Jowar	1.23	0	0
Wheat	60.35	44	54
Vegetables	3.95	30	51
Pulses	19.30	21	13
Sugarcane	0	35	29
Sunflower	1.14	0	0

Table 39: Crop calendar for Kolwan (pre watershed development)

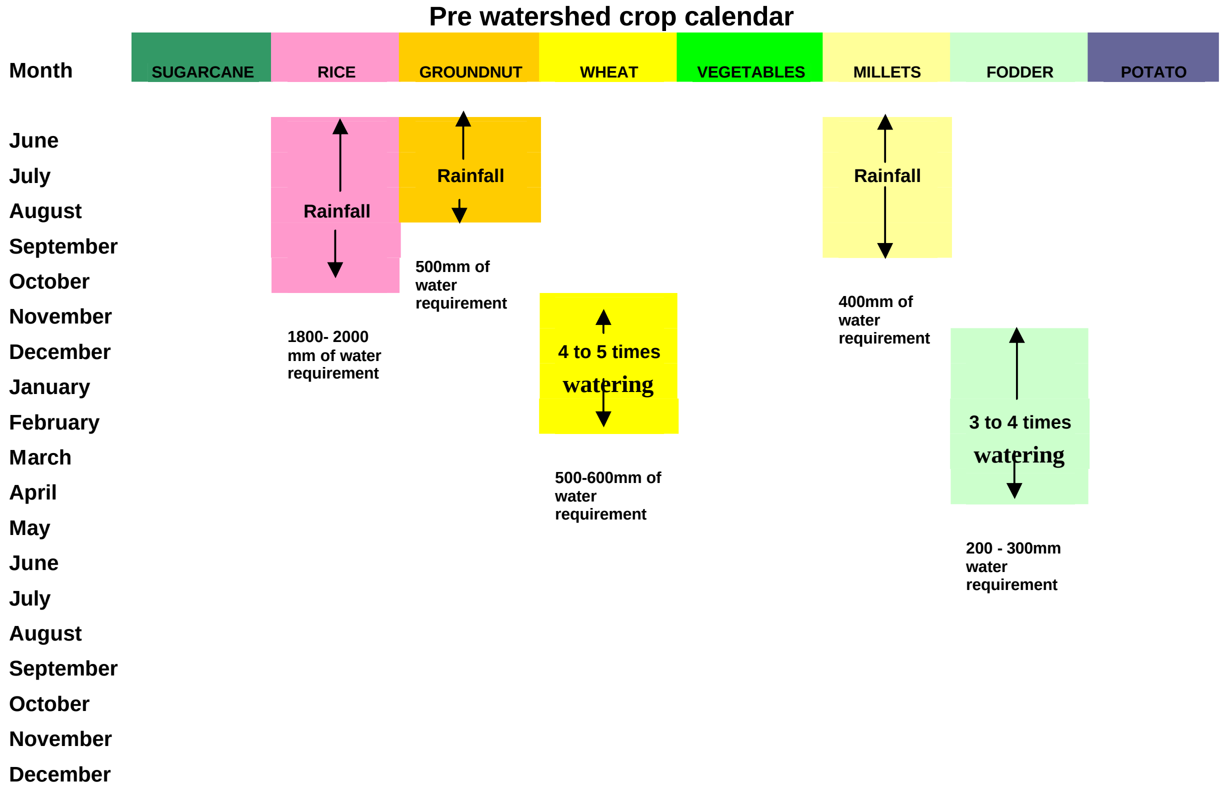
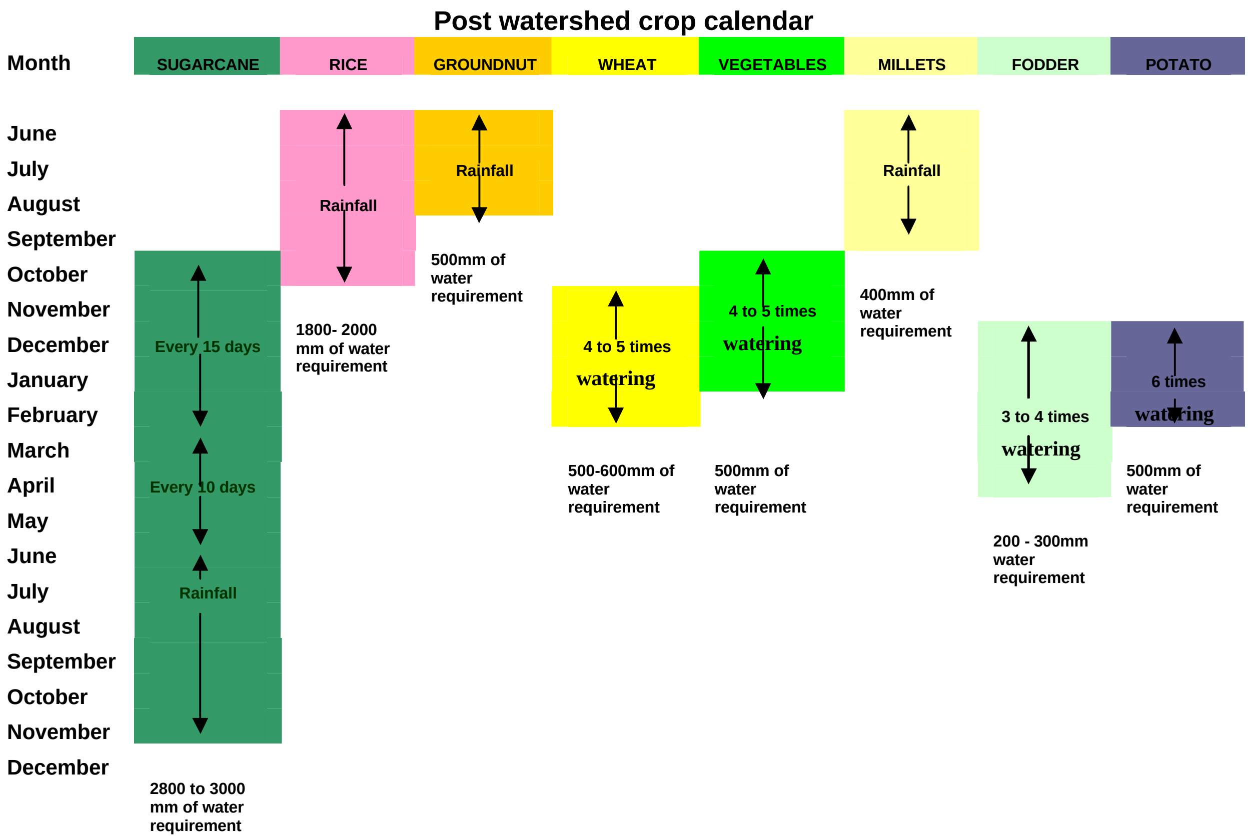


Table 40: Crop calendar for Kolwan (post watershed development)



Successful horticulturist in Hadashi

Mr. Jadhav, a government civil works constructor, has purchased around 200 acres of land along the slopes of the hillock in Hadashi. He has developed a small recreation and religious centre on the hilltop. He has planted around 50,000 trees of different species like mango, coconut and amla along the slopes of the hill. Water for the orchard is pumped from the well, which is located at the base of the hill. Plants are watered using drip irrigation. In summer, when the dug well runs dry, water is pumped from the adjacent borehole into the dug well, from where it is lifted to the top. This is the third year of the plantation and Mr. Jadhav is expecting to harvest the yield from these trees from 2006 onwards.

Resort developed by Mr. Jadhav. A farm pond along with some mango trees are seen in the background(above); drip irrigation technique used for plants(below)

Water being pumped from bore well (above) and is stored in the dug well (below) during the summer period

5.4.5 Other benefits

One of the objectives of the socio-economic survey was to ascertain how villagers perceive benefits from watershed development projects and also attempt to relate findings from the physical study to percepetions of the community. The major benefits perceived by the villagers were in the form of:

- Increase in kharif irrigation (increased reliability of river flows allowing supplementary irrigation when monsoon rains fail)
- Increase in rabi irrigation

- Increase in water table
- Water recharge
- Possibility of sugarcane crop
- Possibility of multiple crops
- Utilization of wasteland
- Increase in plantation of medicinal plants and horticulture
- Regular drinking water supply through community taps

Depending on the village, these perceived benefits seemed to differ. Table 41 indicates the matrix showing perceived benefits in the three villages. Perceived benefits were ranked according to the priority accorded to any benefit by the sample chosen from each village. The benefits in each village were ranked according to the number of villagers who considered that benefit as being most significant (rank 1) through the least significant (rank 5).

Table 40: Perceived benefits in three villages

Village	Increase in water recharge	Possibility of multiple crops	Possibility of sugarcane	Increase in rabi irrigation	Assured drinking water supply
Bhalgudi	1	2	5	3	4
Chikhalgaon	1	3	2	5	4
Hadashi	4	2	3	1	5

Social participation of villagers in various activities has increased. The formation of Self Help Groups and Womens' Groups meant that the participation of women in various activities like the village panchayat has increased. There is almost 30% to 50% increase in the number of people participating in gram panchayats, watershed committees, women SHGs and youth groups.

More than 75% farmers are ready for equitable water distribution from various sources. Around 40%, 74% and 97% people in Bhalgudi, Chikhalgaon and Hadashi respectively feel that the watershed activities proved useful in some way or the other and the project, as a whole, is a success. However, people find it difficult to accord any single benefit to a particular 'recharge' structure.

It appears that there is awareness being generated in the villages about the watershed activities as well as artificial recharge. It is observed that farmers who had their own irrigation source(s) prior to the implementation of the watershed development programme have shown some dissatisfaction from the project. Most of the farmers who themselves have a source of irrigation remain unaware about the details and objectives of the programme as a whole. Bhalgudi village consists of a number of *vastis* (small hamlets) with each *basti* having its own source of irrigation, usually in the form of springs. They have been using this water for protective irrigation for years and are not using any other sources of irrigation. Due to the topographical constraint for Bhalgudi (the terrain is more undulating and most hamlets are located in the upper slopes in Kolwan valley), they cannot cultivate a variety of crops and so benefits in the form of improved or increased irrigation remain limited in case of Bhalgudi. On the other hand, farmers are apparently more benefited directly in Chikhalgaon and Hadashi, where irrigation is concerned.

5.4.6 Other impacts

The impact of watershed development activities on the recharge structure scale is not so apparent. It appears that there is no direct impact on the livelihoods of the nearby farmers. The structures are mainly constructed for water impounding, to increase the recharge to the groundwater. The capacity of these structures is limited and they retain water till the early part of summer. The water can only be used for the rabi crops and is not available during peak summer. But the water levels in the wells downstream have come up. There is an increase in soil moisture and lagging of stream flows. So when one thinks of a combined effect of watershed development activities on the entire watershed scale, there is definitely some impact on the livelihoods from such structures, albeit indirectly.

Watershed development is a complex activity. Its success is a function of not only technical perfections but also attitudinal and behavioural changes. Watershed works done in the project areas not only benefit the project area but the benefits are passed on to the adjacent downstream and upstream villages in some way or the other. Still, around 8 percent respondents in the AGRAR study felt that there were no benefits from the completed works. A few farmers, mainly in Chikhalgaon, believe that their neighbouring village has benefited more than their own village, because the feel that the direct benefit of the check dams is taken by the farmers from Nandgaon who lift the water from CD1 and CD2. The lands on which the check dams have been constructed belong to the farmers of Chikhalgaon and the construction has been done through '*shramadaan*'(labour contribution) from the farmers of Chikhalgaon. A few farmers of Chikhalgaon also lift water from CD1 and CD2, but the main pumping of water is done by the farmers of Nandgaon. And since the stream is a recognised boundary between the two villages, there is a minor conflict between the two villages around ownership of water, a clear-cut signal for the need to develop a formal understanding between villages about water sharing and water use from such structures.

Annexure 1

SUMMARY OF FINDINGS

on

IRRIGATED AGRICULTURE IN CHIKHALGAON VILLAGE

Based on a study conducted by

Harshvardhan S. Dhawan

Department of Environmental Sciences

University of Pune

Pune-411007

The current summary is a gist of the results and synthesis produced in the dissertation undertaken by Mr. Harshvardhan S. Dhawan for completion of his M.Sc. Environmental Sciences Course. The dissertation itself aimed at analyzing the recent agriculture development pattern of Chikhalgaon, a typical village set in the western ghat region of Maharashtra. The study was, as a matter of fact, undertaken under the broader umbrella of an ongoing international research project called "Augmenting Groundwater Resources by Artificial Recharge" (AGRAR), focusing on the Kolwan valley site. The project dissertation titled "**Mapping Of Cropping Pattern Changes Regarding Irrigated Agriculture In Chikhalgaon Village Area Of Kolwan Valley, Pune District"** highlighted the importance scientific information by demonstrating how even a simple synthesis of irrigated cropping pattern in a village is quite complex. Understanding this complexity holds the key to microplanning of land, water and crop management in a village. The study focused on distribution of irrigated cropping and sources of irrigation in Chikhalgaon village, the focus of the AGRAR research and used remote sensing data as a background check for verifying pre-1998 data (not presented here). Synthesis of data was done using GIS software. This section summarises findings from Mr. Harshvardhan S. Dhawan's dissertation, and therefore, is credited with his title and name.

1. Spatial distribution of irrigated crops in Chikhalgaon (2004-05)

The study of irrigated crops in Chikhalgaon for the period June 2004 to April 2005 can be summarized into four parts, given below. This summary provides an insights into irrigated cropping in a typical village in Kolwan valley.

(a) Agriculture Plots: Kharif v/s. Rabi

The total available land for agriculture in Chikhalgaon was 300 ha, of which 50 ha was grassland. About 1100 farmers from Chikhalgaon cultivated the remaining 250 ha, during the kharif season. This 250 ha of land can be considered as rainfed agriculture. Incidentally, there are 1127 registered farmers in Chikhaglaon, implying that some 27 farmers do not cultivate their lands at all. The demand on irrigating the kharif crop through irrigation sources such as the river and wells was virtually nil because of the high-rainfall and good reliability of rain.

The rabi season cultivation (October 2004 to February 2005) amounted to about 40.28 ha, all of which was irrigated. Some 106 farmers out of the total 1100 irrigated rabi crops. The rabi season cultivation crops were wheat as the major crop, followed by sugarcane and a crop of various vegetables. The spatial distribution of irrigated crops was identified for the rabi season of 2004 by visiting and locating each plot on the village map. It was found that these plots were located in close proximity to the Walki river and to the streams flowing on the either side of village boundary. Only a few plots were located in the upland area of Chikhalgaon, away from the river. Most of the irrigated crops received water from lift irrigation schemes at the river, with some pipelines laid out over distances in excess of 2 kms to their fields.

(b) Wheat

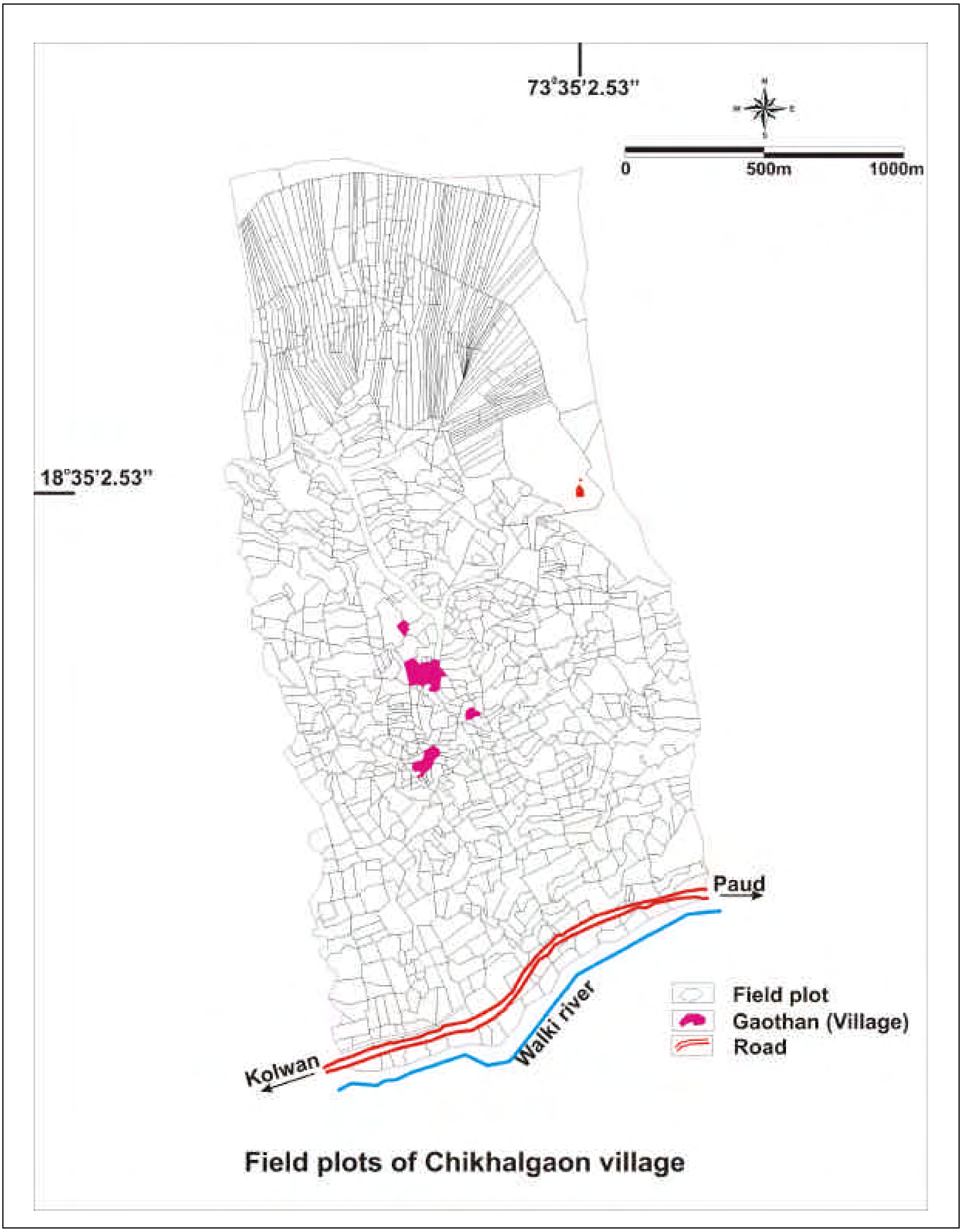
Wheat was the major rabi crop cultivated in Chikhalgaon. Some 26.29 ha of heat is grown by 73 farmers. Spatial distribution of wheat in Chikhalgaon is mostly located away from the Walki river, on the upland area. The main source of irrigation for wheat is lift irrigation from the river. Although difficult to quantify, some farmers reported using well water as protective irrigation when there were problems with their lifts from the river.

(c) Sugarcane

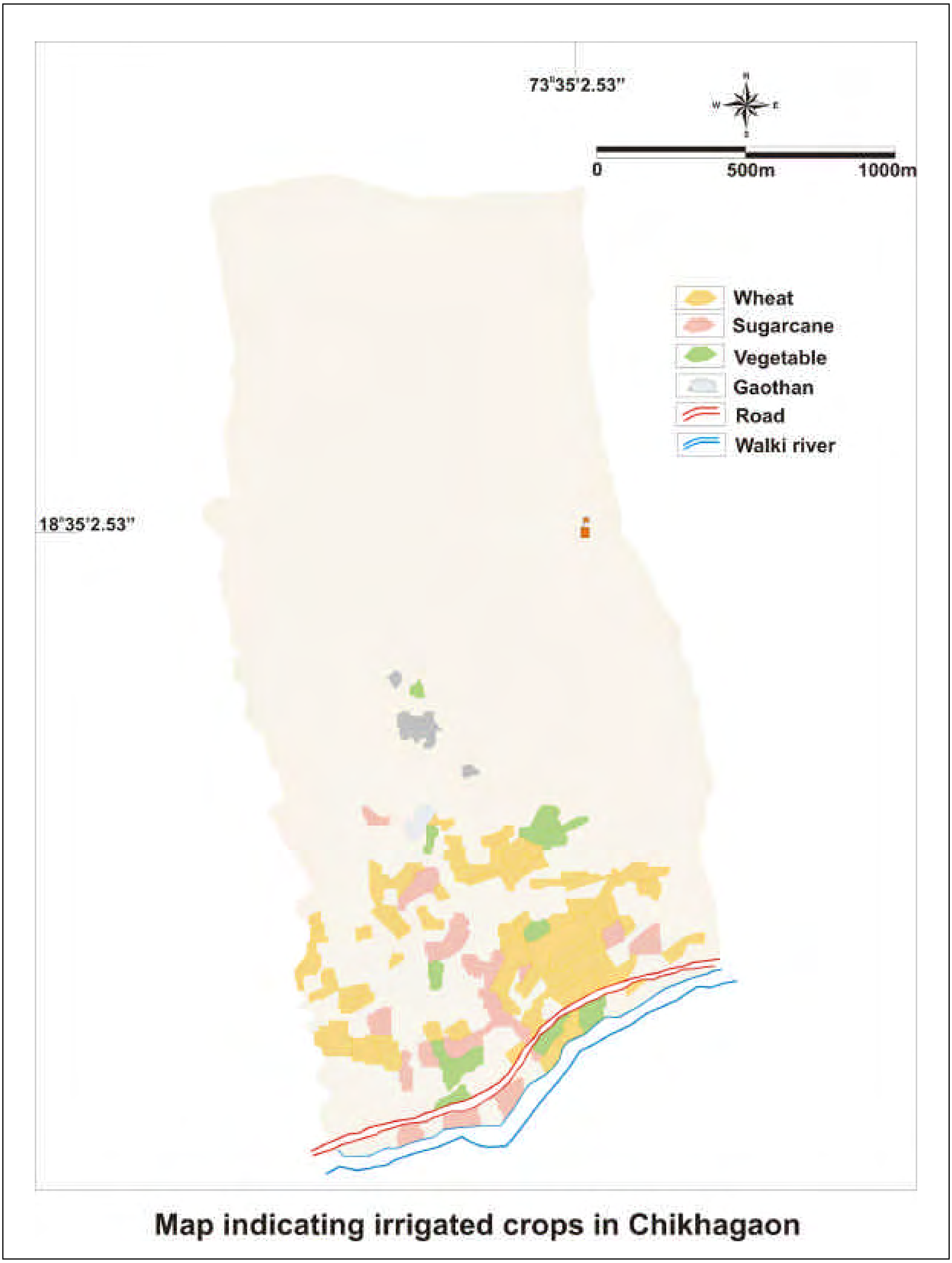
Sugarcane is the second largest irrigated crop cultivated in Chikhalgaon. Although it is an annual crop (unlike seasonal crops like rice, wheat and vegetables), requiring water throughout the year, irrigation from sources like the river and wells is restricted to the rabi season mentioned above. In Chikhalgaon, sugarcane was grown over 10.03 ha of land by 20 farmers. The spatial distribution of sugarcane was dispersed in the sense that it existed from low lands near the main river to fields in higher uplands. Sugarcane being an extremely high-water requiring crop (2800 to 3000 mm) meant that only lift irrigation from the river formed the sole irrigation source.

(d) Vegetables

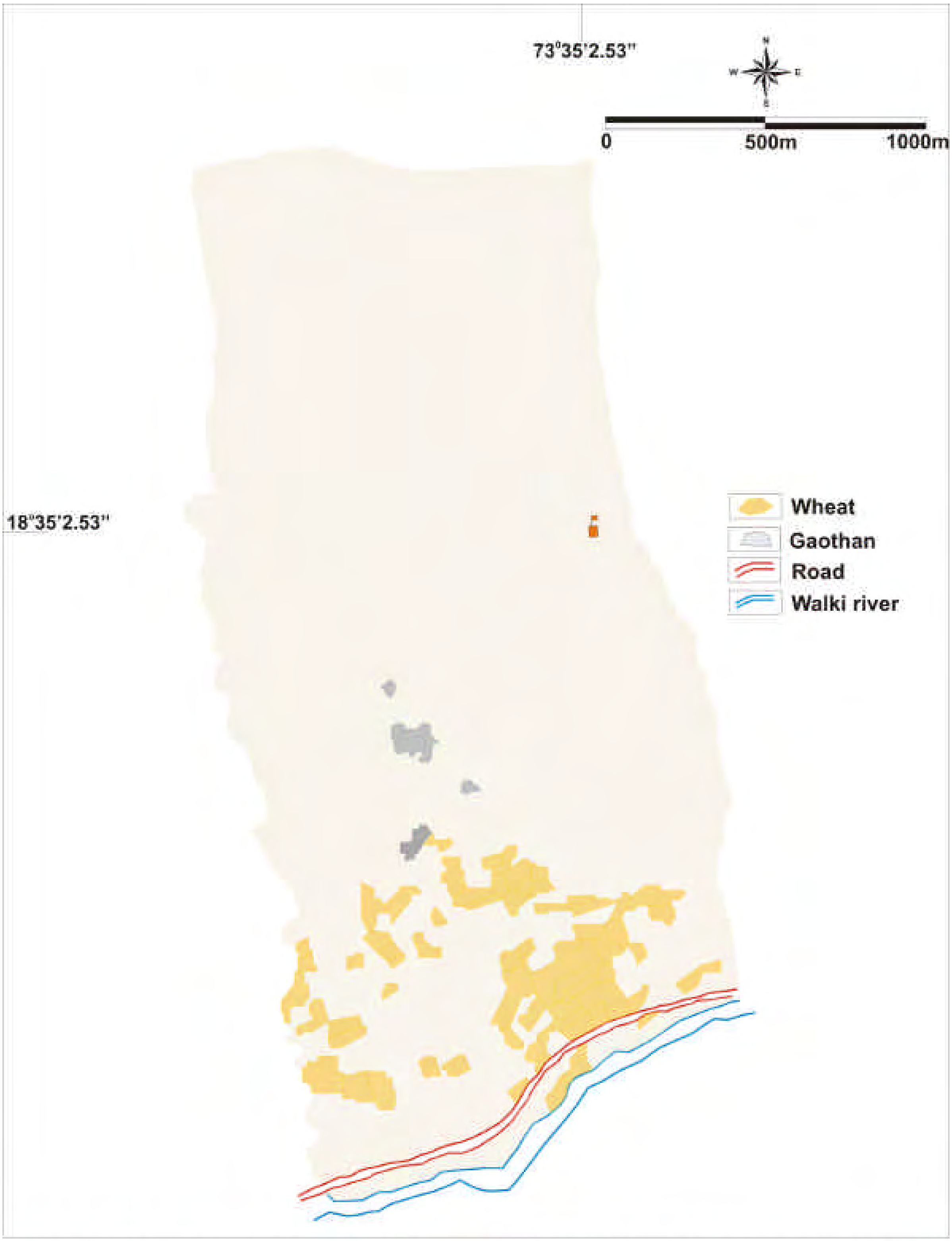
Vegetable cultivation in Chikhalgaon was reported to be quite recent. Only 13 farmers from the village cultivated vegetables over some 6.43 ha. A variety of vegetables like potato, peas, cucumber, tomato and okra (lady's fingers) are grown on small patches of land, usually in the uplands close to Chikhalgaon village. These vegetables were irrigated using lift irrigated water from the river, with marginal support from groundwater.


73°35'2.53"
0
500m
1000m
18°35'2.53"
Paud
Field plot
Gaothan (Village)
Road
Walki river
Kolwan
Field plots of Chikhalgaon village

Map 1

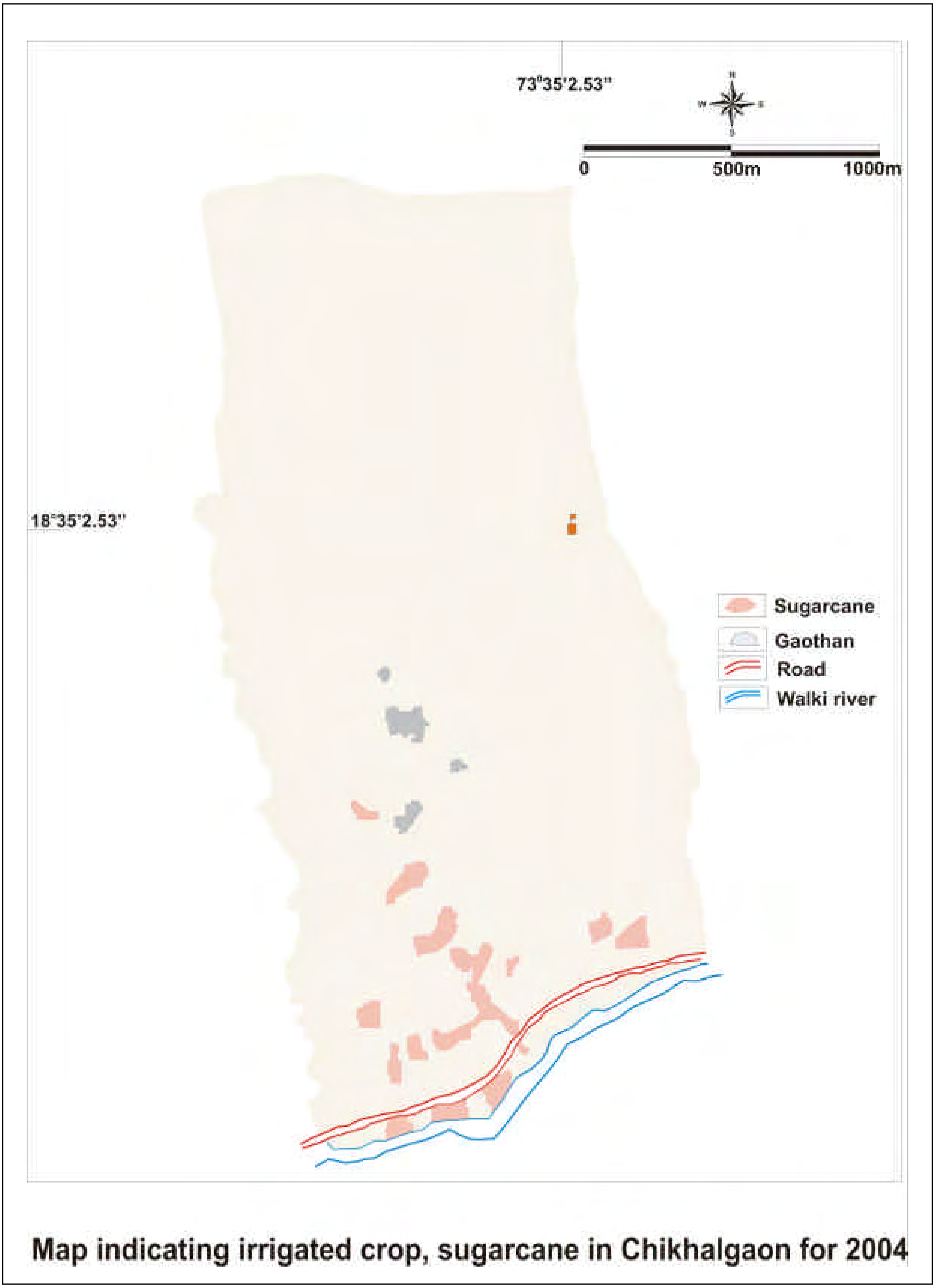

73°35'2.53"
0
500m
1000m
Wheat
Sugarcane
Vegetable
Gaothan
Road
Walki river
18°35'2.53"
Map indicating irrigated crops in Chikhagaon

Map 2

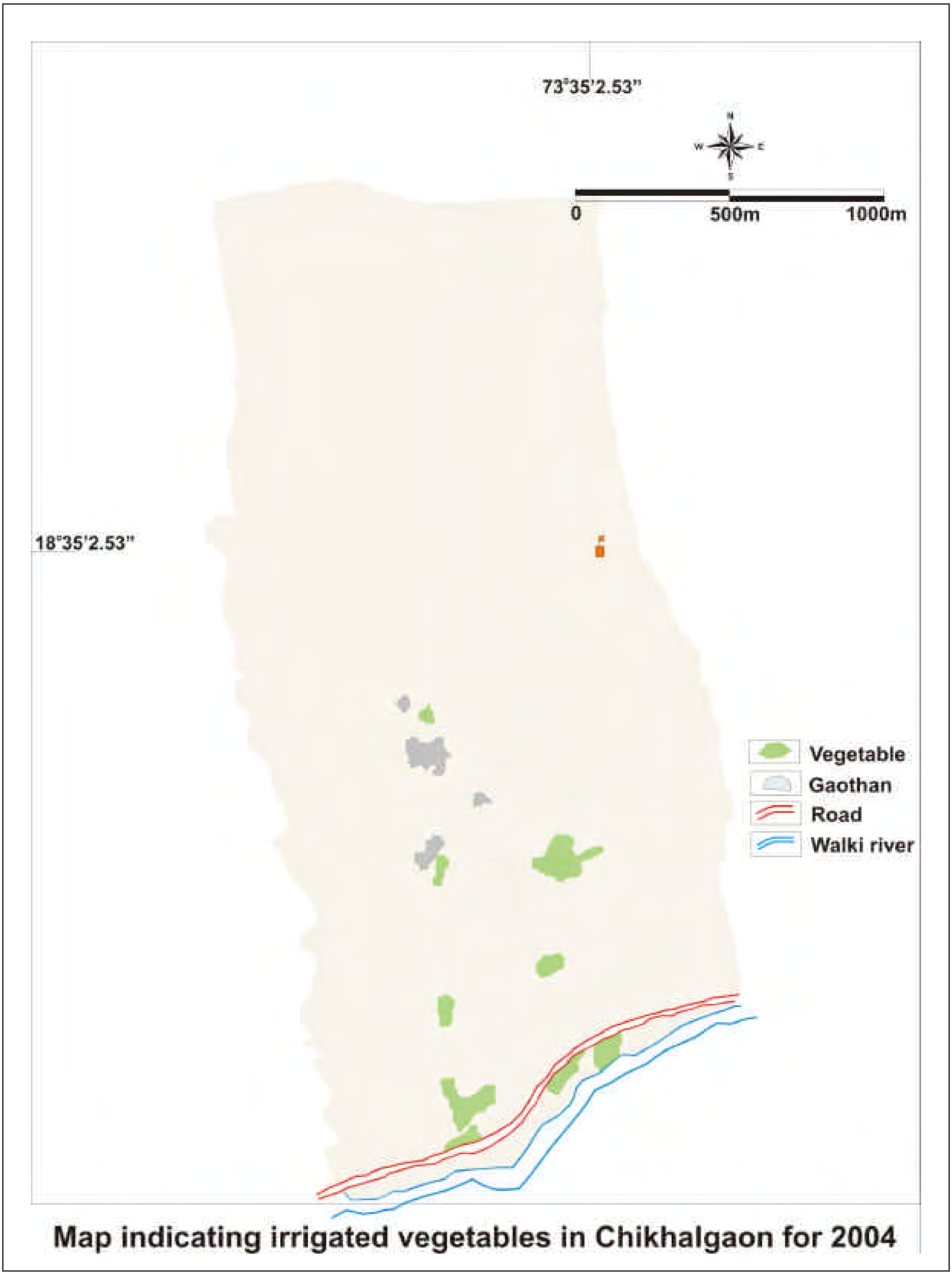


Map indicating irrigated crop, wheat in Chikhalgaon for 2004

Map 3


73°35'2.53"
0
500m
1000m
18°35'2.53"
Sugarcane
Gaothan
Road
Walki river
Map indicating irrigated crop, sugarcane in Chikhalgaon for 2004

Map 4


73°35'2.53"
0
500m
1000m
18°35'2.53"
Vegetable
Gaothan
Road
Walki river
Map indicating irrigated vegetables in Chikhalgaon for 2004

Map 5

2. Brief history of crop cultivation in Chikhalgaon

Until the last decade, cropping pattern in Chikhalgaon, was in the form of the ancestral practice of cultivating a single, rainfed Kharif crop, almost wholly paddy. Subsequently, cropping pattern, in the Chikhalgaon area, changed significantly during the last decade. Prior to 1995-96, there was hardly any rabi season cultivation in this area and clearly no irrigation demand. Most farmers cultivated paddy on their lands, without much problems (the crop water requirement for paddy in this area is between 1500 to 2000 mm: *ICAR, 1997*). Paddy still continues to dominate the area during the kharif season and is still pretty much rainfed.

Rabi cropping (irrigated) took off only in the late nineties. The probable reasons for non-cultivation of rabi crop until 1995-96 are listed below:

- Prevalent practice of conventional and traditional farming and resistance to change to increased cropping.
- Rabi season irrigation sources like lift irrigation systems from rivers and wells were either not available or were not accessible to farmers until more recently.
- Lack of technical information or know-how on cultivation of rabi crops.
- Lack of information on tapping surface / ground water as sources of irrigation.

Wheat

Wheat i.e. *Triticum dicoccum*, a short duration succession crop for the rabi season cultivation became popular in the study area during the last ten years or so. A relatively less water-demanding crop (500-600 mm) wheat became popular as rabi crop on irrigated conditions only after 1997-98, the year when GOMUKH began large-scale watershed development and artificial recharge work in Kolwan valley, including Chikhalgaon. Farmers report that the presence of soil moisture in the field, after the paddy harvest, helps cultivate wheat, as the initial water requirement for growing the crop is met through soil moisture available over a period of a month after the last spell of rains. However, AGRAR findings indicate that soil-moisture is relatively small (less than 50 mm) as compared to the crop water requirement for wheat. Farmers actually start pumping water from the river as soon as the crop is planted.

During the course of this investigation it was observed that wheat was sown in the fields of Chikhalgaon immediately after the paddy crop harvest. Irrespective of the size of land holding, the wheat crop forms a benchmark for the changing phase of agriculture in the history of the village. The wheat crop being short duration, i.e. maximum of 120 days / 4 months, has been successfully adopted by the farmers as a major rabi crop. The crop is cultivated over a range from 0.03 ha to 1.68 ha land holding. Generally speaking, a farmer in Chikhalgaon can obtain a profitable yield from wheat over this land holding range. There has been a steady increase in the number of farmers cultivating the crop, probably due to better returns than from other crops.

Sugarcane

A considerable number of farmers are cultivating sugarcane, i.e. *Saccharum officinarum* L. in the Chikhalgaon area under irrigated condition. During the last half-decade, i.e. 1999 onwards, the crop of sugarcane was introduced in the Kolwan valley, and concurrently in Chikhalgaon. In terms of area and number of farmers engaged in cultivation of sugarcane it was the second largest crop during the rabi season in Chikhalgaon.

In the present study, and data on sugarcane under irrigated condition of 2004 rabi season in Chikhalgaon, it is evident that farmers have adopted advanced agricultural cropping systems where sugarcane is concerned. The water required for cultivating sugarcane ranges from 2800 to 3000 mm. Sugarcane in Chikhalgaon was planted after the harvest of the kharif paddy crop. “Suru” is the type of sugarcane crop grown in Chikhalgaon, where the crop matures within a year of its plantation. Initial irrigation coincides with rabi season irrigation and extends into the following monsoon when irrigation is purely rainfed.

The land holding for sugarcane in Chikhalgaon varied from 0.08 ha to 0.95 ha. Sugarcane fetches good returns to farmers but it is too premature to establish long-term effects, that in other areas have proved detrimental from an environmental perspective.

Vegetables

As mentioned earlier, vegetable cultivation is observed to have increased significantly in Chikhalgaon during the last 2-3 years. Intensive cropping of vegetables may be done either by growing a sequence of crops or through relay cropping, i.e. one crop undersown in a standing crop. The vegetables cultivated in Chikhalgaon were short duration crops, i.e. 90 days to 120 days or 3 - 4 months, perhaps the reason why intensive cropping was more popular. A variety of vegetables are grown during this period in the study area.

Vegetables are cultivated on a smaller scale as compared to sugarcane and wheat. Lands under irrigated vegetable cultivation ranged from 0.10 to 1.20 ha., with plantation of vegetables after the harvest of the kharif, paddy crop. The water requirement for the set of vegetables cultivated in Chikhalgaon is about 450-500 mm. depending on the type of vegetable. The number of farmers and area cultivated under various vegetables is reported to be increasing in Chikhalgaon.

3. Results from the study

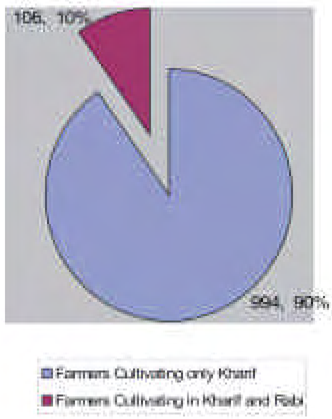
Data analysis was essentially Chikhalgaon-centric and looked exclusively at how irrigated rabi crops were distributed spatially and proportionately to the 'traditional' kharif paddy crop, which continues even today. 'Proportion analysis' was done using Microsoft Excel graph and database tables, whereas spatial distribution of crops was plotted as maps using a GIS platform.

(a) Only 10% of farmers cultivating crops grow rabi crops

There are some 1100 farmers in Chikhalgaon, all of whom grow a kharif crop (mostly paddy). It is evident from the *Pie Chart 1* that the number of farmers cultivating in kharif and rabi is as follows:

- Some 106 farmers cultivated different irrigated rabi crops implying that only 10 % of the total farmers grow irrigated rabi crops. Of the 1100 farmers, 994 cultivate crops only in kharif season, i.e. 90 % of farmers cultivate only kharif paddy.
- However, even this is a significant change from the cropping pattern for Chikhalgaon after 1995-96, when, apart from rainfed paddy there was virtually no irrigated rabi crop (GOMUKH, 2000).
- All farmers growing rabi season crops cultivate kharif season crops, again mostly paddy.

Pie Chart 1: Number of Farmers Cultivating in Kharif v/s Rabi Season of 2004.



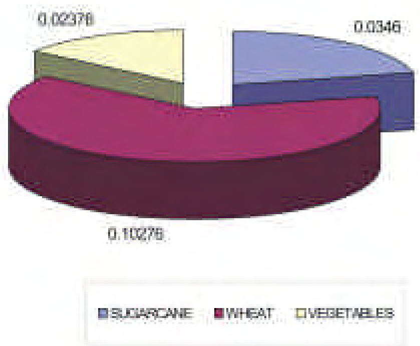
(b) Area on which rabi crops are grown is still quite small as compared to that used for kharif cropping

The proportion of cropped rabi area to the cropped kharif area is illustrated as *Pie Chart 2*. This relationship is based on the area under respective rabi crops to that under the kharif crop, expressed as the percentage to the actual cultivable agricultural land of 250 hectares in Chikhalgaon, in the pie chart.

Hence, we have:

- Wheat is grown on 10 % of the total cropped land (Kharif plus rabi).
- Sugarcane is grown on 3.46 % of the total cropped land.
- Vegetable is grown on 2.38 % of the total cropped land.

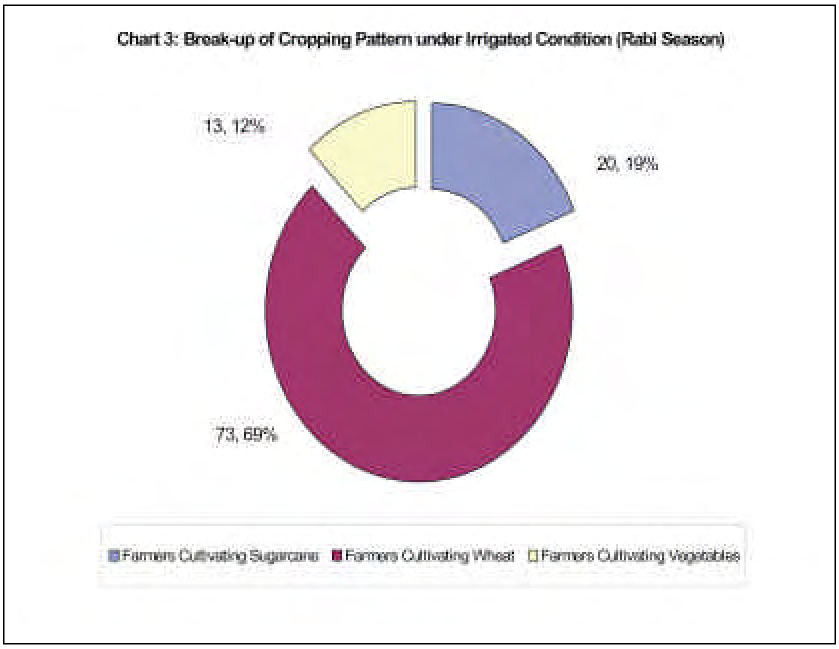
Pie Chart 2: Proportion of Rabi to Kharif Crops in 2004.



(c) A majority of farmers taking rabi crops grow wheat

Chart 3 (doughnut diagram), represents the break-up of the irrigated crops for the rabi season (2004-05) in Chikhalgaon. The farmers cultivating rabi season crops under irrigated condition can be classified as:

- There are 73 wheat-cultivating farmers, i.e. 69 % of the rabi season farmers grow wheat.
- There are 20 sugarcane-cultivating farmers, i.e. 19 % of the rabi season farmers grow sugarcane.
- There are 13 vegetable-cultivating farmers, i.e. 12 % of the rabi season farmers grow vegetables.



(d) Irrigated crops: proportion of cropped land to plot size and distribution of farmers utilizing whole and part of their plot for irrigated cropping

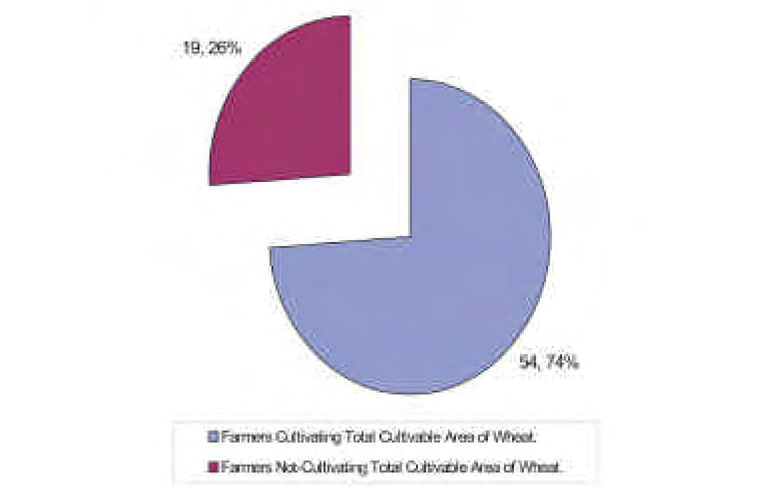
Despite the shift from pure, rainfed cropping to irrigated cropping in Chikhalgaon, not all the cultivable area in Chikhalgaon was cropped under rabi crops. It was thought interesting to study the amount of actually cropped land to the cultivable land for the three irrigated crops in Chikhalgaon.

1.1.1

1.1.2 Wheat

- *Total cultivable area under wheat is 26.29 ha (Land Records Office Register, Kolwan, 2004-05) out of which net cropped area is 25.69 ha, implying that nearly all the cultivable area is cropped by wheat.*
- *The minimum area under wheat for the rabi season of 2004 was 0.03 ha.*
- *The maximum area under wheat for the rabi season of 2004 was 1.69 ha.*
- *Wheat is a benchmark crop for Chikhalgaon, because it is grown over small as well as larger land areas.*
- *Pie chart 3 shows that 54 farmers, i.e. 74 % of the total, cultivated wheat on their entire plot of land whereas only 19 farmers, i.e. 26 %, do not cultivate their total cultivable area with wheat.*

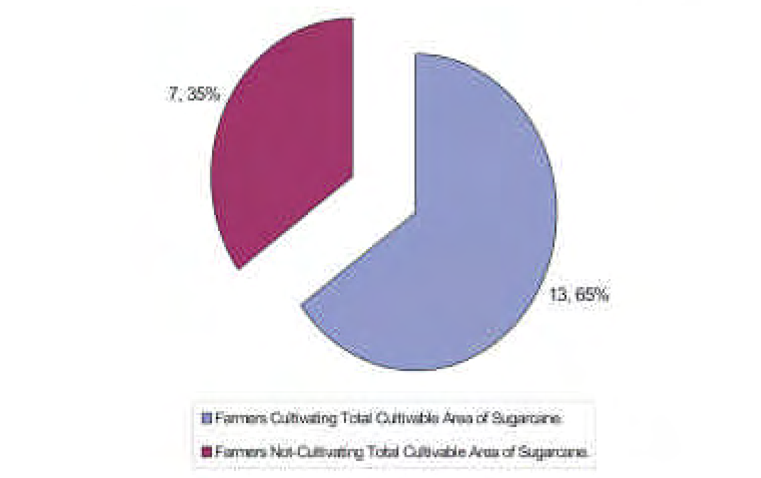
Pie Chart 3: Break-up of the Farmers According to Cultivation of Total Cultivable Area of Wheat under Irrigated Condition (Rabi Season 2004).



SUGARCANE

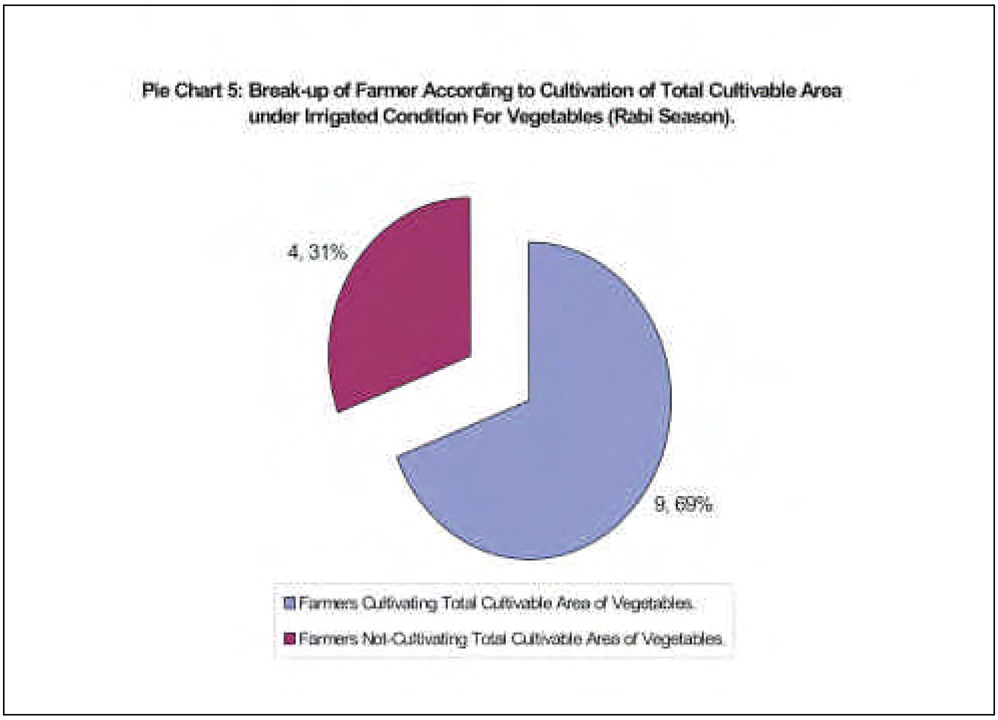
- *Total cultivable area under sugarcane is 10.03 ha ha (Land Records Office Register, Kolwan, 2004-05) out of which net cropped area is 8.65 ha.*
- *The minimum area occupied by sugarcane for the rabi season 2004 was 0.08 ha.*
- *The maximum area occupied by sugarcane for the rabi season 2004 was 0.95 ha.*
- *Pie chart 4 illustrates that 13 farmers cultivated total cultivable area of sugarcane, i.e. 65 % of the total sugarcane cultivated during the rabi season of 2004. On the other hand, some 7 farmers did not cultivate total cultivable area of sugarcane, i.e. 35 % of the total sugarcane cultivated under irrigated condition in rabi season 2004.*

Pie Chart 4: Break-up of Farmers According to Cultivation of Total Cultivable Area of Sugarcane under Irrigated Condition (Rabi Season 2004).



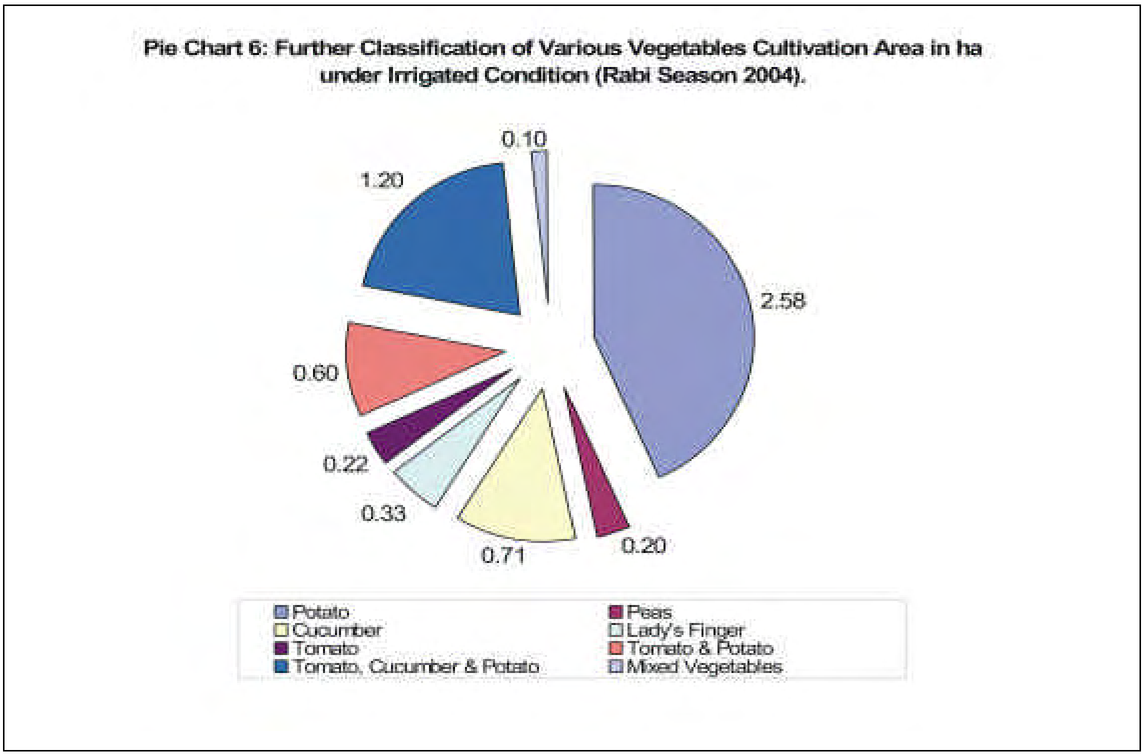
Vegetables

- *Total cultivable area under vegetables was 6.43 ha (Land Records Office Register, Kolwan, 2004-05), out of which net cropped area was 5.94 ha.*
- *A minimum of 0.10 ha was occupied irrigated vegetables in the rabi season of 2004.*
- *A maximum of 1.20 ha was occupied irrigated vegetables in the rabi season of 2004.*
- *Intensive and multiple cropping pattern in vegetable cultivation has been the most recent cropping pattern advancement in Chikhalgaon.*
- *Pie Chart 5* shows that 9 farmers, i.e. 69 %, cultivated their entire plots with vegetables in the rabi season of 2004, while 4 farmers, i.e. 31 % did not cultivate their total cultivable area under vegetables in the rabi season 2004.



Vegetables form the smallest proportion of the three irrigated crops in Chikhalgaon village. However, investigating a little further into vegetable cultivation, it was observed that farmers take a single crop of vegetables as well as practice a multiple vegetable cropping. *Pie Chart 6* indicates a break-up of various vegetables cultivated during the rabi season of 2004. Pie chart 6 illustrates this distribution and can be summarized It can be further classified (also illustrated in pie chart 6) as:

- Potato – 2.58 ha of cultivated area under irrigated condition.
- Peas – 0.20 ha of cultivated area under irrigated condition.
- Cucumber – 0.71 ha of cultivated area under irrigated condition.
- Lady's finger – 0.33 ha of cultivated area under irrigated condition.
- Tomato – 0.22 ha of cultivated area under irrigated condition.
- Tomato & Potato – 0.60 ha of cultivated area under irrigated condition.
- Tomato Cucumber & Potato – 1.20 ha of cultivated area under irrigated condition.
- Mixed Vegetables – 0.10 ha of cultivated area under irrigated condition.



CONCLUSIONS

The major conclusions from this study are summarized into four parts, given below.

1. Sources of Irrigation

Lift irrigation forms the major source of irrigation to cultivate rabi season crops in Chikhalgaon. Some of the farmers also use well water to irrigate their crops but only marginally so, mostly as protective or supportive irrigation in times when the main source develops problems (like breaking down of pumps at the river, pipeline leaks etc.).

2. Increase in groundwater irrigation recently: this may have induced vegetable cultivation

Farmers in Chikhalgaon tended to traditionally farmlands, using rainwater. This involved growing paddy during the kharif season. In the last half-decade a lot of water-related works in the form of Watershed Development, Minor Irrigation Tanks and general awareness about water conservation in the Kolwan valley has occurred. These factors, together, have resulted in increasing water flows to streams and the river. Although groundwater abstraction for irrigation is not significant, a tendency to deepen wells and extract groundwater has been noticed recently, concurrently to a boom in lift irrigation schemes. All the factors, together, may have induced vegetable cultivation in Chikhalgaon.

3. Wheat is currently the most popular rabi crop

Wheat is the major rabi crop, both in terms of the farmers growing it as well as the area covered. Although one has the impression that it is too early to tell (farmers have been experimenting and will continue to try out combination crops), wheat remains popular, arguably because the benefit-to-cost ratio for wheat is maximum.

4. Comparison with baseline Kolwan valley information (based on GOMUKH's 1996 data)

In the data analysis done, there has been a significant change in the cropping pattern of Chikhalgaon and Kolwan valley as compared to the report of GOMUKH 1996. Few people cultivated wheat then and there was no sugarcane and vegetable cultivation in Chikhalgaon (GOMUKH 1996 data). In the present study, as per data generated and analyzed there has been increase in the number of farmers cultivating wheat while sugarcane and vegetables are also grown in the Chikhalgaon. A significant number of farmers have started cultivating their fields with different crops on irrigated condition for the rabi season.

6 Discussion

6.1 PHYSICAL EFFECTIVENESS OF RECHARGE STRUCTURES

Mitigating water scarcity was the primary objective behind GOMUKH's interventions in the Kolwan valley. GOMUKH approached the problem through a programme on "integrated watershed development", with a few project villages to begin with and is currently 'scaling up' the programme to progressively bring all villages in the Walki river basin under watershed development. The AGRAR project studied the impacts of artificial recharge to aquifers in project villages where GOMUKH initiated its watershed development projects in 1997-98. Even as this report was being written, watershed development has commenced in villages like Nandgaon and Nanegaon (the non-project villages in this study), clearly indicating that GOMUKH intends to use watershed development, including artificial recharge, as a part of its larger vision of attempting Integrated Water Resources Management (IWRM) for the Kolwan valley.

Artificial recharge to groundwater was only one of the objectives of the watershed development programme implemented by GOMUKH, the primary objective being improving livelihoods and income earning opportunities of communities in the Kolwan valley. Check dams were meant to form only one part of the watershed development projects in different villages. There was no individual specific objective to any of the check dams, which were simply regarded as one of the components (drainage line treatment) of the watershed development programme, reflecting structural features of the DPAP programme under which the projects were (and are being) implemented. At the same time, artificial recharge to groundwater was mentioned to be an important component of the programme, albeit in a 'generic' sense.

The generic nature of artificial recharge is not uncommon in watershed development projects implemented across India and, in the absence of water balance studies, questions of sustainability of groundwater resources even in areas subjected to watershed development remain unanswered (Joy and Paranjape, 2004). The AGRAR case study in Kolwan valley was therefore an attempt to understand some of the dimensions that remain 'grey' areas in and around the artificial recharge of groundwater in the Deccan basalts covering large areas of states in central-west India, especially Maharashtra.

Before discussing the implications of different results obtained in the AGRAR case study, it must be mentioned here that the 'confidence' level in ascertaining different quantities (as values) is quite different, based on limitations imposed by instrumentation, frequency and nature of measurement. Many such factors have been mentioned while presenting the results in Chapter 4. Moreover, due to the lack of a sufficient amount of time series data, it also becomes difficult to present data with 'statistically correct' confidence limits – there just isn't enough data (still) to determine how data are statistically distributed. Nevertheless, just to give the reader an idea about the precision of specific data, a qualitative indication in the form of a 'guesstimate' on the *confidence* was possible, and terms like *high, moderate and low* are used to indicate the levels of such confidence. These levels of confidence are based on an overall rating of limitations in measurement, instrumentation or source of data (primary/secondary).

Moreover, the short periods of events in Kolwan valley makes precise estimation of various components of the water balance difficult. Automatic collection methods are therefore vital if new data and understanding on aspects like filling up of small structures and short recharge episodes have to be gained in the future.

6.1.1 Natural and artificial recharge

Of the 7 structures studied in Kolwan valley, only one each in Chikhalgaon, Bhalgudi and Hadashi clearly indicate evidences of artificial recharge. The other 4 structures are largely 'water harvesting' structures, often collecting baseflows from stream sections upstream. Structures in Hadashi also collect water released from the Minor Irrigation Tank 2 in Hadashi. Being a high rainfall region, water is available in large quantities for filling up check dams, whether it is for artificial recharge or simply harvesting runoff water, directly from surface flow in the monsoon and baseflows during the dry season. In fact, on an average, each structure is quite small and stores only 2-4 mm of water (with respect to its catchment area) even in its state of full storage. This volume is quite small compared to the rainfall and runoff (1860 mm and 825 mm respectively, for instance, in Chikhalgaon).

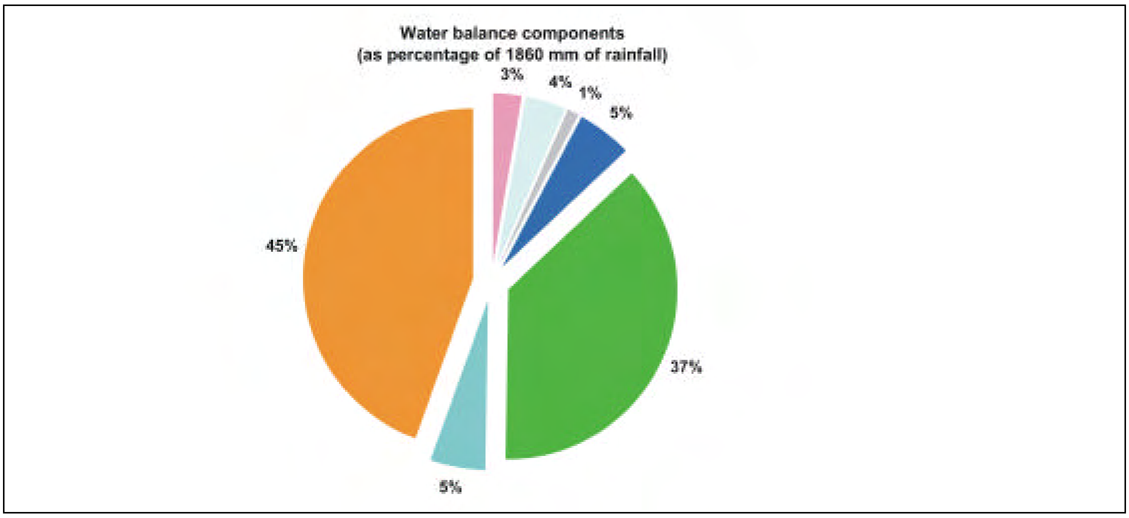
In Kolwan valley, most structures dependent only upon rainfall fill up after the first 150-200 mm of rainfall and continue overflowing until the end of the monsoon season (October or November). Thereafter, water remains in the structures for 2 to 4 months. Infiltration or recharge-facilitating structures tend to dry up sooner (CD3 or BCD1) than structures that gather groundwater discharges in the form of baseflow (CD2 or BCD2) or structures that are fed from other sources of water upstream (e.g. HD1 and HD2). This overall analysis stems from data that has a *high confidence* level. The longer duration of water in baseflow-fed structures often creates a wrong impression regarding the success (holding water longer) or failure (?leaking water) of structures.

Table 42: Comparison of water retention periods for structures in Kolwan valley (AGRAR)

Structure	Generalised water retention period (months)	Generalised total water retention time (in days)	Comment
CD1	June to December / January	211	Receives some baseflow
CD2	June to February / March	260	Receives baseflow
CD3	June to December	200	Mainly infiltration
HD1	Perennial	365	Baseflow and releases from MI tank
HD2	Perennial	365	Releases from MI tank ; some infiltration (?)
BCD1	June to December	180	Infiltration
BCD2	June to March / April	300	Receives baseflow

Estimation of recharge, especially artificial recharge, was attempted through two methods. Firstly, estimates were made on the basis of water balances for the check dams. Secondly, estimates for water balance were complemented using short-term water level data from observation boreholes around the structure. Both these methods require a set of different parameters to be measured. These parameters include inflows, outflows, evaporation losses, stage heights, water levels and aquifer specific-yield. Many of these parameters are estimated through methods using empirical equations or procedures that use primary data but with a set of given assumptions, e.g. specific yield is based on pumping test data that requires measurement of water levels and pumping rates with time. Hence, estimating recharge involves first, second or even third generation estimates of different parameters. This in itself can attribute a certain uncertainty to such estimates.

Quantities of artificial recharge from structures in Kolwan valley are quite small when compared to rainfall or surface runoff and bearing in mind the number of parameters required for arriving at these estimates, the confidence interval for these estimates can be said to be *moderate*, but as monitoring continues and additional data becomes available, the confidence level will improve and confidence intervals can actually be attributed to such estimates. At the same time, natural recharge in Kolwan valley is also quite limited. On an aquifer scale, natural infiltration exceeds 100 mm, whereas the estimated artificial recharge from CD3 is about 33 mm. Hence, both natural recharge and artificial recharge are relatively small quantities as compared to the rainfall (Figure 76) but this limitation has more to do with the available storage in the aquifer than the availability of water or the capacities for infiltration. In fact, measurements around the main site (i.e. CD3) indicate that large quantities of water are lost as baseflow downstream, even after water has infiltrated the ground as both natural and artificial recharge. Hence, even if the proportion of artificial recharge to rainfall is quite small (2%) on an individual aquifer scale, it is not insignificant in proportion to the natural recharge (41%).



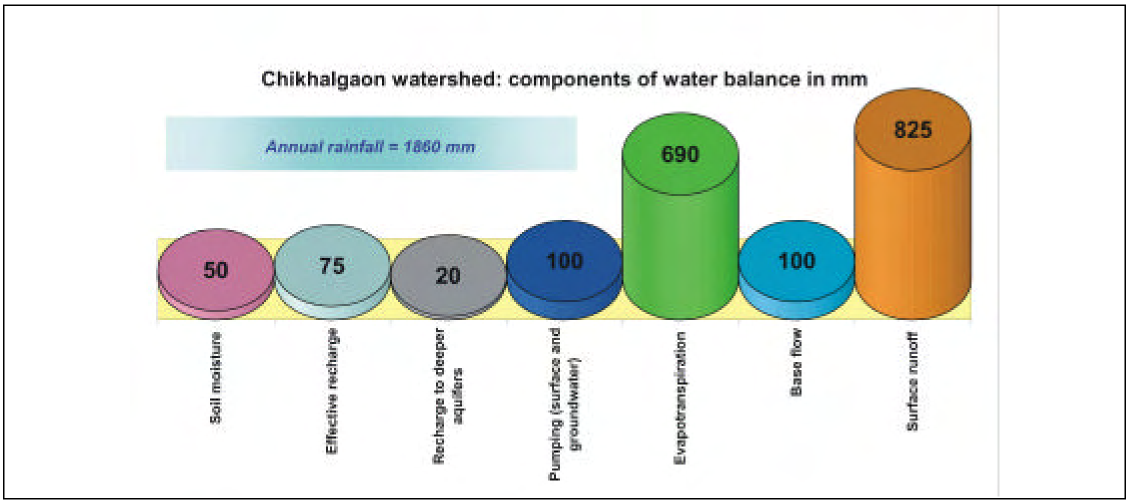


Figure 76: Pie chart showing components of a generalised water balance for Chikhalgaon watershed (based on actual data gathered from the main research site around CD3). ***Colours for components in the two illustrations are co-incident.***

Despite minor variations across areas and even within the same aquifer, both groundwater and surface water are quite fresh, as the hydrochemistry results in Chapter 4 indicate. Dominance of HCO3 suggests freshening and well-flushed waters after the monsoon season, across the Kolwan valley, implying that the natural recharge process occurs throughout the basin. Increased mineralisation into the dry season is not unexpected, with reduced saturation levels and increased rock-water interaction. The chemistry of deeper groundwater supports the hypothesis of recharge to deeper aquifers lagging by about 85 days as compared to the shallow natural and artificial recharge (Figure 77).

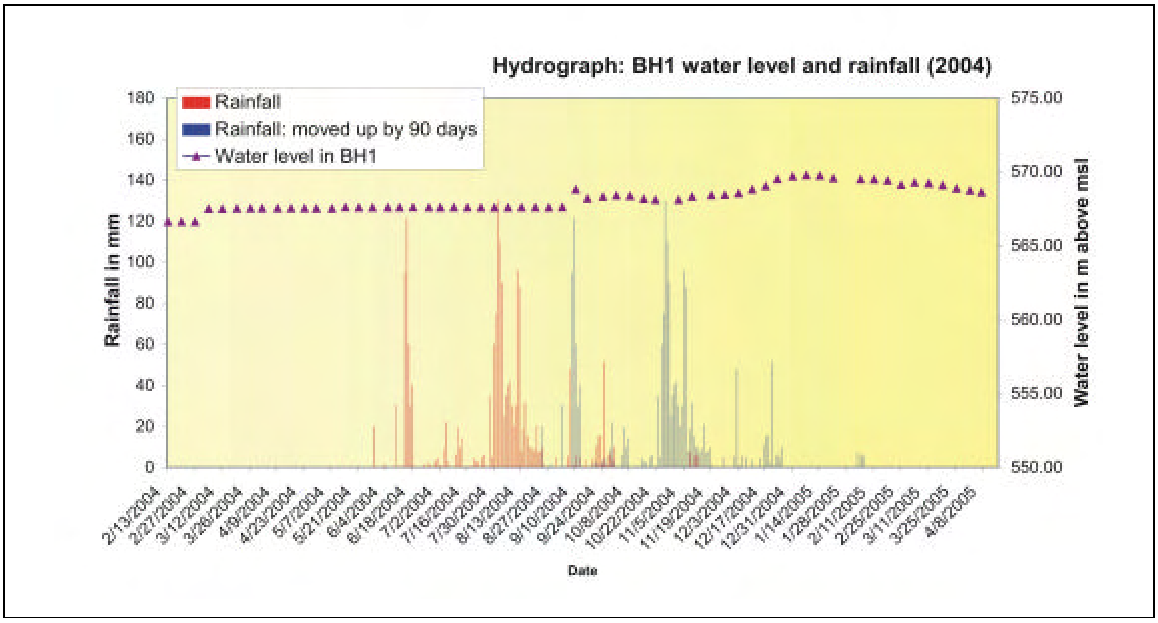


Figure 77: Rainfall-water level relationship in BH1 indicates water level rise after 85 days of the first rainfall. The rainfall events almost immediately affect shallow wells/observation boreholes (Chapter 4)

6.1.2 Spatial and temporal influence of artificial recharge

Deccan basalt aquifers in Kolwan valley possess low hydraulic conductivity and aquifer storage. Moreover, the storage available to accommodate additional, artificial recharge (over and above natural recharge), is further limited because of the small amounts of water abstracted from these aquifers. In other areas of the Deccan basalt, almost the entire aquifer thickness is dewatered, requiring more than 20% of the average annual rainfall to overcome such deficits (Macdonald et al, 1995; Sharma et al, 2003).

In Kolwan valley, the influence area of a single structure, is quite limited, with water level data from observation boreholes indicating that artificial recharge is quite local, with the effects being restricted to a distance of 30-35 m adjacent to the structure. Beyond such distances there may be some effect but even with a denser monitoring of observation points, effects would be quite small in comparison to those within the specified area of influence. The complexity of water level geometry in the Deccan basalt also implies that the influence of artificial recharge is not evenly distributed around a structure, often governed by the distribution of transmissivity around the structure.

The major component of natural and artificial recharge occurs during the first spell of rainfall, i.e. within a span of about 8-10 days of the monsoon season. Thereafter, recharge takes place as short events during the wet season, these spells being governed by rainfall events and the drop in water levels in the aquifer in close proximity to the structure (Figure 78). During the dry season, a local mound develops on account of the infiltration from the structure and persists for more than two months, although the volume of infiltrated water that builds up into a small groundwater mound is quite small - *about 2* *mm distributed over the catchment area of the structure (0.786 km^2)*. This feature also indicates the limited specific yield of the aquifer as well as its low diffusivity. The 'controlled' environment (Chapter 3: Methodology) under which observation boreholes were drilled and monitored (for water levels) attributes a *high* confidence level to this conclusion.

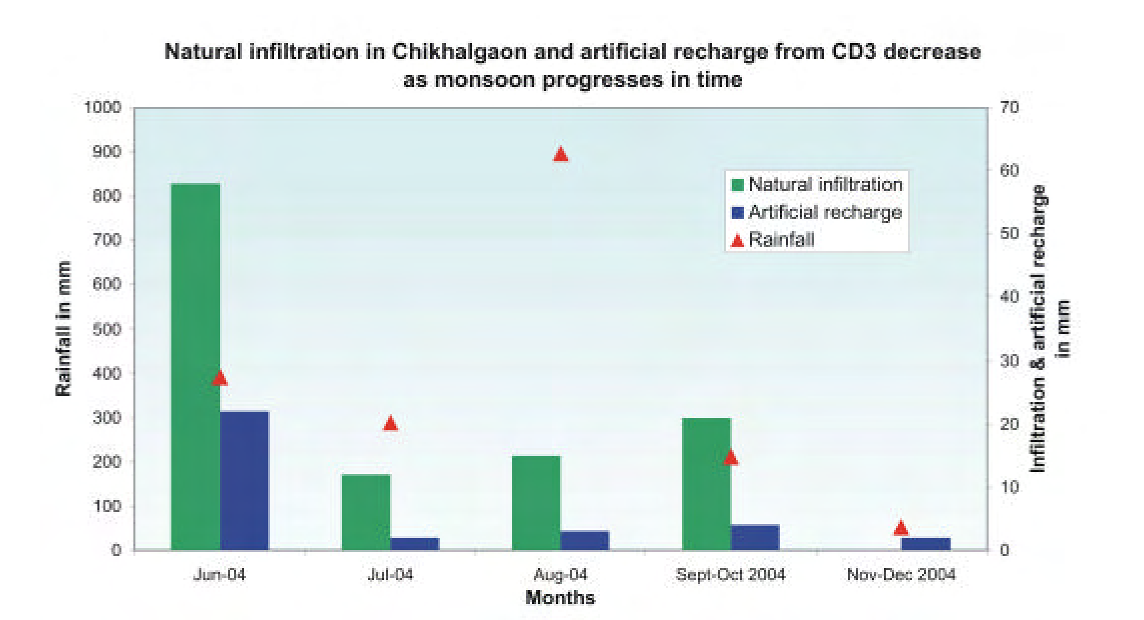


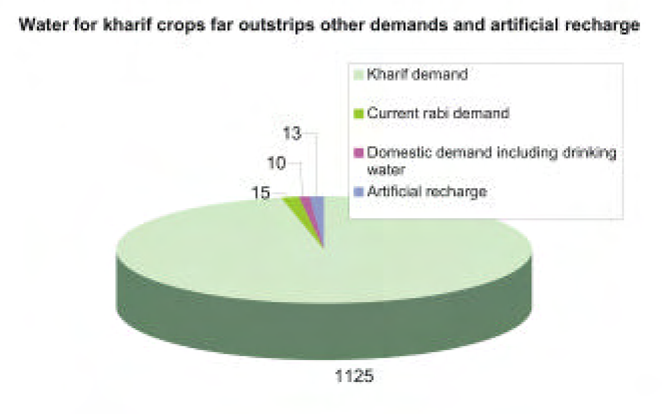
Figure 78: Artificial recharge to Chikhalgaon aquifer occurs in spells, with the initial spell being the largest because of the greater available storage space in the aquifer at the end of the summer season preceding the first rainfall event.

The quantity of artificially recharged water being small means only limited quantity of additional water can be made available for use from the aquifer, possibly only locally, through wells around such structures. However, a sequence of check dams, some of which result in artificial recharge, have ensured more sustained baseflows in project areas of Kolwan valley. Hence, despite small quantities recharged, water resources are now available in these areas over prolonged periods now, than before. It is difficult to quantify the improvement in baseflows that feed into irrigation systems because releases from minor irrigation tanks (larger structures as compared to the artificial recharge structures) also feed into the lift irrigation schemes making precise estimation of baseflow contribution to the river difficult.

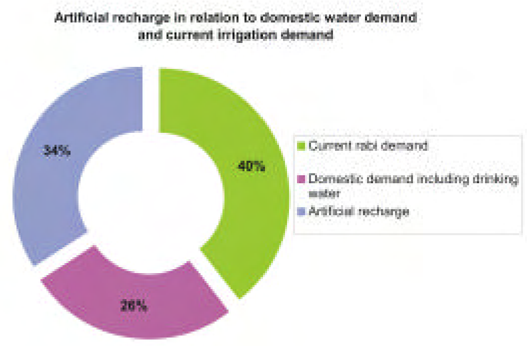
6.1.3 Scale and variability

Surface runoff clearly dominates water balances on all three scales, i.e. recharge structure, microwatershed and river basin scales. This finding is significantly different from water balances in other areas of the Deccan basalt where groundwater abstraction is the single largest component of the water balance (Macdonald et al, 1995; Batchelor, 2000). The diversity in hydrological and hydrogeological conditions in the Kolwan valley, including variability in the rainfall across the river basin is clearly evident from the results of the study on artificial recharge on three different scales. Despite limited quantification and measurement on the river basin scale, a comparison of results on the three scales brings out subtle differences in the estimates of recharge (natural and artificial). This is primarily because at the recharge structure, this study estimated recharge to a single, shallow unconfined aquifer. At the microwatershed and river basin scales, the layered sequence of basalts creates shallow aquifers at different levels along the slope of a catchment. Such sequences of aquifers, especially in well-defined basins such as in Kolwan valley, imply recharge possibilities at different locales as against the one recharge zone as defined geomorphologically in a catchement with homogeneous geology.

Small structures meant for artificial recharge in microwatersheds contribute small quantities to the overall water budget of the microwatershed or river basin. However, in aquifers with limited storage, such as the Chikhalgaon aquifer where the total aquifer storage is less than 100 mm, even the relatively small quantity of artificially recharged water may be a significant contribution in many ways. This is especially significant in areas that entirely depend on groundwater to support drinking water requirements, such as in the Kolwan valley (Figure 79). The figure also shows that currently, with limited irrigation demand, the proportion to irrigation is also quite significant despite a large part of the irrigation demand being met from surface water.



A



B

Figure 79: The water demand for Kharif crops in Chikhalgaon far outstrips other demands (A: values in mm). The proportion of artificial recharge to drinking water demand and current demand for rabi irrigation vary within the same order of magnitude (B).

6.2 ARTIFICIAL RECHARGE AND LIVELIHOODS

In the absence of large-scale groundwater abstraction, the Kolwan valley situation is a case of a natural balance between the recharge and discharge components of the aquifer. The Walki river carries significant amounts of water into the Mula river, although it was not possible to accurately separate evaporation from runoff (including baseflows). Artificial recharge, more than adding some water to aquifer storage, has meant that water simply flows out in the form of increased baseflows, consequently lagging stream and river flows considerably (streams in project watersheds flow a couple of months more than those in non-project watersheds). The limited demand for groundwater helps maintain water levels and baseflows to streams and the river.

Utilisation of storage even in the low porosity basalt aquifer is currently quite limited, although this study found that it was growing in small increments. This growth in groundwater use could not be ascertained through the physical measurements in Chikhalgaon and other villages because it is still quite small as compared to other components of the water balance. However, the socio-economic survey and the informal discussions with farmers indicated a slow but sure increase in groundwater abstraction, especially as protective irrigation for both kharif and rabi crops. Increased groundwater use is evident both in project and non-project villages and therefore a direct correlation to the physical factors of artificial recharge becomes irrelevant.

6.2.1 Limitations in attributing causality to impact on livelihoods

Attributing physical effects of recharge to changes in livelihood conditions in Kolwan valley is virtually impossible. It was evident that livelihood changes were a consequence of multiple factors and occurred in project and non-project areas. Factors like proximity to cities like Pune and Mumbai that offer employment or non-agriculture livelihood options, and at the same time contribute to improved incomes, are unrelated to recharge activities.

Moreover, because artificial recharge was envisaged as one of the many objectives of the watershed development programme in Kolwan valley, a direct 'one-to-one' correlation between physical effectiveness and socio-economic changes was not possible even through formal surveys or through informal discussion with different individuals and institutions. Even with comprehensive official Government data (e.g. census data) the multiplicity of factors influencing livelihoods makes it difficult to attribute a single cause for changing socio-economics including livelihood changes. For instance, changes in income are reflected in the fact that (across castes/land-holding classes/houselhold sizes), people are constructing 'pucca' houses. The felt need for 'pucca' houses overrides the need to construct wells and harness relatively undeveloped groundwater. At the same time, this relationship becomes clearer when one considers that irrigation demands have certainly increased (and so have irrigated crops, based on a 'before' and 'after' comparison) and are being met from 'lift irrigation' schemes based on surface water. Again, expanding the scope of the analysis, one finds such lift irrigation to have generated improved incomes. Increased and lagged baseflows (as a consequence of watershed development of which artificial recharge is one component) will have certainly contributed to improvement of such schemes making water available over prolonged periods, in turn, helping support annual and/or summer crops.

The socio-economic survey (Chapter 5) and the pilot study in Chikhalgaon (Annexe to Chapter 5) clearly bring out the increase in irrigated agriculture in the region, especially over the last few years. Crops like wheat, sugarcane and vegetables have contributed significantly to agricultural incomes. At the same time two distinct limitations present themselves in correlating AR measures to improved incomes. These are:

- Income in a large proportion of households is diverse, cutting across sources like agriculture, service and non-farm businesses. Hence, improvement in agricultural income is quite diverse and there are practical difficulties in obtaining responses to the question of causality to improved income from AR.
- Even when one compares the before and after situation or project vs non-project areas, direct contribution of surface water and groundwater to improvement in cropping (and consequently in agricultural income) is difficult to quantify. *However, a dominant component of such income would actually be a result of better availability, access and distribution of surface water sources wherein baseflow lagging can certainly be established as a consequence of the AR from structures built under the watershed development programme.*

The impacts on livelihoods were studied using surveys conducted by GOMUKH and ACWADAM during the pre & post watershed project (Chapter 3: Methodology). A salient observation during these surveys was the fact that farmers often withhold or give limited information, especially pertaining to water resource use. Generally farmers tended to be more open in their responses to queries on their social status, family background and assets but were quite guarded when questions on irrigation, livestock, cropping, water sources and pumping hours were asked. This indicated that they preferred not to openly state their involvement in 'informal water transactions' that became clearly evident through quantitative and qualitative survey methods.

Nevertheless, the survey was able to pick up certain trends regarding impacts of watershed development interventions on livelihoods. Firstly, it is quite clear that livelihood changes in Kolwan valley are a result of a complex set of factors ranging from watershed development (including artificial recharge) to 'pull' factors drawing educated youth to cities and towns closeby, thereby causing livelihood diversification and improved incomes. Such trends were noticed across caste and income groups. Moreover, the physical quantities of water added as artificial recharge to low-storage aquifers like the Chikhalgaon aquifer imply that the local impacts created, imply either benefits to a few people or quick dissipation of benefits over larger areas, the latter thereby implying only a fractional benefit per farmer or per individual. Indirect benefits like baseflows resulting from various catchments like Chikhalgaon, Bhalgudi and Hadashi together maybe compounded enough to impact larger populations.

6.2.2 Groundwater dependent activities

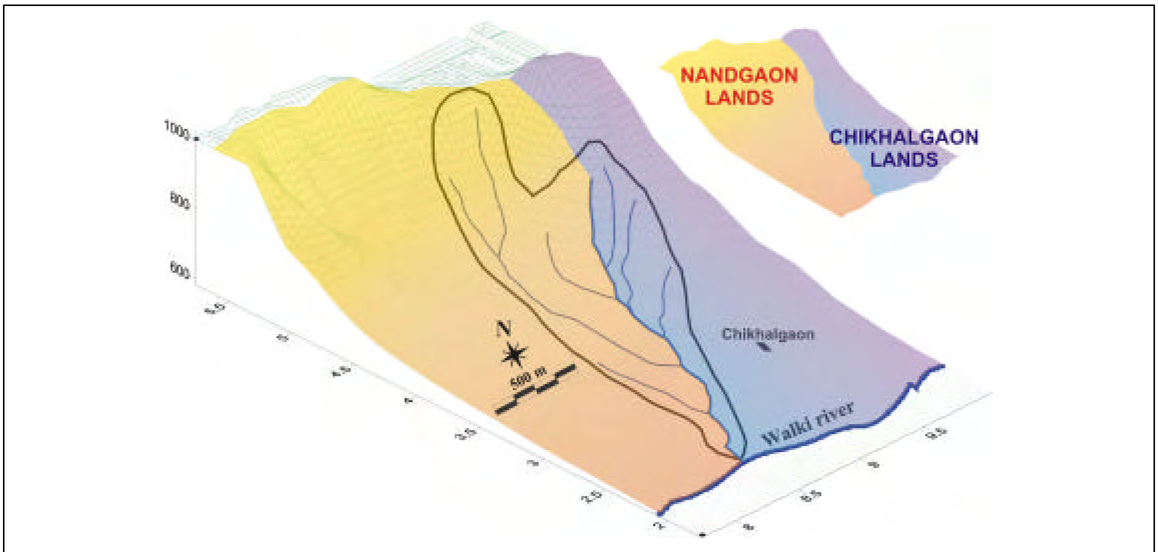
While writing up this report (i.e. summer period of 2005), the intensification of watershed type activities, mainly in the form of slope treatment (contour trenches/bunds and afforestation) and more check dams on streams and the river was clearly evident. Non-project villages like Nandgaon and Nanegaon have been covered under this activity. As mentioned time and again, AR is only a small component of watershed or river basin water balances (Chapter 4). Nevertheless, groundwater forms a small but important component of groundwater utilisation in Kolwan valley. Even a gross estimate of about 100 lpcd for the 20000 odd inhabitants of villages in Kolwan valley, means some 9 mm of water is used through formal (piped water) and informal water supply (collection at source) for drinking and household purposes, considering 80 km^2 as the total catchment area of the Walki river basin. Including other activities like construction and livestock (livestock also use surface water), groundwater use for domestic purposes can be estimated to be between 10 and 15 mm currently. Almost the entire component for these uses is dependent on groundwater and is not only the top priority but is also used perennially. Artificial recharge (in Chikhalgaon) is some 30 mm, clearly implying that it is at least twice the drinking water requirement for villages in Kolwan valley.

Irrigation demand from groundwater remains limited but informal discussions with farmers, institutions and land purchasers from outside the valley clearly bring out the fact that the dependence on groundwater is bound to increase manifold during the next 3-4 years. The overall irrigation demand (estimated from the Chikhalgaon case study presented as Annexe to Chapter 5) is currently some 1150 mm, with only about 15 mm during the dry season (with respect to the catchment area for Chikhalgaon watershed). Well deepening, drilling of a few boreholes for water supply (in Kule and Dongargaon villages) and irrigation of small patches of summer crops from groundwater bear a clear testimony to this projection. Again, income from such activities is bound to be quite small (some 10% of the total agricultural incomes…a *crude guesstimate* at this stage) but is clearly emerging as people diversify within agriculture and beyond. However, these estimates are only 'back-of-the-envelope' calculations and therefore the confidence level on these estimates is certainly *low*.

One cannot single out the impact of artificial recharge from the watershed development activities as well as from the other 'push' and 'pull' factors dictating livelihood changes in Kolwan valley. The actual impact of the check dam on the livelihoods of the people, although quite small, cannot be neglected, at least not on the scale of four or five watersheds where GOMUKH is in the process of scaling up this activity. Groundwater abstraction for irrigation is still quite limited but there are signs of increasing abstraction, after the check dam was constructed. This is an effect of some degree of visual impacts (more from the overall watershed programme rather than from any single structure) as well as simply a response to the structure 'being there' (symbolism). This increase can be attributed to a perceivable improvement in groundwater conditions, artificial recharge being one of the drivers to this effect.

The cumulative effect of various factors influencing livelihoods is apparent in the form of a clear-cut increment in the annual income. This increase in the income can be attributed to the gross increase in agriculture, livestock and horticulture as well as income from other sources like service and non-farm labour. The AGRAR socio-economic survey indicates that around 40% people were living below poverty line just before the project, with the current percentage having reduced significantly to less than 10%. A generally improved asset-holding also indicates an improved standard of living.

Another issue that is not entirely covered within this report but which deserves a mention is the constraint imposed by non-coherent boundaries between physical entities like a watershed and administrative (revenue) boundaries defined for villages in cadastral maps. A classic example can be cited for Chikhalgaon and Nandgaon, where the stream on which the AR structures are located defines the village boundary between Nandgaon (east) and Chikhalgaon (west). The impacts of AR, in such a situation will be distributed across the two villages because the underlying aquifer extends underneath either side of the stream, i.e. underneath both Chikhalgaon and Nandgaon lands (Figure 80). Moreover, benefits of AR often are likely to be distributed inequitably across these two areas due to the heterogeneous nature of the underlying basalt aquifer.



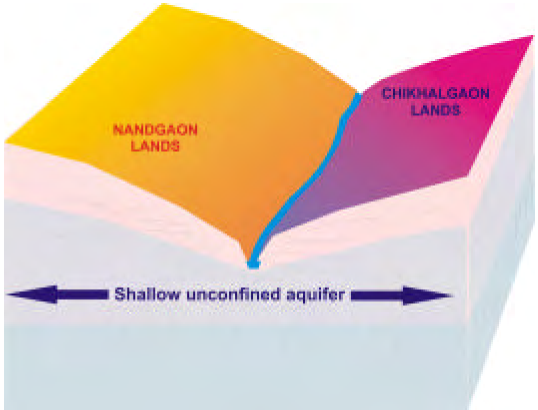


Figure 80: Shallow aquifer boundaries maybe coherent with watershed boundaries but not with administrative village boundaries

6.3 MANAGEMENT AND INSTITUTIONAL ARRANGEMENTS

In Kolwan valley, a number of NGOs, including GOMUKH, have acted as project implementing agencies for watershed development since 1996. GOMUKH has been the main agency that has, and continues to, implement watershed development projects under the DPAP programme through the district administration, i.e. Zilla Parishad. Conceptually, GOMUKH considers the process of project implementation as one programme, aiming to cover the entire Walki river basin over a period of time (they began work in 1996). However, each project is technically and financially a separate microwatershed development project, with GOMUKH hoping to integrate all these projects into an IWRM type programme eventually.

Project requirements have meant interfacing with PRIs, primarily because finances for these projects need to be channeled and disbursed only through PRIs. At the same time, PRIs are represented by individuals, and our observations clearly show that the long-term performance in project villages (including maintenance aspects) depend upon the performances of these individuals during a particular period of the programme (rather than on a group). For instance, people's representatives in PRIs change from during the period of implementation to the management phase and eventually, it boils down to leadership from certain individuals, and significantly, on how these individuals have perceived the whole programme.

Even though the river basin receives good rainfall, the region used to face severe water scarcity during the summer; no water sources were perennial. However, a range of project/programme interventions, including village drinking water supply schemes, spring development/protection, construction of tanks in upper reaches and watershed development activities, have alleviated problems, creating a complex environment for establishing a direct "cause-effect" relationship between artificial recharge and livelihoods. The increased number of lift irrigation schemes that support a growing irrigation demand is perhaps the only direct indicator of linking institutions (water users' associations) to the perceived increase in availability of water, part of which comes through artificial recharge. Again, a severe limitation here is the absence of quantification, because most planning is on the basis of improved river flows rather than exact quantification of change.

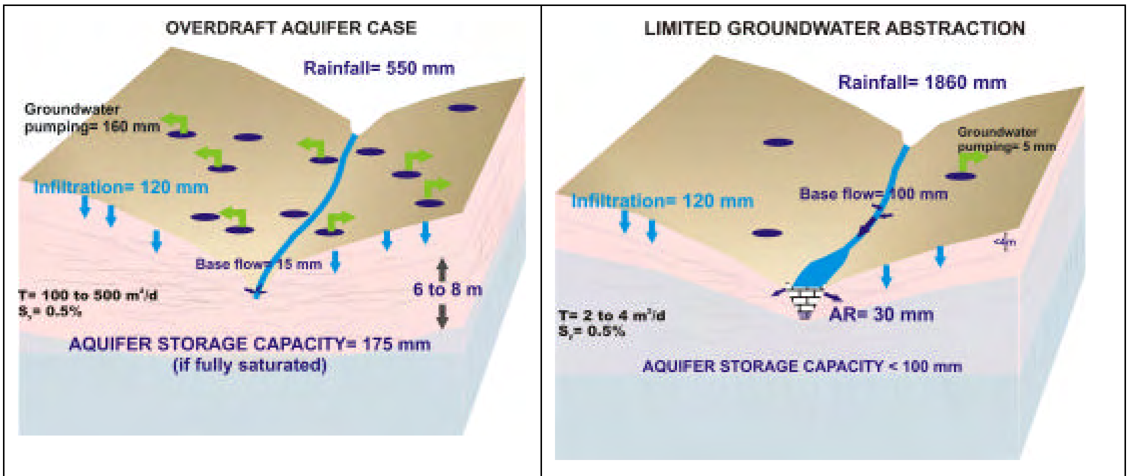
Since the 100 odd lift irrigation schemes are based on surface water resources, they have to be registered with the Irrigation Department of the State Government. This has meant that schemes are generally in the form of registered ‘water users associations’, the formation and running of schemes requiring some degree of institutional support. GOMUKH has been instrumental in formation of some 10-15 such schemes. GOMUKH has intentions of formalising community based groundwater schemes, especially around potentially effective AR structures like CD3. The findings from the AGRAR project will be useful during the planning and implementation of such schemes and GOMUKH hopes to use project findings, including ACWADAM’s support during this phase of its work.

In the absence of large-scale groundwater abstraction and the presence of irrigation tanks, check dams and other water harvesting structures across the entire river basin, there are currently no upstream-downstream issues. Two clear factors ensure downstream flows; firstly, large volumes of surface runoff still dominate the water balances on all scales, in the wet season. Lagging of stream flows through prolonged baseflow activity, along with releases from the three minor irrigation tanks has meant near perenniality to the Walki river, feeding it during the dry season.

6.4 SUSTAINABILITY OF BENEFITS

Groundwater abstraction in Kolwan valley is still quite limited, even though there are clear signals of increase in groundwater use. People across groups are exploring possibilities of sourcing water in the vicinity of their farmlands. Lift irrigation, although currently the major source of irrigation, is a major limitation for access to irrigation water where farmers with lands away from the river are involved. Groundwater use is bound to increase as the demand for irrigated agriculture grows, especially on lands near villages, i.e. away from the main course of the Walki river. For instance, Kule, the village located east of Chikhalgaon has evidenced drilling of bore wells for agriculture. Although a couple of bore wells in irrigation lands were not successful (low yields), two borewells drilled for the drinking water supply for the village showed high yields. This clearly indicates a trend for wells and bore wells as sources of tapping groundwater resources.

It is projected here, on the basis of observations such as the above and discussion with local communities that the full repercussions of AR in Kolwan valley will be evident during the next few years, when groundwater abstraction will increase from deepened and new dug wells as well as from deeper bore wells tapping both shallow and deeper groundwater. Such a trend, based on experience gained from other areas of the Deccan basalt (Macdonald et al, 1995, Batchelor et al, 2000 and Kulkarni et al, 2000), will result in a greater magnitude of water level fluctuation in the shallow basalt aquifers during the course of the annual hydrological cycle. Given the scenario of increased groundwater abstraction, the quantum of recharge will increase as more space will be available in the shallow aquifer for accommodating additional recharge (Figure 81).



Groundwater overabstraction scenario	Limited groundwater abstraction scenario
• Proportion of infiltration to rainfall= 22% • Nearly all infiltration builds up into effective recharge • Baseflow is minor when compared to groundwater abstraction	• Proportion of infiltration to rainfall= 6% • Only a part of the infiltration converts to effective recharge • Prolonged baseflow

Figure 81: Two contrasting scenarios depicting an overabstracted Deccan basalt aquifer in contrast to a basalt aquifer under limited groundwater abstraction with an artificial recharge structure (*as in Chikhalgaon*)

It remains to be seen whether AR benefits (both physically direct and socio-economically indirect) will increase significantly because:

1. *Natural recharge may increase and fill out a major component of aquifer storage as enough water (through rainfall) is available for recharge in the area; in this case AR will remain limited and may still be about the same as it is now, despite increased number of AR structures, watershed development projects and river basin interventions.*
2. *Natural and AR will increase hand-in-hand depending upon location of structures; AR recharge structures, if located in 'potentially rechargeable' areas will contribute significant amounts of water to the aquifer, especially during the early phases of the monsoon season.*

Notwithstanding any of the two scenarios above, the sustainability of groundwater resources in the area will depend upon the magnitude of groundwater abstraction because the groundwater storage in basalt aquifers in the Kolwan valley is quite limited and will not exceed more than 100 mm. It is truly during the period of increased groundwater utilisation, that the issue of sustainability will need to be considered while managing water resources in Kolwan valley. During such clearly foreseen periods one clearly sees the importance of not only managing the supply side of the water management using AR, also a felt need to manage demand for limited groundwater supplies. Striking a balance between the supply and demand sides, based on continued monitoring and improved knowledge will hold the key to sustainability of the groundwater resources in Kolwan valley.

7 Conclusions and recommendations

The Western Ghats form a unique physiographic feature in peninsular India and almost entirely transect hard-rock terrain. Many portions in this region have settings similar to that of the Kolwan valley. The conclusions and recommendations presented here, therefore, have a great significance in the planning and management of groundwater resources, including artificial recharge, in these areas.

7.1 Impact of recharge activities as a part of watershed development

1. Artificial recharge in Kolwan valley had measurable impacts on a local scale, although the magnitude of water added artificially is quite small as compared to the rainfall. What is significant, however, is that the quantity of water added to the shallow basalt aquifers as artificial recharge, is *not* a small proportion when compared to the aquifer storage and natural recharge. Normally, in the absence of monitoring on a proper scale, visible impacts are not immediately apparent. A combination of scientific and socio-economic monitoring helps gauge the amount and nature of impacts in rather complex hydrogeological and socio-economic environments such as in the Kolwan valley. The impacts from artificial recharge interventions clearly point to an overall improvement on the scales of a microwatershed or even regionally, i.e. the river basin scale, but it becomes difficult to precisely quantify such impacts and assign causality to factors that are likely to be impacted, again due to the complex environments mentioned above.
2. Quantifying how recharge activities have made a difference to livelihoods involves a great deal of uncertainty. This uncertainty stems from factors such as lack of scientific information, especially in the form of 'long-term' time-series data, a mix of controlling factors on socio-economic indicators such as income and a rapidly changing 'livelihoods' environment. Nevertheless, this should not deter attempts in qualifying, and possibly even quantifying (with specified confidence levels as more information is acquired) impacts of artificial recharge, especially through watershed development programmes. Such attempts will at least ensure improved planning, implementation and management of artificial recharge projects.
3. Scientific investigation coupled with livelihood studies clearly help understand processes taking place in areas where artificial recharge projects are implemented. A totally unexpected finding from the AGRAR case study in Kolwan valley was the improved baseflows feeding streams and river, in turn contributing to the irrigation as well as environmental demands of the area.

7.2 Overall lessons: planning, design, implementation and management of artificial recharge

1. Large gaps between planning and implementation of artificial recharge projects need to be narrowed down. These gaps are a result of either or both of the following two factors.
   1. *lack of technical inputs during implementation;*
   2. *'push' from external factors, either as a strong demand from the community (which may view the scheme as a form of 'capital investment' in their village…**not at all unjustified economically!**) or in the form of achieving targets for certain programmes that include artificial recharge as **one** of the components.*
2. From a technical perspective, it is necessary to locate structures for artificial recharge at appropriate sites. *Some basic hydrogeological inputs like hydrogeological mapping (ready-to-use maps are not available on the scales of implementation), water level surveys and stream flow behaviour (qualitative) can be used as simple tools to determine potential recharge and discharge areas. This delineation, in turn, can be used to objectively determine sites with a fairly high degree of confidence.* This approach is currently absent in most watershed development projects but organisations like GOMUKH have begun gathering such inputs for improved location of artificial recharge and water harvesting structures. Moreover, such information can also provide insights regarding the status of aquifer development during the period of project implementation or even after.
3. It is necessary to understand the degree of groundwater abstraction from an aquifer underlying artificial recharge projects. *In other words, information is required on how much an aquifer is dewatered as a consequence of natural and pumping discharges and the proportion of space available in the aquifer for storing artificially recharged water*, although the latter may require a slightly higher level of technical expertise and interpretative skills.
4. On a more generic level, principal implementing agencies like GOMUKH, develop a strong rapport with project communities. This rapport essentially results in better co-ordination between the implementing agency and the community during project implementation. However, this co-ordination seems to dwindle after the implementation phase of the project is over. *Consequently, the post-project maintenance remains a 'grey area', often dependent upon individuals from the community rather than a 'committee' or 'group' responsible for post-implementation activities like maintaining structures.* However, since GOMUKH is just going into the management phase, considering their earliest projects in Kolwan valley, specific comments on management aspects, at this stage are not entirely justifiable, although the above observation holds good even in Kolwan valley. In terms of projected management of groundwater resources, artificial recharge being one important aspect of such management, there is scope to increase and improve interface between project implementing agencies and communities.

5. Finally, management of artificial recharge ought to involve a component of 'better informed' communities. *What **after** watershed development and artificial recharge?* Communities ought to be posed with such questions during the phase of post-project management of groundwater resources. In Kolwan valley specifically, communities need to be informed about the limitations in uncontrolled development of groundwater resources and the need for 'increased community involvement' in groundwater management and artificial recharge.

7.3 Strengthening positive outcomes and mitigating negative impacts

This section deals with specific recommendations for work in Kolwan valley but also has potential to be useful in a more generic sense in the planning and execution of artificial recharge activities in the Deccan basalt, and even in other hard-rock regions. The recommendations are listed as bullets below and are based on a combination of observations and scientific studies in Kolwan valley, both a part of the research conducted under the AGRAR project.

- Appropriately placed, fewer structures will ensure the desired results in Kolwan valley. In other words, in low-lying areas where aquifers can be understood and defined (as has been done in this study focussing on the Chikhalgaon aquifer) a lesser number of structures could serve the purpose of recharging groundwater under the current set of conditions. In fact, such an approach will also make it viable to study and develop a more comprehensive plan for artificial recharge to springs in the upper slopes/areas of the microcatchments, albeit with a more thoroughly studied aspect on springs in Kolwan valley.
- Communities need to be better informed in order to mitigate negative impacts such as *how much of recharged water will actually be available for use during a season; for what purposes; and how can this be harnessed keeping in mind the objectives of a project like watershed development?*
- Although not strongly evident in Kolwan valley, it is necessary to look carefully into whether structures affect inundation of agricultural of lands and destruction of crops, especially during abnormally heavy spells of rain. *High runoff areas like Kolwan valley are prone to the risk of flooding in some lands.* Such lands could be identified and treated as potentially "high-risk" areas for creating impoundment structures. Similarly, groundwater discharge zones also need to be identified and studied for their vulnerability to water-logging.
- Even though it is a difficult task and would probably require *policy* based interventions, some degree of reconciliation between physical and administrative boundaries is necessary to attain a higher efficiency in limiting the impacts of recharge within the physical unit wherein watershed development (and artificial recharge) is implemented. Two simple options are possible in this regard and the question of *scale* gains importance in both.

- In order to reconcile boundaries, it may be useful to consider more than one watershed to limit benefits from artificial recharge to the village lands.
- The areas actually covered under one watershed wherein artificial recharge is implemented may be shared by one project involving both the villages on the two sides of the mainstream, e.g. Chikhalgaon and Nandgaon or Bhalgudi and Hadashi.

7.4 Learnings: expected and unexpected results

When GOMUKH began work on watershed development in Kolwan valley, it was essentially guided by the DPAP objectives, wherein artificial recharge was embedded within the broader set of objectives of improved access, distribution and use of water, both from the socio-economic upliftment of the people in Kolwan valley as well as environmental considerations like improved biomass production. Generally, one can surmise that these objectives have been achieved and artificial recharge, in its own small way, has contributed to meeting the specified objectives. At the same time, some specific outcomes from the whole effort of watershed development has led to some expected and unexpected results. These salient outcomes, bulleted below may simply be read as the main 'set' of learnings from the AGRAR project.

- The magnitude and scale of lift irrigation schemes and the growth of sugarcane as an irrigated crop after 1998, was somewhat unexpected. However, although sugarcane continues to be a popular crop with the richer farmers, diversification of cropping is clearly noticeable in the last couple of years, creating an enabling environment for improved management of water resources.
- The AGRAR study discussions with farmers brought out the limitations in awareness levels regarding the watershed development programme. Hence, continuity in the process of disseminating findings and an increased interaction with the community is desired. The increased interaction will not only help in awareness improvement, but will also go a long way in developing an enabling environment for progressively improved (perhaps even 'sustainable') management of water resources.
- Water levels in aquifers in Kolwan valley were quite shallow even before the programme was implemented. The fact that they are probably shallower now indicates a positive outcome from the programme as a whole, although this principally conflicts the trend shown by the CGWB observation well. This point clearly highlights the question of the scale on which smaller impacts are apparent. One well over an area of about 100 km^2 is far too less to capture the dynamics of recharge and impacts, especially in heterogeneous conditions like those in the Deccan basalts.
- The AGRAR study produced estimates on various hydrogeological aspects, including natural and artificial recharge. These estimates were useful in drawing conclusions on the physical nature of impacts from artificial recharge, clearly indicating the importance of good information in order to

put outcomes from projects like watershed development and artificial recharge in a factual light. Therefore, improvement in the status and type of data that is currently collected by implementing agencies is certainly recommended. In short, some basic scientific data like identification of aquifers through hydrogeological mapping, rainfall, seasonal water level behaviour, estimates on groundwater abstraction and stream flow behaviour must be gathered during the planning phase of such projects. Further, the strategy for monitoring (frequency of measurement, degree of automation required and the types of data) should be decided after developing a sound conceptual understanding of these factors.

7.5 Wider lessons

On a wider platform, the AGRAR study highlighted the importance of understanding the limitations of technologies like artificial recharge. This, by no means, underrates the need for artificial recharge, but only stresses the need to study groundwater resources in all their dimensions *prior to, during and after implementation* of an artificial recharge project. It becomes necessary, therefore, to study the physical and livelihoods environments where such projects are implemented.

Further, the status of water resources needs to be fully understood at all scales of implementation and the 'impact of impacts' discussed with communities to ensure sustainability. *What after watershed development and artificial recharge…how will water be managed and who will do it?* This is precisely the nature of work that ACWADAM and GOMUKH intend to take up as a follow-up to this research. However, this is not under the scope of the present project but possibilities to fund a continuation of this project into the phase of 'improved management of artificial recharge' in Kolwan valley is being explored.

7.6 Future work

ACWADAM intends to continue monitoring the Kolwan case study site during the current year. Future monitoring and work will depend upon availability of funding. Nevertheless, it would be useful to lay down certain aspects on which future work is intended. These are:

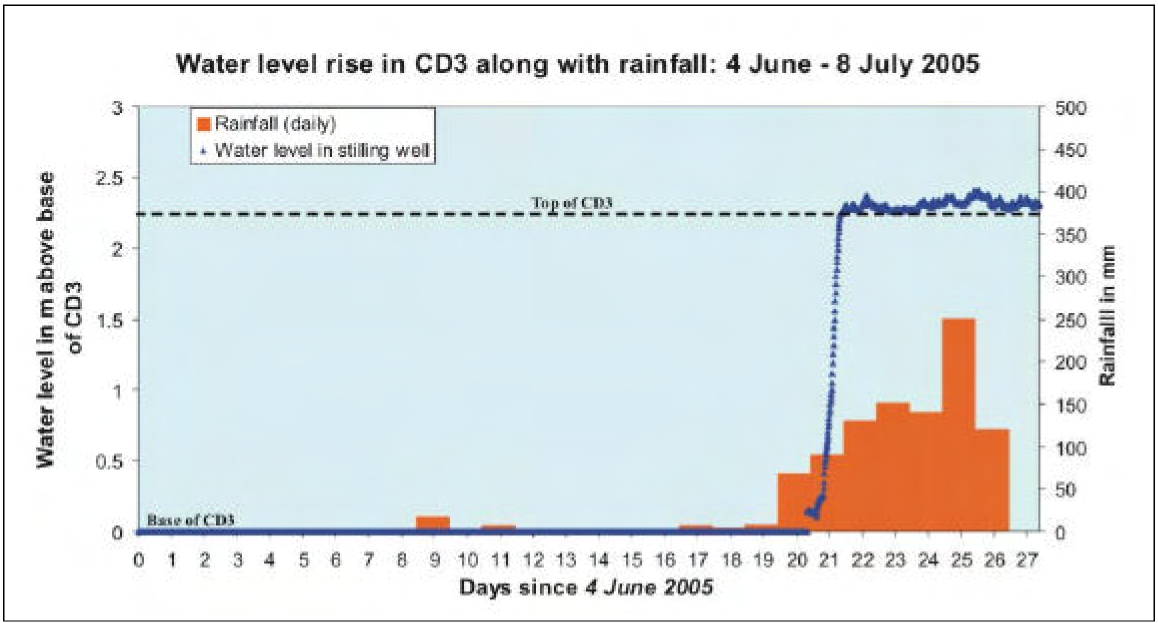
1. Continued monitoring along the same lines as this project, wherein both, physical and socio-economic aspects will be covered. There is better baseline information now on current projects (Nandgaon and Nanegaon) than on the earlier projects (Chikhalgaon, Hadashi and Bhalgudi), *again an outcome of continued monitoring and dialogue with GOMUKH and the communities from these villages, as a part of AGRAR project.*
2. Environmental isotope studies will be conducted around CD3, wherein Bhabha Atomic Research Centre (Government of India), based in Mumbai has promised analytical support in the form of collaboration for one year. BARC scientists

visited the site and found the AGRAR research interesting enough to complement their ongoing extension work on application of isotopes.

3. Community based management of groundwater resources is envisaged as the next step in villages like Chikhalgaon, especially for the small and marginal farmers. Some of the learnings from other DFID projects like COMMAN, WHIRL and APRLP will prove useful in planning and implementing groundwater management in such villages.

END NOTE

Concurrent to the finalisation of this report, the monsoon has set in. Data from the AGRAR network in Kolwan valley has started coming in. The first major spell of rain, in large parts of western and southern India was very intense and stretched out over a period of more than a week. It followed the same pattern in Kolwan valley, and although we haven't been able to systematically compile all the data, we are ending this report with a few illustrations that indicate the pattern and impacts of a strong 'first' monsoon spell.



Plot indicating the rainfall received in Kolwan from June 4, 2005 till July 8, 2005 along with the rise in water level in CD3

Walki river in flood…

…damage to adjacent farms

Soil erosion caused due to intense spells of rainfall

Sparse paddy saplings due to inundation from heavy spells of rain prior to transplantation

Drilling of new boreholes very close to the stream (right and above) indicate a shift to groundwater irrigation