Artificial Recharge and Water Quality around Hubli and Dharwad.

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Summary

The effects of urbanisation on water resources in the periurban interface around the twin cities of Hubli and Dharwad, Karnataka, India was conducted. A review of existing hydrological data and a water quality survey revealed that leakage from the mains and sewerage systems applied across the Hubli Dharwad Municipal Corporation area (HDMC) was 73mm (20.5 million m^3/yr) and this was equivalent to current estimates of natural recharge of 53-85 mm. Abstractions in the rural areas of the Hubli and Dharwad Taluks were 14 mm (23.9 million m^3/yr), 16-26% of natural recharge which is within official guidelines of sustainable use of groundwater resources.

A review of water quality data collected in 2001 confirms that additional recharge due to leakage is diluting the groundwater near to the cities. If current plans for the development of water resources for Hubli and Dharwad proceed and mains water and sewage leakage are not addressed it is likely that in 2010 there will be a dramatic increase in both groundwater levels and dilution of groundwaters within the HDMC and surrounding areas. Health implications of these findings are discussed.

Introduction

Recent concerns have been expressed about rising watertables within urban areas as a result of leakage from mains water supplies and sewerage systems [1,2]. Other studies have pointed out that can also be attributed to lower groundwater abstraction rates as mains water supplies increase and the urban aquifers become polluted [3-5].

This paper is based on a water resources assessment of peri urban villages around the twin cities of Hubli and Dharwad, Karnataka, India (Figure 1) as part of a wider resources and development project [6]. Before 1956 there was little difference in water sources between the urban and rural areas; both relied on hand dug wells and large water harvesting dams known locally as tanks. Since 1956 the Hubli and Dharwad cities have relied on piped reservoir sources, while the rural areas have increasingly relied on boreholes, pumped first by hand pumps and then motorized pumps, as mains electricity became available to the villages [7,8].

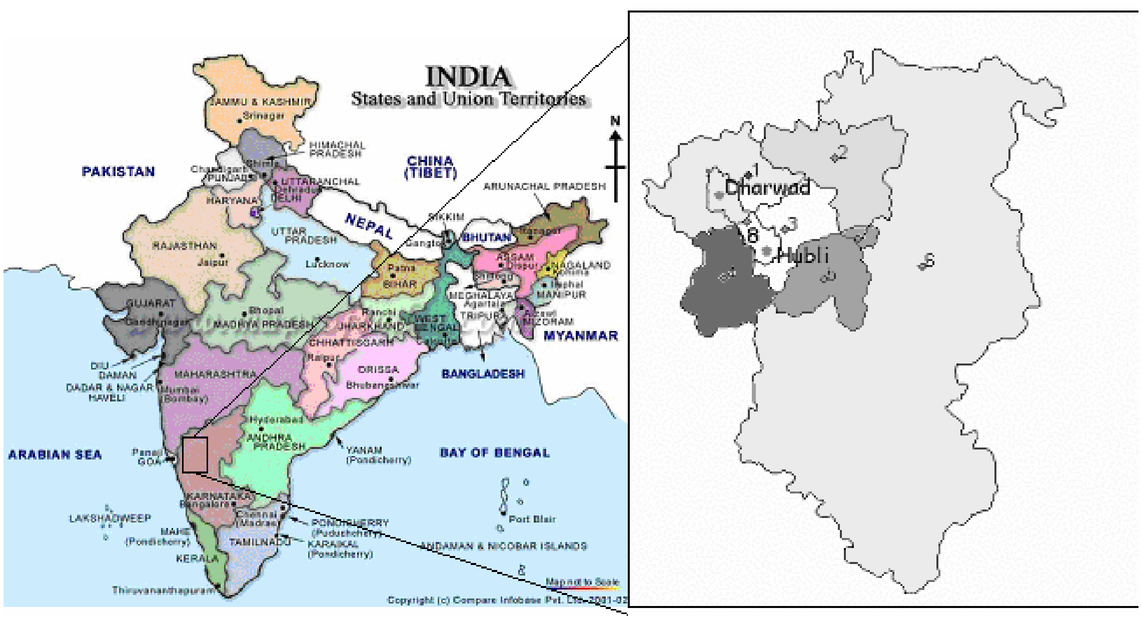
The peri urban project sought to identify the pressures on the livelihoods of poor people living in villages adjacent to the suburbs of large cities. Water is part of the natural resource capital fundamental to the livelihoods of people [9]. Increasing abstractions for agriculture combined with erratic rainfall have led to the general perception that water tables are falling, that groundwater has become more saline in rural areas [10,11], whilst groundwater in urban areas appear to be prone to sewage pollution [13].

To determine whether these perceptions were true in fact and to what extent urban expansion was having on water resources; a water budget was calculated based on an analysis of rainfall data, mains and sewage water leakage, and an estimate of abstraction using data drawn from official government sources. A water quality survey was also carried out.

Study Area

Together Hubli - Dharwad is the 44th largest conurbation in India. It lies 80 km east of Goa and sits on the north Karnataka plain between 600m and 700m, on the watershed between rivers flowing east and west. The area is characterized by a monsoonal climate, rainfall occurring from April to October. The measured average annual rainfall at University of Agricultural Sciences Dharwad for 1980-1999 ranges from 400-1100mm (average 768mm), and the annual potential evaporation rate based on pan measurements for the same period is 868mm. Hubli tends to be drier on average than Dharwad.

Figure 1. Map of India, Showing location of Hubli and Dharwad Taluks within the Dharwad District.



Key for Dharwad District Map: modern Dharwad District (areas 1-5) = 3966 Km^2, Hubli Taluk (area 3) = 624 Km^2, Dharwad Taluk (area 1) = 1033 Km^2 and the Hubli Dharwad Municipal area (S.Hedge, 1991) (8) = 280Km^2. Old administrative Dharwad District (areas 1-6). Taluk=subdistrict.

Hydrogeology

The underlying geology is complex and subject to a number of different interpretations [14, 10, 15]. Generally Hubli and Dharwad lie on schistose formations (schists, grewackes, shales and ferruginous quartzites) of Dharwar super group of Archaean age (Figure 3).

Groundwater occurs in weathered zones and under semi confined conditions in deep jointed formations. Groundwater is contained in an upper probably unconfined, and a lower confined or partially confined aquifer. These are described, in a regional context, by Subhash Chandra [16] and, in the Hubli-Dharwad area, by S. Hegde [17] and Bhat and M.Hegde [10].

The upper shale aquifer is accessed by a number of open wells, which have largely been dug in relic river channels where the alluvium overlies the well weathered rock material which forms an aquiclude. These alluvial channels are easily recharged by rains. Open wells are typically 10 – 15m deep and typically dry up in March. Groundwater in the in the Hubli-Dharwad Municipal Corporation (HDMC) area occurs mainly in the fractured and weathered zone in an unconfined state. The increasing numbers of boreholes are abstracting groundwater from a deeper confined aquifer which fluctuates less than the open wells [18] Maximum yields are achieved in boreholes drilled to between 40 and 80m depth, which can be interpreted as the zone of most intensive fracture in the greywackes, with the fractures tending to be less well developed or closing below 100m [17].

Measured values for the lower aquifer transmissivity ranged from 12 - 66 m^2/day (average 30m^2/day) and Specific Yield ranged from 1.8E-06 – 2.5E-01 (average 0.03 However neighbouring wells had very different values. The specific yield of 0.03 implies that every 10mm of effective recharge would raise the water table by 0.3m

Water balance

A full water balance accounts for all inflows and outflows from the catchment area. In this study it was not possible to locate flow records for flows in the rivers out of the catchment. Natural river flows result from natural recharge. By accounting for artificial recharge and abstractions the net effect on water tables and river discharges can be ascertained. The net ‘artificial’ balance is then compared against natural recharge to judge the magnitude of its effects.

Natural recharge

The main source of recharge is rainfall, but some allowance must be made for evaporation and runoff. Analysis of rainfall records for the period 1980-2001 shows a slight decrease in rainfall, largely as a result of dry conditions in 2001. Rain falls mainly between April and November. However not all of this precipitation permeates into the ground. Hubli tends to be drier than Dharwad.

Estimates of recharge range from 7% to 11% of rainfall [19, 20]. Table 1 gives details of estimated equivalent depth of recharge based on the recharge rate and minimum, maximum and average rainfall. The estimated recharge is found to range between 28 and 121 mm/yr, while the estimate for annual average recharge is 53 – 85 mm.

Table 1. Equivalent depth of recharge based on the recharge rate and minimum, maximum and average rainfall.

Effective recharge rate (% of Rainfall)[19, 20]	Min (400 mm)	Max (1100 mm)	Average (768 mm)
7%	28 mm	77 mm	53 mm
11%	44 mm	121 mm	85 mm

Artificial recharge

Leakage from mains water and sewage supply systems are the main sources of artificial recharge. Leakage has increased as the population has grown and the original water main and sewage networks have been expanded.

The combined volume of mains and sewerage leakage within the HDMC area is estimated as approximately 58% of that supplied from the reservoirs. In 2001 this was estimated to be 20.5 million m^3/yr. Table 2 gives details of the estimated combined leakage.

Mains Water Leakage

Initially Hubli and Dharwad had only two tanks as sources of water supply, Unkal Tank for Hubli and Kelageri Tank for Dharwad. As both cities grew the existing water supplies became inadequate and newer sources had to be developed [8].

The Neersagar reservoir was built in 1956 and still supplies drinking water to a part of Hubli city. The Malaprabha reservoir, initially built for irrigation, meets the drinking water water needs of both Dharwad and the rest of Hubli. In 2001 an estimated 31.7 million m^3/yr was supplied to the HDMC water supply network [8].

From 1993 to 2001 about 3.7 million m^3/yr was lost from the Malaprabha source, due to leakage and power failure, before reaching Hubli -Dharwad. The water main to the cities was constructed of concrete which was easily damaged and readily broken by villagers along the pipeline trying to gain access to free water. Work started in 2001 and was completed in 2002, to replace the concrete pipe with a more robust bitumen lined steel pipe. From 2002 the total water supplied reached 35.4 million m^3/yr[7,8]. Table 2 gives details of current water supplies to the Hubli - Dharwad.

Table 2. Volumes of water supplied to the HDMC area. (millions m^3/yr)

	Reservoir	Water supplied[8]		Leakage		
		Contribution	Total	Mains	Sewage	Total
1956	Neersagar (unenhanced)	6.6	6.6	2.6	1.2	3.8
1967	Neersagar (enhanced)	13.1	13.1	5.2	2.4	7.6
1983	Malaprabha stage 1	12.4	25.5	10.2	4.6	14.8
1993	Malaprabha stage 2	6.2	31.7	12.7	5.7	18.4
2002	Malaprabha repaired pipeline	3.7	35.4	14.2	6.4	20.5
2010	Malaprabha stage 3	22.3	57.7	23.1	10.4	33.5

The population of the HDMC area has grown from 525,000 in 1981 to 736,000 in 2001 and water use per head is also increasing, as modern plumbing fittings and water using machines are installed. The current annual population growth rate of 2.35% means that the population of the twin cities will reach 1 million by 2010 and at that time the demand for water in the twin cities is expected to reach 54 million m^3/yr at 150 l/head/day which cannot be met by current water supplies. [13].

Current resources are not considered adequate and a third stage of the Malaprabha reservoir has now been approved and is designed to supply a further 22.3 million m^3/yr by 2010 [13].

Within the city the water distribution network has been expanded and extended well beyond its original design. A recent survey by Anglian Water UK estimated that 40% of water supplied to the distribution network was lost through leakage and illegal connections[8]. Table 2 gives estimates of mains water leakage which in 2002 was estimated to be 14.2 million m^3/yr.

Sewerage leakage.

Leakage from the sewers can be assumed to be far worse than that from mains water supplies as sewer mains have more cause to be neglected, however Polisgowdar[7] believes very little of this sewage leakage ends up in the rivers, 80-90% seeping into the water table. Kulkarni [13] disagrees estimating that the total amount of sewage generated is assumed to be equal to the amount of water actually supplied to households, and that 30% goes to cesspits, the remaining 70% flows through the sewers to the rivers.

Leaking sewers can also drain the water table, by allowing groundwater to seep in the sewer pipes when flows in the sewers are low. For the purposes of this paper it is assumed that only leakage from cesspits recharges the groundwater, while leakage from sewer pipes is assumed to drain away in the rivers. As leakage from the sewers is ignored, the estimates of groundwater recharge will be conservative. In 2002 this sewerage leakage is estimated as 6.4 million m^3/yr (Table 2).

Abstractions

Estimates of groundwater abstraction can be made using the method adopted in 1994 by the Indian Department of Mines and Geology[20]. This method uses standard abstraction rates for different groundwater abstraction structures. The net abstraction rate per structure (0.7 of the gross values) for each type of structure are presented in Table 4.

Estimates of numbers of the different types of groundwater abstraction structures within the Hubli and Dharwad Taluks are shown in Table 3. These figures are based on the Department of Mines and Geology [20] 1994 census of groundwater abstraction structures. Figures in this report for 2002 assume that there was an annual growth of 2% in abstraction structures since then.

In 2002 the estimated number of boreholes was 484, an increase of 70 over eight years. This appears to be an underestimate, since one Dharwad based drilling company claims to install at least 2 boreholes per week (1 irrigation and 1 domestic) [21].

The net abstractions in 2002 is 23.9 million m^3 increasing to 28 million m^3/year by 2010. The effect this has on groundwater levels will be more noticeable in Dharwad Taluk where the abstraction rate is 2.5 times that of Hubli Taluk, as illustrated in Table 4.

Table 3. Numbers of groundwater abstracting structures for irrigation in the Hubli and Dharwad Taluks.

		Borehole	Dug well	Dug cum borewell	Others	Total
1994[20]	Hubli	414	111	3	49	577
	Dharwad	1102	222	19		1343
1999	Hubli	457	123	3	54	637
	Dharwad	1217	245	21		1483
2002	Hubli	484	131	3	57	675
	Dharwad	1291	259	22		1572
2010	Hubli	568	152	4	67	792
	Dharwad	1513	305	26	0	1844
2021	Hubli	707	190	4	83	985
	Dharwad	1881	379	33		2293
2031	Hubli	862	232	5	101	1201
	Dharwad	2293	462	40		2795

Table 4. Estimated and projected groundwater abstractions (million m^3 /year) for Dharwad and Hubli taluks.

		Borehole	Dug well	Dug cum borehole	Others	Total Gross Draft	Total Net Draft
	Annual Draft/ structure	0.017	0.009	0.014	0.002		
1994	Hubli	7.04	1.00	0.04	0.10	8.18	
	Dharwad	18.73	2.00	0.27	0.00	21.00	
	H+D					29.18	20.4
1999	Hubli	7.77	1.10	0.05	0.11	9.03	
	Dharwad	20.68	2.21	0.29	0.00	23.18	
	H+D					32.20	22.5
2002	Hubli	8.25	1.17	0.05	0.11	9.58	
	Dharwad	21.95	2.34	0.31	0.00	24.06	
	H+D					34.18	23.9
2010	Hubli	9.66	1.37	0.06	0.13	11.23	
	Dharwad	25.72	2.74	0.37	0.00	28.83	
	H+D					40.05	28.0

There are no published figures of amounts of water abstracted within the HDMC area from private boreholes. Such boreholes are largely used for drinking water particularly when the mains water supplies become erratic. As most of this water is used for domestic purposes, a large proportion will enter the sewage system or cesspits and consequently enter the groundwater system. A rough estimate based on 10% of the population in 2001, consuming 100 l/head/day is equivalent to 3 million m^3/yr. Assuming the same fate as the rest of water entering the sewage system , 1 million m^3 (30%) ends up in cesspits and recharges the groundwater leaving 2 million m^3/yr (70%) which is assumed to flow in to the rivers. As this is relatively minor, abstractions from urban households are ignored.

Calculation of artificial water balance

The projected figures for total combined leakage and abstractions from above are compared against estimates of natural recharge. An Artificial Water Balance (AWB) is also calculated.

$$AWB = (L_m + L_s) - A_r$$

Where

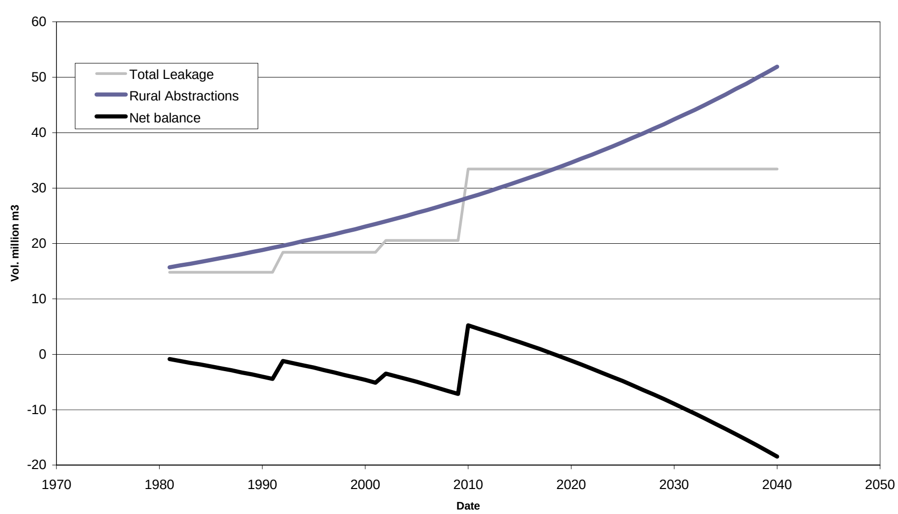
L_m = Mains Leakage

L_s = Sewage Leakage

A_r= Rural Abstractions

Figure 2 shows the net water balance between abstractions and total leakage. Generally the net balance is 0 to -10 million m^3/yr, as the volume of mains and cesspit leakage is less than net abstractions. When the third stage of the Malaprabha scheme starts to supply water the net balance becomes briefly positive, increasing to 5 million m^3/yr in 2011. The effects of this leakage locally within the HDMC area would be noticeable. Groundwater levels would be expected to rise and surface flooding may occur. However this would only last for 8 years before the net balance becomes negative again and by 2025 would be back at the same level as 2001.

Figure 2. Net water balance between artificial recharge and abstractions.



Comparison of artificial recharge with natural recharge

While there seems to be little cause for concern when the net balance of abstractions and leakage is considered, if the volumes of water leaked and abstracted are converted into equivalent depths across the areas where they actually occur, a different picture emerges. Combined mains and cesspit leakage occurs in the HDMC area, while abstractions occur all over the Hubli and Dharwad Taluks (Figure 1); 1 million m^3 = 3.6 and 0.6 mm equivalent depth respectively. Table 5 shows details of the equivalent depths of leakage and abstractions in 2002 and 2010.

Table 5. Comparison of depths of water (mm/yr) being abstracted and recharging the Aquifer (figures in brackets millions m^3 applied over relevant area)

	Annual average Natural Recharge	Leakage within HDMC suburban area (280 km^2)	Abstractions within H+D Taluks (1657 km^2)
2002	53 - 85	73 (20.5)	14 (23.9)
2010	53 - 85	119 (33.5)	16 (28.0)

The amount of leakage within the HDMC area derived from leakage in 2002 is similar to that derived from average natural recharge, but by 2010 recharge from leakage will be greater than average natural recharge. Meanwhile in the rural area across Hubli and Dharwad Taluks total abstractions remain nearly constant at 14 – 16mm between 2002 and 2010. This is between 16 and 26% of natural recharge. The ideal rate of recharge utilization whereby groundwater resources are used sustainably determined by the Dept. of Mines and Geology [(22)] is 65% of net recharge.

From this there would seem that local concerns about water quality and water levels are unfounded, however it is likely that agricultural and irrigation activities are more intense nearer the HDMC area and water use in rural areas is underestimated.

Water quality assessment

If leakage was occurring in the volumes suggested above then groundwaters within the HDMC area should be significantly more dilute than the surrounding rural area where the only recharge is from rainfall.

Water quality in eight periurban villages was surveyed in May 2001 at the start of the monsoon [(6)]. The water quality survey looked at four Near villages (2-7 km) and three Far villages (8-15 km) from the urban area located on N, S, E and W transects. Water samples were not collected from the Far village on the eastern transect because there were no hand pumps in use there, as the water was known to be non potable because of high conductivity.

Seventeen village hand pumps from the remaining villages were surveyed and the water samples then analysed at SDM college in Dharwad. A large number of parameters were tested but only conductivity values are presented (Table 6). Figure 3 shows the location of the villages.

A statistical analysis of the water data was carried out, comparing Near and Far villages to see if groundwaters near the HDMC area were more dilute.

The water quality survey results were compared against the Indian water quality standards. It was found that the majority of hand pumps, 14 out of 17 (82%) were non potable according to the Max Permissable Limit in Absence of Another Source (MPLAAS)[(23)] (70%, without bacterial contamination being considered). The major parameters contributing to non portability were hardness (50%), bacterial contamination (23.5%) pH, turbidity, TDS, and calcium.

When compared to the Highest Desirable Limits (HDL)[(23)] for water, none of the water samples passed. All samples failed on hardness, and calcium, 88% failed on conductivity, and 50% on chloride.

When the water quality results were considered on a Near Far basis, 33% of Near villages were within the MPLAAS limits [(23)] while 0% of Far villages had potable hand pump water supplies.

Figure 3. Geology overlay [24] with the locations of water quality sampling points, markers indicate low, median and high conductivity sample sites

A	Pudakalkatti	E	Virapur
B	Dasanakoppa	F	Gabbur
C	Kelgeri	G	Bidnal
D	Mandihal		

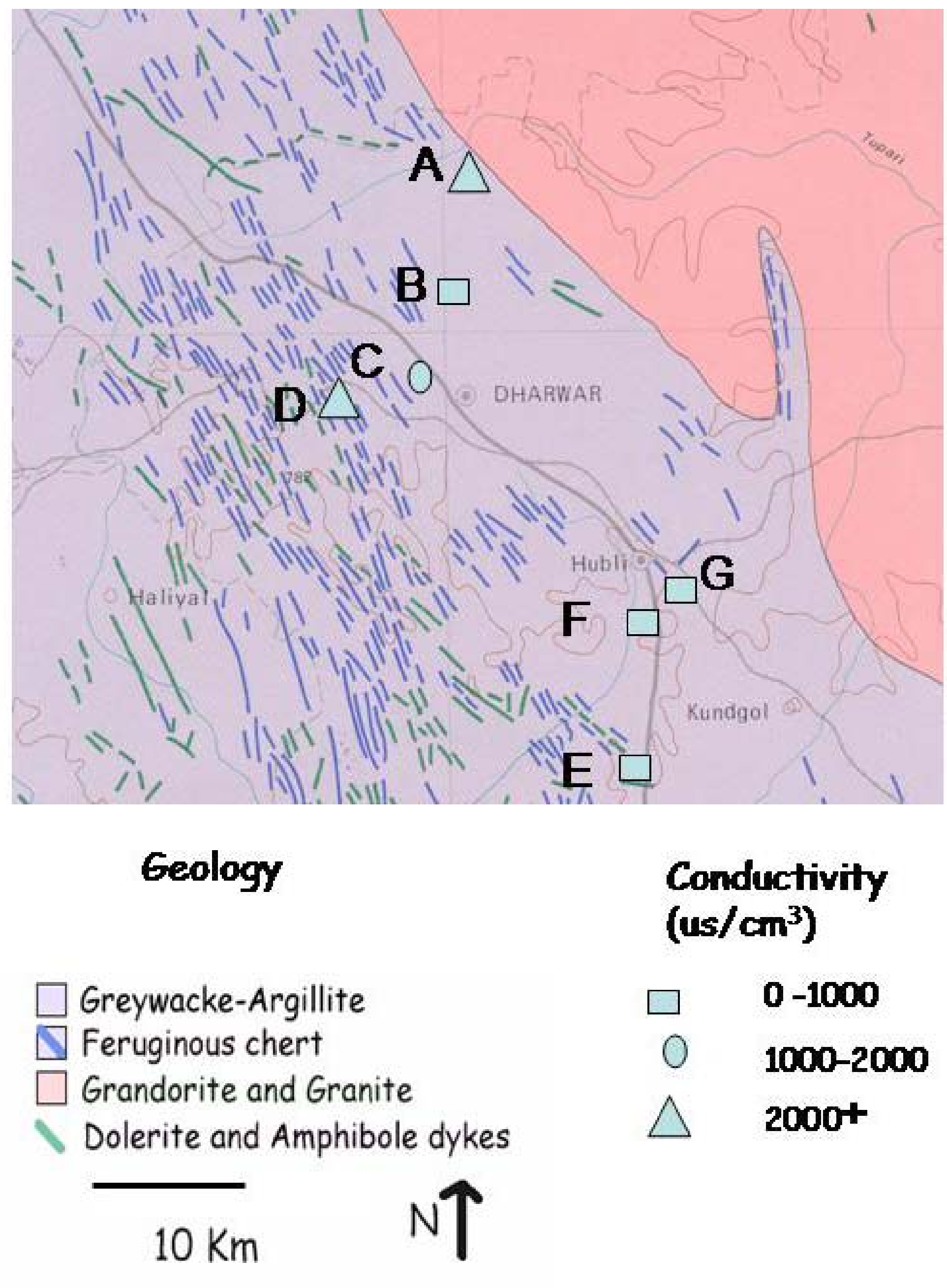


Table 6. Conductivity values in 2001 for DFiD PUI Water quality survey [(6)].

Village	Sampling location	Cond µS/cm
Far		
Pudakalkatti	Harizan keri Near Temple	3200
	Nala Road	2900
	Inchageri Math	1770
	Average	2623
Virapur	Janatha Plot	1760
	Mulla Oni	1070
	Karevva Temple	1080
	Goudar Oni	1070
	Average	1245
Mandihal	Alnavar Road Near School	1880
	School Premises	2200
	Average	2040
Near		
Dasanakoppa	Near entrance to village	1480
	Dasanakoppa -Narendra Road	1300
	Average	1390
Kelgeri	Shivashakti Nagar 4th Cross	890
	Shivashakti Nagar 1st Cross	660
	Average	775
Gabbur	Main Road	1590
	Near Temple	1680
	Average	1635
Bidnal	Laxmi Nagar	1300
	Govt. Primary school	1420
	Average	1360
	Average	1602
	Max	3200
	Min	660
	St Dev	671
Mains Water		**190**

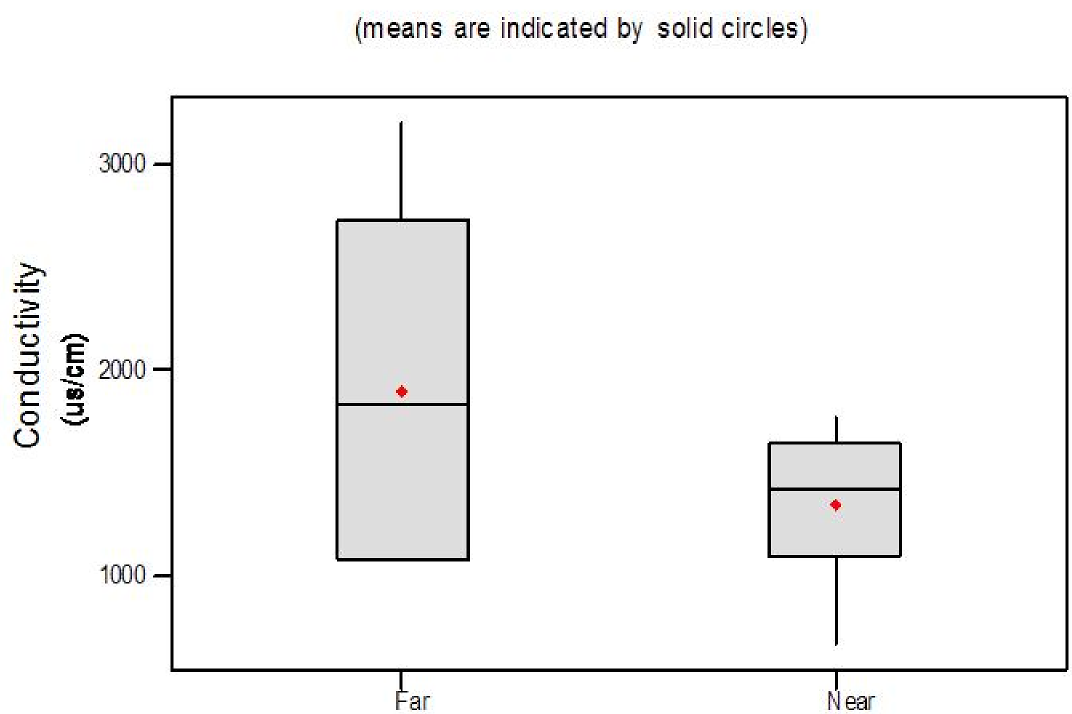
Compared to the hand pump samples the mains water is much more dilute, on average 10% of the conductivity values found at the hand pumps. Mains water supplies were potable in all the survey villages, however only the Near villages of Kelgeri, Gabbur and Bidnal had access.

To determine if groundwaters near to the HDMC area were more dilute box plots of villages Near and Far were drawn (Figure 4) and a Mann Whitney one sided U test conducted.

The box plots show that although the lower end for the 95% confidence interval was similar for both data sets (1095 and 1073 uS/cm respectively, largely because of the low conductivity found in the Far village Virapur), the higher end of the 95% confidence interval (1635 uS/cm for Near and 2725 uS/cm for Far) is much greater for the Far villages.

The Mann Whitney one sided U test was confirms that at the 95% probability level, Far villages have greater conductivities than Near. In the Near villages close to urban areas, groundwater is generally more dilute compared to Far villages in rural areas. This implies that in urban areas that more recharge than abstraction is occurring relative to the rural areas. The positions and values of the average conductivity for hand pumps in each village are plotted in Figure 3.

Figure 4. Boxplot of conductivities of hand pumps in Near and Far villages in 2001



Conclusions

There is evidence of a hydraulic gradient from the high ground occupied by the HDMC area to the outlying rural regions. This evidence is in the form of records of abstraction and leakage, and analysis of water quality data from villages subdivided into near and far villages from the HDMC urban areas.

In 2002 14mm of equivalent depth of water was being abstracted across Hubli and Dharwad Taluks, while the average annual natural recharge rate was estimated as 53-85mm. There would seem little cause for concern that recharge is not adequate. However annual and seasonal variations are causing local concerns about both water levels and water quality. Meanwhile within the HDMC area leakage is recharging an equivalent depth of approximately 73mm which is within the estimated range of average annual recharge.

The net effect of leakage is to raise water tables and dilute the groundwater within the HDMC area and prolong flows in rivers which has implications for dry season irrigation using wastewater (see Bradford et al., this issue). Evidence of dilute water near to the HDMC area was found. There are additional concerns that leakage from cesspits and sewers are polluting the groundwater which may be abstracted by borewells within in the HDMC area. As the water holding properties of the aquifer are largely dependant upon NW-SE trending fractures both rising water tables and the movement of more dilute but sewage polluted waters would be expected to move out from the HDMC area primarily in these directions.

If the third stage of the Malaphrabha water supply scheme goes ahead then recharge due to leakage would be expected to increase by 30% to 119mm. This would raise water tables within the HDMC area dramatically, further dilute groundwaters around the HDMC area and cause increased flows in rivers, unless the mains water supply network is repaired.

In order to provide adequate water for the populations of Hubli and Dharwad in 2025 the HDMC will have to develop new supplies or repair the mains water pipe network. If new water supplies are developed then leakage will increase and the effects of artificial recharge of diluting groundwater quality and raising groundwater levels will extend further into rural areas. If the water supply network is repaired then there will be less recharge and surrounding rural areas will have waters with higher conductivities.

Alternatively if new supplies are not developed the number of private boreholes in the HDMC area will increase and so will abstractions which will minimise the effects of leakage.

Sewage treatment is lacking in Hubli Dharwad. The unregulated use of cesspits and boreholes could result in contamination of private water supplies reliant on boreholes unless they are adequately treated. Leakage from the sewerage system only makes this situation worse. Repairs to the water mains would reduce the volume of water leaking into sewerage system.

More research is required to assess the groundwater situation. At present there are no observation only wells from which to get an accurate picture of water levels, neither is water quality sampled on a widespread routine basis. Currently there are no restrictions to the development of new boreholes and no accurate census of boreholes so it is impossible to estimate accurately groundwater abstractions. River flows also need to be assessed to get an accurate water budget.

References

[1] Hassan, MM; El Shiwi, M; Smidt, E (1995). Impact of improved sewerage systems on groundwater heads in eastern Cairo region. Middle East Wastewater Management., pp. 171-177, Water Science and Technology [Water Sci. Technol.], vol. 32, no. 11. IWA publishing.

[2] Alderwish, A. and Dottridge, J., 1998. "Recharge components in a semi-arid area: the Sana'a Basin, Yemen". In: Groundwater Pollution, Aquifer Recharge and Vulnerability (Ed. Robins, N.S.), Geological Society Special Publication, 130, 169-178.

[3] Lerner D.N., 1988. Unaccounted for water - a groundwater resource? Aqua (Journal Intern. Water Supply Assoc.) 1,33-42.

[4] Brassington, F.C. (1990) Rising Groundwater Levels in the United Kingdom Proceedings of the Institution of Civil Engineers PCIEAT, Vol. 88, No. Pt 1, p 1037-1056, December 1990.

[5] Foster S., and Adrian B. (1998), Groundwater in urban development : assessing management needs and formulating policy strategies. World Bank Technical Paper 390. World Bank, Geneva.

[6] Brook, R. (2002) Filling gaps in Knowledge about the peri-urban interface around Hubli and Dharwad. Final Technical Report, DFID project R7867, Natural Reources Systems Programme.

[7] Polisgowdar S. (2001) Long term perspective planning of water supply and sanitation to Hubli Dharwad Twin Cities. Bhageerath workshop on water and sanitation problems in Hubli Dharwad cities. (30/5/01)

[8] Reddy S. (2001) Water supply and sanitation problems in Hubli- Dharwad cities. Bhageerath workshop on water and sanitation problems in Hubli Dharwad cities. (30/5/01)

[9] Chambers R., and Conway R. (1992) Sustainable rural Livelihoods: Practical concepts for the 21st Centuary'. IDS discussion paper No. 296 Brighton. IDS.

[10] Bhat S.K. and Hegde M. R (1997) Electrical resistivity behaviour of shale and schistose greywacke in northern part of Dharwad Schist Belt- a case study. Dept. of Mines and Geology, Bangalore, Groundwater study No. 336.

[11] Hegde V.S. (2001) pers. comm. Geologist SDM College, Dharwad

[13] Kulkarni S (2001) (KSPCB) Status of Sewage Treatment and Solid Waste Disposal in Hubli Dharwad city. Bhageerath workshop on water and sanitation problems in Hubli Dharwad cities. (30/5/01)

[14] Anatha Iyer G.V. (1994) Metamorphic Geology of Karnataka, in B.M. Ravindia and N. Ranganathan (Eds.), GeoKarnataka, Mysore, Geological Dept. centenary volume, Karnataka Assistant Geologists Association, Dept. of Mines and Geology, Bangalore. pp 117-128.

[15] Chadwick B. (1994) The Dharwar supergroup in western Karnataka, in B.M. Ravindia and N. Ranganathan (Eds.), GeoKarnataka, Mysore, Geological Dept. centenary volume, Dept. of Mines and Geology, Bangalore. pp 81-94.

[16] Subhash Chandra K.C. (1994) Occurance of groundwater and aquifer characteristicsof hard rocks in Karnataka, in B.M. Ravundia and N. Ranganathan (Eds.), GeoKarnataka, Mysore, Geological Dept.

centenary volume, Dept. of Mines and Geology, Bangalore, pp. 337-359.

(17) Hegde S.N. (1991) Groundwater studies of Hubli Dharwad Municipal Corporation area. Karnataka, India. PhD Thesis, Kanataka University, Dharwad.

(18) Hegde G. (2001) pers. comm. Geologist, Dept. Mines and Geology, Dharwad.

(19) Ministry of Irrigation (1984) Groundwater Estimation Methodology., Report on the groundwater estimation committee, Ministry of Irrigation, Govt. of India. New Delhi.

(20) Department of Mines and Geology (1995b) Groundwater sources of Dharwar District as of 31/12/1994. Department of Mines and Geology ,Government of Karnataka, Bangalore.

(21) Basavaraj A. (2001) pers. comm. Consultant Hydrogeologist.

(22) Department of Mines and Geology (1995a) Groundwater sources of Karnataka as of 31/12/1994. Department of Mines and Geology, Government of Karnataka, Bangalore.

(23) Bureau of Indian Standards (1991) IS 10500. Water quality standards. Government of India.

(24) Krishnaswamy, V.S. (1981) Geological and Mineral Map of Karnataka and Goa, Geological Survey of India.