Experience in improving piped water supply to the 18 medium-sized towns of Bangladesh

M. A. I. Chowdhury, M. F. Ahmed, M. Quadiruzzaman and M. A. Mannaf

ABSTRACT

Arsenic contamination in shallow aquifers is severe, and drinking water status is seriously affected in Bangladesh because the majority of the people rely on hand tubewells in both rural and urban areas. Consequently a piped water supply based on deep groundwater aquifers and surface water is considered more important to provide arsenic and iron free water to the consumers in urban areas of Bangladesh. As a result, a few water supply projects were initiated to manage piped water supply systems in core areas of the district towns and paurashavas (municipalities) of Bangladesh. One such project is the 18 District Towns Water Supply Project, which also includes hand tubewell supply in fringe and slum areas. The paper describes the existing piped water supply system condition, performance and management following recommendations to improve the piped water supply system in 18 medium-sized district towns of Bangladesh.

Key words | 18 DTP, arsenic, leakage, Paurashava, PWSS, wastage

M. A. I. Chowdhury (corresponding author)
Environmental Engineering & Pollution Control Department,
SUST,
Bangladesh

M. F. Ahmed
Civil Engineering Department,
BUET,
Bangladesh

M. Quadiruzzaman
M. A. Mannaf
Department of Public Health Engineering (DPHE),
Bangladesh

INTRODUCTION

In Bangladesh, a densely populated country, poverty is widespread but more concentrated in areas outside the capital city Dhaka where poor health conditions stemming from poor water supply and sanitary conditions cause adverse effects on poverty. To this effect the 18 District Towns Water Supply, Sanitation, Drainage and Hygiene Education Project (18 DTP) executed by DPHE was started in May 1989. The project aimed to upgrade the deteriorating health condition of the inhabitants of the towns by improving drinking water facilities; the project concluded in March 2000. The towns included in 18 DTP were Barguna, Bhola, Jhalokati, Joypurhat, Lalmonirhat, Magura, Manikgang, Meherpur, Moulvibazar, Naogan, Narail, Netrokona, Nilphamari, Panchagarh, Satkhira, Shariatpur, Sherpur and Takurgaon. The location of the study area is shown in Figure 1 (DPHE 2000). The specific objectives of the water supply component of the project were to (DPHE 1995):

- set up sustainable water supply (piped water supply);
- set up institutional structures for management, operation and maintenance of water supply facilities in the Paurashava Water Supply System (PWSS) of 18 medium-sized district towns;
- give priority to the areas where water supply conditions do not meet minimum local standards;
- guarantee maximum involvement and participation of the local people for improving the water supply system.

The main targets of the project were as follows:

- 75% of the population of the 18 towns will be served with a sustainable drinking water supply system;
- approximately 5–20% of households will be provided with house connections, a fee will be charged which will be sufficient for the operation and maintenance of the PWSS;
- about 30% of the population will be served by street hydrants within a maximum walking distance of 250 m;
- piped water installations will last for a minimum of 20 years and international technical design criteria will be provided.

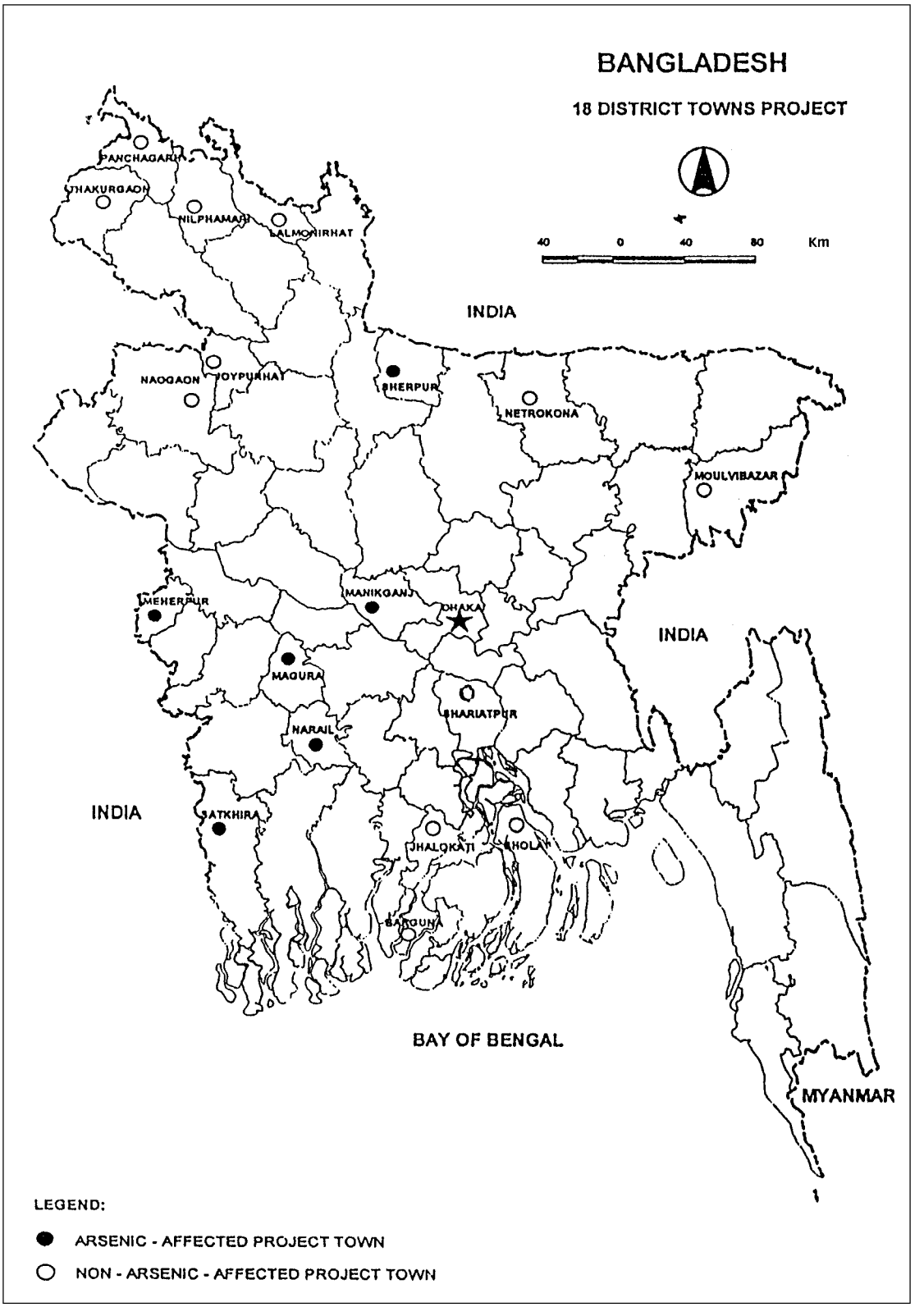

Figure 1 | Location of the 18 District Towns.

MANAGING ORGANISATIONS OF PWSS IN 18 DTP

In medium-sized district towns, the Directorate of Public Health Engineering initiated the water supply system (WSS) and was solely responsible for drinking water management in towns up to the 1970s. In the course of time, the operation and maintenance of the distribution system were transferred to the Paurashavas under the guidance of the Local Government Engineering Bureau (LGED) in the 1980s and then LGED left the responsibility of installing the production and distribution system and water quality monitoring and testing to Department of Public Health Engineering (DPHE) as the successor of the Directorate of Public Health Engineering (DPHE 1993). Recently, the responsibility of laying service connections and distribution mains of diameter <100 mm and revenue generation lies with the Pourashava (LGED 1994).

EXISTING PIPED WATER SUPPLY SYSTEM UNDER 18 DTP

The piped water supply system, used to supply domestic water in core areas of the 18 DTP towns, fulfils a significant part of total water demand (on average 12%) of the towns. To evaluate existing conditions as well as the system performance of the piped water supply system, field surveys were carried out in the project towns during the project period.

System condition of the piped water supply

The piped water supply consists of production tubewells (PTWs), overhead tanks (OHTs), iron removal plants (IRPs), arsenic removal plants (ARPs), surface water treatment plants (SWTPs), distribution pipe lines and service connections.

Production system

Groundwater is the major water source in the 18 DTP towns except for Barguna; the lion's share of drinking water in Barguna comes from surface water. Groundwater is extracted in every town including Barguna. OHTs were constructed in order to provide more regular supply periods throughout the day, providing a buffer stock of water between constant production flow and fluctuating distribution flow. Only in Satkhira did an OHT of 650 $m^3\ h^{-1}$ exist before 18 DTP. With respect to water quality, since its inception, 18 DTP has focused primarily on iron and salinity. The criterion of 1 mg l^{-1} Fe determined whether construction of an IRP was necessary or not. Salinity of groundwater in coastal belt towns (Barguna, Bhola, Jhalokati and Shariatpur) forced the installation of production wells with filters at a depth of 200–300 m where fresh water could be found. The filter is considered to remove iron and manganese present at a slightly or moderately higher level than the permissible limit in groundwater. Frequent press reports allude to spreading arsenic panic among the public; experts estimate that 15–20% of the nation's 13 million people are at risk from the arsenic hazard (UNICEF Bangladesh 1990). In 1995, 18 DTP tested groundwater sample from a series of production and hand tubewells in Meherpur; the result was unambiguous: 90% of the samples had arsenic concentrations above the WHO guideline of 10 μg l^{-1} and 60% of the samples were above the Bangladesh standard of 50 μg l^{-1}. In 1996, water quality with respect to arsenic was given high priority and an investigation into arsenic began in 18 DTP towns (DPHE 1996). The arsenic content in tubewell water of six arsenic affected towns—Magura, Manikgang, Meherpur, Narail, Satkhira and Sherpur—exceeded the WHO guideline value (van Agthoven *et al.* 1999). In six towns, about 150,000 (50%) people are at risk of chronic arsenic poisoning through the use of hand tubewell water; and about 75,000 (25%) people may have been consuming water with arsenic content over 100 μg l^{-1} on a daily basis (Hanchett *et al.*). Based on test results and estimation, efforts were made to install deep production tubewells in Meherpur, Magura and Narail to avoid arsenic. IRPs were constructed in Joypurhat, Manikgang, Meherpur, Naogaon, Netrokona, Nilphamari, Panchaghar, Satkhira and Sherpur and are planned in Lalmonirhat, Magura and Narail where iron content in water exceeded 1 mg l^{-1}. ARPs of the same

Table 1 | Description of production system

Town	PTW*	OHT**	IRP**	CWR**	ARP
Barguna	1 + (5) = 6				
Bhola	2 + (6) = 8				
Jhalokati	2 + (5) = 7	1 (450)		1 (160)	
Joypurhat	2 + (2) = 4	1 (450)	1 (100)	1 (160)	
Lalmonirhat	2 + (4) = 6	1 (450)		1 (160)	
Magura	3 + (2) = 5				
Manikgang	2 + (4) = 6	1 (450)	1 (200)	1 (160)	1
Meherpur	3 + (3) = 6	1 (450)	1 (200)	1 (160)	1
Moulavibazar	3 + (7) = 10	1 (450)		1 (160)	
Naogaon	4 + (6) = 10	2 (450)	1 (400)	2 (160)	
			1 (300)		
Narail	3 + (2) = 5				
Netrokona	2 + (4) = 6				
Nilphamari	2 + (3) = 5	1 (450)	1 (100)	1 (160)	
Panchagarh	0 + (3) = 3	1 (450)	1 (100)	1 (160)	
Satkhira	3 + (4) = 7	1 (450)	2 (200)	1 (160)	2
		+ 1 (680)†			
Shariatpur	1 + (3) = 4				
Sherpur	3 + (2) = 5	1 (450)	1 (200)	1 (160)	
Takurgaon	3 + (1) = 4				
Total	41 + 66 = 107	13	10	12	4

*First figure indicates the number of PTWs installed before 18 DTP, figure in parentheses the number under 18 DTP.
**Number within parentheses represents respective plant capacity ($m^3\ h^{-1}$).
†OHT of 680 $m^3\ h^{-1}$ existed in Satkhira before 18 DTP.

size were combined with IRPs in Manikgag, Meherpur and Satkhira where arsenic content exceeded the WHO guideline value (van den Berg 1997*a*, *b*). A description of PTWs, OHTs, IRPs and ARPs is given in Table 1.

Distribution system

Initially the distribution system consisted of distribution lines and house connections only. In 18 DTP, a

Table 2 | Detail of distribution pipelines with length in km

Town	Pipelines before 18 DTP	New pipeline under 18 DTP	Reticulation lines under 18 DTP	Rehabilitated pipelines	Total pipeline
Barguna	3.56	20.67	12.98	2.10	37.21
Bhola	6.8	18.76	13.38	6.33	38.94
Jhalokati	9.42	15.95	16.08	6.47	41.45
Joypurhat	7.58	17.00	5.90	6.03	30.48
Lalmonirhat	6.88	32.88	10.43	6.73	50.19
Magura	9.0	19.21	8.00	6.00	36.21
Manikgang	8.13	25.59	13.48	7.63	47.20
Meherpur	10.48	15.11	6.52	6.50	32.11
Moulavibazar	9.0	15.67	7.61	4.50	32.28
Naogaon	11.60	25.24	9.36	11.40	46.20
Narail	6.98	13.06	6.10	6.00	26.14
Netrokona	8.00	15.04	6.02	5.26	29.06
Nilphamari	4.90	11.83	6.92	5.50	23.65
Panchagarh	0	21.99	7.30	0	29.29
Satkhira	15.5	38.54	15.15	9.50	69.19
Shariatpur	1.5	9.94	9.19	1.00	20.63
Sherpur	5.70	14.91	4.58	4.80	25.19
Takurgaon	13.36	30.28	9.00	12.68	52.64
Total	138.39	361.67	168	108.46	668.06

reticulation system was introduced with 50 mm diameter PVC pipe; a sufficient number of new distribution lines of diameter ≥100 mm were laid and old and leaky AC pipe was replaced and rehabilitated with PVC pipe. Details of the pipeline are given in Table 2.

There were neither adequate numbers of service connections nor a single street hydrant in the existing water network of 18 DTP towns. New house connections (HCs) in core areas and street hydrants (SH) in slum and fringe areas were installed and old leaky house connections were rehabilitated. To reduce the wastage of water, a significant number of modified street hydrants (MSHs) with a hand tubewell installed on a small reservoir were constructed in every town. The connection to the reservoir has a floating valve to control inflow of water and the hand tubewell is operated manually to pump water and consequently

Table 3 | Details of house connections and street hydrants

Town	HC before 18 DTP	Newly installed HC under 18 DTP	SH installed under 18 DTP	Rehabilitated HC under 18 DTP	Total house connections
Barguna	172	1,011	7	413	1,183
Bhola	440	1,533	11	1,106	1,973
Jhalokati	616	1,874	20	2,539	2,490
Joypurhat	20	716	4	9	736
Lalmonirhat	85	1,076	4	85	1,161
Magura	494	1,487	21	357	1,981
Manikgang	407	1,628	24	938	2,035
Meherpur	397	1,253	27	650	1,650
Moulavibazar	532	1,022	5	433	1,554
Naogaon	943	2,744	16	1,369	3,687
Narail	163	631	15	78	794
Netrokona	516	1,282	14	645	1,798
Nilphamari	56	501	5	0	557
Panchagarh	0	58	5	0	58
Satkhira	453	1,817	21	2,173	2,270
Shariatpur	40	618	11	30	658
Sherpur	179	740	20	177	919
Takurgaon	289	1,408	13	410	1,697
Total	5,802	21,399	243	11,412	27,201

prevent the wastage of water. Moreover MSHs provide water for 24 hours; if the main water supply system is not operational water will be available from the storage reservoir. Table 3 shows the details of house connections and street hydrants.

System performance of piped water supply

Although service connections have increased five-fold, the coverage of piped water supply is still not satisfactory due to rapid urbanisation and unplanned extension of the boundary of the towns as well as uncontrollable migration of rural people to towns especially in slum and fringe areas. PWSS water supply coverage ranges from 1% in Panchagar to 26% in Meherpur; while average coverage is only 12%. In spite of the ultimate goal of supplying 24 hour continuous supply to everyone, only 12% of the inhabitants of 18 DTP towns are supplied with piped water for 12 hours a day. This is due to insufficient production capacity to cope with the demands of an increasing population although water pressure has been

increased significantly in at least ten towns. Twenty-four hour supply has been realised only in Jhalokati while two mini-water supply systems are being operated for 24 hours in Panchagarh. Takurgaon is close to establishing continuous water supply. Presently Takurgaon PWSS can be kept at sufficient pressure at non-peak hours which proves that good pressure can also be ensured in a system without water meters if proper operation and maintenance is employed, timely rehabilitation work is performed, leaks are repaired at once and consumer's co-operation and awareness about water use are available. Continuous supply has been arranged privately by 40% of the households in Satkhira by constructing overhead tanks. The survey showed that majority of the consumers (67%) wanted a 24-hour water supply and almost all of them (95%) were willing to pay a reasonable water tariff for such supplies with adequate pressure. The reasons were that it has advantages over an intermittent supply, it is more reliable, there is no need for a manually operated hand tubewell, for good hygiene and a constant supply of fresh water. The estimated population, coverage of piped water supply and supply hours in 18 towns is shown in Table 4. The PWSS survey also looked at metered connections in Jalokhati and Satkhira. Metering prevented wastage of water leading to economy for the customers; the average water bill (Tk. 150 per month in Satkhira) was higher than the average metered bill (Tk. 122 per month) which was within the limit and ability of the consumers. The majority of the consumers accepted the metered system of payment and complaints due to fluctuation of the bill were below 15%. Fear that the meter would be rotated by air was not found to be a concern among the consumers. The complaint that meters were stolen, particularly in Jhalokati, was only 11%. Water users benefited from the lower payment by meter reading than average water billing (Khan Mohidul Hoque 1999).

Table 4 | Population, piped water coverage and supply hours (January 2000)

Town	Estimated population	Piped water coverage (%)*	Supply hours
Barguna	30,000	17	3
Bhola	51,000	18	11
Jhalokati	46,000	24	24
Joypurhat	54,000	8	7
Lalmonirhat	77,000	8	12
Magura	54,000	16	13
Manikgang	61,000	16	13
Meherpur	29,000	26	7
Moulavibazar	53,000	13	12
Naogaon	155,000	10	12
Narail	40,000	9	13
Netrokona	51,000	15	6
Nilphamari	52,000	6	6
Panchagarh	49,000	1	24
Satkhira	101,000	10	10
Shariatpur	44,000	7	10
Sherpur	76,000	6	12
Takurgaon	58,000	14	15
Total	1,081,000		
Average	60,000	12	12

Note: The coverage related to the use of street hydrants is not included in the figures presented in the table.

OPERATION AND MAINTENANCE (O&M)

Due consideration and proper attention was given for O&M of the water supply system. Water superintendents, bill clerks, pump drivers, treatment plant operators, plumbers of PWSS were trained up under 18 DTP. Instruction and operation manuals, training materials and guidelines were developed and distributed to PWSS. These contained all the relevant background information, procedures and instructions to maintain and operate the

water supply system properly. Although the O&M system in PWSS of 18 DTP has been established, it can not be regarded as an up-to-date and standard one due to the time limit of the project. Poor O&M of service connections is still a common scenario in 18 DTP towns. Replacement of the same service connection more than once in 18 DTP towns during project period shows the poor O&M of service connections.

REVENUE MANAGEMENT OF PWSS

PWSS in 18 DTP towns showed very poor revenue management performance. There is always an unnecessary incidence of subsidy due to the political motivation of the Paurashava Chairman although there is no need for subsidy except for a few consumers like schools, colleges and religious institutions. Currently 18 DTP piped water supply caters to a large extent to people who are able to pay the full cost of the services. Unfortunately, in towns without metering, the water tariff is a very low fixed amount per connection per month. In 13 towns, PWSS charge a water tariff of only Tk. 100 (US$2) per month for a domestic service connection of half inch diameter, while in three towns the tariff is still below Tk. 100. In metered service connections, the water tariff is Tk. 5 m^{-3}. Although the water tariff is very low in comparison to the high investment and O&M costs, PWSS's seller performance (that is, the performance of water selling to the consumers with respect to the realisation of water revenue of the PWSS of the Paurashavas) with collection efficiency (1998/99) is quite satisfactory. On average 82% of the tariff was realised by PWSS; above 95% was realised by PWSS of Barguna, Joypurhat and Thakurgaon; and with the exception of Shariatpur and Sherpur, all other PWSS realised more than 70% of the tariff which shows better collection efficiency. Joypurhat PWSS has been consistent in achieving a quarterly collection efficiency above 80% over the last two years. The monthly water tariff for domestic connections of half-inch diameter and the water tariff collection efficiency of PWSS of 18 DTP towns during financial year 1998–1999 are presented in Table 5.

LEAKAGE AND WASTAGE

Due to poor quality materials and lack of proper O&M, many leak points were found, with tremendous leakage at a level of 33–80% in the existing water supply system. Also there was too much wastage of water by consumers who left the tap open intentionally or carelessly. As a result consumers living at the end of the pipeline far from production wells or overhead tanks often would not receive water during some of the operating water supply hours or sometimes would get no water at all; the service hours for affected consumers were certainly less than the average operating hours of the system. Poor water pressure hampered the existing water supply system severely even getting no water from the system due to interrupted supply in many areas of the PWSS jurisdiction, and air and water from outside would enter the distribution system through leaks. This enhanced the risks of bacteriological contamination and outbreak of water-borne diseases. The leakage and wastage condition of the piped water supply system of 18 DTP was severe. Leaks in the water distribution system which go undetected, particularly underground leaks, constitute a significant part of real losses. On the other hand, leakage and other losses which have been detected and attended to, can still contribute to non-revenue water (NRW) if they are not properly accounted for (Foo and Chan 1997). From this standpoint, a visual leakage survey as well as a proper water audit in the billing and revenue management function including system rehabilitation is a must. To improve the alarming condition of NRW, due consideration and efforts were given to rehabilitation of the old distribution mains and service connections, installation of reticulation lines, water meters at service connections and bulk meters in pump houses, increasing supply hours and service levels, increasing the water tariff to make the public aware of the cost of water, and motivating consumers not to leave taps open after use. PWSS operators and plumbers as well as revenue management and administrative staff like bill clerks, water superintendents and store keepers were trained to improve their skills and to maintain the water supply system properly; to plan and implement programmes for rehabilitation of old pipes and service connections as well as pipe cleaning, leak detection and leak

Table 5 | Monthly water tariff rate and collection efficiency

	Water tariff				
	Non-metered connection		Metered connection		
Town	Taka per month	US$/month	Taka m^{-3}	US$ m^{-3}	Tariff collection efficiency
Barguna	100	2			97
Bhola	100	2			84
Jhalokati	100	2	4	0.08	77
Joypurhat	100	2			96
Lalmonirhat	60	1.2			70
Magura	100	2			83
Manikgang	100	2			83
Meherpur	80	1.6			87
Moulavibazar	100	2			83
Naogaon	125	2.5			90
Narail	100	2			93
Netrokona	75	1.5			76
Nilphamari	100	2			73
Panchagarh	100	2			76
Satkhira	150	3	5	0.1	86
Shariatpur	100	2			63
Sherpur	100	2			67
Takurgaon	100	2			97
Average	99	2	5	0.1	82

repair; to issue water bills promptly; to prepare cost estimates for materials, tools and equipment accurately and to keep them in the store carefully. The staff were also trained in planning and implementing campaigns for waste control, installation as well as O&M of house connections, group taps and street hydrants. Consequently, the level of NRW was reduced to a low level of 12% in Jhalokati town where 24 hour supply is ensured, to below 35% in 11 towns, although in six towns NRW is still higher than 35% such as 51% in Lalmonirhat.

REHABILITATION

Today utilities are making every effort to reduce NRW to a standard acceptable level. To accelerate the leakage control programme, water organisations have parallel, major programmes of work to rehabilitate their water supply network, which are often driven by water quality considerations. In parallel, probably in another part of the organisation, leakage control is being assessed, planned and methods to reduce it implemented. It is vital that if water mains network management is to be as efficient and cost-effective as possible, the two activities of mains rehabilitation and leakage control must be considered jointly from an economic standpoint (Conroy and Hall 1995). Keeping this idea in the mind, to reduce NRW to an acceptable level in 18 DTP towns, the rehabilitation programme for the distribution system as well as service connections was given priority. Old pipes were rehabilitated by new ones, leaky AC pipes were replaced by PVC pipes; rehabilitation of service connections included replacement of old and rusted GI house connections, low quality plastic service pipes and installation of water meters in Jalokhati and Satkhira towns. Over 100 km of pipelines and 11,412 house connections were rehabilitated. Table 6 depicts the rehabilitation statistics of PWSS for the 18 towns.

Table 6 | Rehabilitation works in PWSS of 18 DTP towns

Town	Rehabiliatated pipelines (km)	Number of rehabiliatated house connections under 18 DTP
Barguna	2.10	413
Bhola	6.33	1,106
Jhalokati	6.47	2,539
Joypurhat	6.03	9
Lalmonirhat	6.73	85
Magura	6.00	357
Manikgang	7.63	938
Meherpur	6.50	650
Moulavibazar	4.50	433
Naogaon	11.40	1,369
Narail	6.00	78
Netrokona	5.26	645
Nilphamari	5.50	0
Panchagarh	0	0
Satkhira	9.50	2,173
Shariatpur	1.00	30
Sherpur	4.80	177
Takurgaon	12.68	410
Total	108.46	11,412

CONCLUSION AND RECOMMENDATIONS

Although 18 DTP has already been implemented, the target of the project was not completely met because of unplanned expansion of towns as well as continuous migration of people to towns from rural areas. Whether the first target of 75% of the population with access to a guaranteed and safe source of drinking water will be achieved, is difficult to answer, as it strongly depends on the use of service connections, hydrants and hand tubewells as well as the identification of the severe arsenic hazard recently identified in Bangladesh. The second target of charging a fee to cover the operation and maintenance of the system has not been achieved in all towns. This is due to the very low water tariff (only Tk. 100 or US$2 per month) charged by the Paurashava; it is not in the political interest of the Paurashava Chairmen to increase the tariff. The third target of 30% of the population to be served by street hydrants has not been achieved. This target was wishful thinking, in particular because on one hand the PWSS superintendent is advised to act professionally, on the other hand he must allow quite a

number of public taps that do not provide any revenue but are notorious for wasting water. Except for those modified street hydrants with a fixed water rate given by Paurashava, a large number of public taps have negative financial impact. Experience of the project revealed that a limited number of existing modified street hydrants fulfil a need; many street hydrants may not be demand driven. The last part of the fourth target of using international standard technical design criteria has more or less been achieved but the first part about piped-water installations lasting for a minimum of 20 years could only be evaluated after this period has elapsed. In spite of a few shortcomings in achieving project targets, 18 DTP has had some significant success. 18 DTP put much effort in the development of PWSS to become an effective and efficient organisation for the provision of drinking water in urban settings. The impact evaluation concludes that, 'without doubt, the human resource development (HRD) activities were successful in developing the capacity of the PWSS staff to manage, operate and maintain the water supply facilities in technical, financial and administrative fields'. The introduction of the system of double entry bookkeeping has proved successful in solving financial problems; there was no accounting system in PWSS before the inception of this project. The financial viability of the piped water supply in 18 DTP towns has been established by the project; O&M costs of PWSS in all but two or three Paurashavas are covered by the revenues. 18 DTP played a pioneering role in introducing modified street hydrants instead of traditional public taps to reduce wastage of water significantly and in constructing arsenic removal plants to supply arsenic free water to the consumers given the emerging arsenic hazard in Bangladesh. The number of production tubewells, length of distribution pipe line and number of service connections has been increased 1.5, 5 and 4 times respectively in 18 DTP towns. Service hours in most towns have been increased to about 12 hours daily on average. 18 DTP has realised continuous supply in PWSS of Jalokhati and in two mini-water supply systems of Panchagarh; also Takurgaon PWSS is close to establishing continuous water supply. In 18 DTP, it has been revealed that water pressure at the tap is greatly affected by leakage of the distribution network as well as by excess demand and wastage of water by the consumers. PWSS in Takurgaon and Jhalokati has shown that good pressure (at least 10^5 Pascal or 10^5 N/m^2) is possible by maintaining NRW at a level of 15% and 12%. Takurgaon PWSS has shown that at least 1 bar pressure can be maintained without metering of service connections and may thus be considered a shining example for all urban water supply systems in Bangladesh.

Finally, using PWSS of Takurgaon and Jhalokati as a model, if the following priority recommendations based on the findings of the 18 DTP water supply project are implemented to develop PWSS in all District and Pauarashava towns of Bangladesh, the urban water supply system may contribute a lot to fulfilling the increasing water demand of a growing population.

1. Production capacity should be increased to fulfil the demands of the growing population in towns using both surface and ground sources. Priority should be given to surface sources where arsenic and salinity content exceed allowable limits.
2. A comprehensive water quality management policy should be developed embodying the principles of pollution prevention, a precautionary approach and a receiving water quality objective that will meet users' requirements. In this regard water quality of treatment plants and deep tubewells should be tested regularly.
3. To ensure that water quality remains within the permissible limits, proper water treatment must be performed especially in cases of surface water as a safeguard against water-borne diseases. IRP should be constructed in towns like Magura and Narail where iron exceeds the allowable limit (Fe >1 mg l^{-1}). Combined iron and arsenic treatment plants of the same size should be taken into consideration in cases of groundwater abstraction where arsenic and iron content are excessively high.
4. The distribution system must be expanded to ensure adequate water supply to the consumers. Pipes under roads or drains are recommended to be provided with a reticulation system.
5. As service mains and connections are the major sources of leakage, due consideration should be given to upgrading service mains of diameter

<100 mm and house connections. Provision should be made to take house connections from the reticulation lines. New house connections must be laid in the presence of water works officials and materials for house connections should be supplied by the water works to ensure proper workmanship and quality of the fittings.

6. Modified street hydrants should be constructed in slum and fringe areas to reduce wastage of water.
7. Operation and maintenance of all the accessories of the water supply network should be strictly maintained.
8. To keep NRW within acceptable limits (within 5–15% of water production), the development of a sound leakage control strategy should be enacted following an economic evaluation. In this regard, to handle the leakage and wastage problem in the water supply system, leakage control performance through passive methods and regular sounding should be monitored with a programme of robust data collection as part of the leakage survey. Data collection and recording systems should be established for each water supply zone and sub-zones covering information such as: man hours spent on active leakage control, broken down into detection, location and equipment maintenance, level of leakage, occurrence of bursts, repair cost and frequency on mains, communication pipe and supply; cost of new equipment, installation for leakage control, zone reconfiguration and staff training in the leak detection department of the water works (Bessey 1995). Active leakage control at an interval of five to ten years should also be conducted and leaks repaired without delay.
9. PWSS should have regular work programmes to rehabilitate the existing distribution system as well as the production system.
10. Conversion of non-metered connections to metered ones should be initiated in each town as soon as possible.
11. Service level should be improved through increasing supply pressure to at least 10^5 Pascal or 10^5 N/m^2 during normal supply hours to create consumer confidence in the water supply system. In this regard continuous instead of intermittent water supply should be ensured for minimising wastage.
12. Revenue generation should be increased by streamlining revenue management functions or privatisation of billing. To secure cost recovery, water tariffs as well as collection efficiency would be increased gradually.
13. The community must be motivated to participate in all kind of activities related to the water supply system and to raise public awareness about the adverse effect of leakage and wastage as well as to increase willingness to pay.
14. A double-entry accounting system should be initiated to improve financial status of PWSS until a standard utility type account is introduced.
15. Existing water bylaws should be enforced against illegal connection and unauthorised bypass lines and to realise reasonable water tariffs.
16. Selected personnel from the operation and maintenance section as well as the revenue management section should be trained from time to time to improve the overall performance of PWSS.

REFERENCES

van Agthoven, A., van de Weed, J. & Qumrun Nahar 1999 18 DTP Phase III Advisory Team Report: Arsenic in the 18 District Towns Water Supply Project. *18 DTP,* DPHE, Dhaka.

van den Berg, R. 1997*a* Pre-evaluation Design of Iron/Arsenic Removal Plant at Manikgang and Satkhira. Report of Field Trip to Manikgang and Satkhira, *18 DTP.* DHV Consultants, The Netherlands.

van den Berg, R. 1997*b* Evaluation of Removal Capacity of Iron/Arsenic Removal Plant at Satkhira, *18 DTP*. DPHE, Dhaka.

Bessey, S. G. 1995 The Economics of Leakage Control in the UK: Theory and Practice. *Special Report, World Congress, IWSA, Cape Town, South Africa*. IWSA, London. pp. SS 12-1–SS 12-5.

Conroy, P. J. & Hall, M. J. 1995 Rehabilitation and Leakage—a Joint Approach. *J. Wat. Suppl.: Res. & Technol.-AQUA,* **44**(4), 196–201.

DPHE 1993 Executive Summary of Final Report Vol. 1—Main Report; *Second Water Supply and Sanitation Project*. DPHE, Dhaka.

DPHE 1995 *18 District Towns Water Supply Project* 18 DTP-III, Project Document. DPHE, Dhaka.

DPHE 1996 Arsenic in Meherpur Town, *18 DTP*, DPHE, Dhaka.

DPHE 2000 *18 District Towns Water Supply Project* Final Report. DPHE, Dhaka.

Foo and Chan 1997 Unaccounted for Water–Singapore's Experience. *J. Wat. Suppl.: Res. & Technol.-AQUA,* **46**(5), 235–241.

Hanchett, S., Qumrun Nahar, van Agthoven, A., Geers, C. & Md. Ferdous Jamil Rezvi 1998 Arsenic Awareness in Six Bangladesh Towns, *18 DTP*, DPHE, Dhaka.

Khan Mohidul Hoque 1999 Piped Water Consumers' Interest in Meters and 24 Hour Water Supply. *18 DTP*. DPHE, Dhaka.

LGED 1994 Final Report on Water System Leak Detection of Sylhet City. *Secondary Towns Infrastructure Development Project-I*. Local Government Engineering Department, Dhaka.

UNICEF Bangladesh 1990 Arsenic Mitigation in Bangladesh, *Media Brief*, UNICEF, Dhaka.