CHAPTER 2 PRESENT SITUATION OF WATER RESOURCES AND WATER USE IN SANA'A BASIN

2.1 GENERAL

In this chapter, present situations of water resources in Sana'a Basin, which are well known as being in critical situation, are described in order to understand the availability of water resources, followed by the description of present condition of water use. Then, the current situation of institutional framework and organizational structure concerning water resources management are described.

2.2 WATER RESOURCES

2.2.1 SURFACE WATER

(1) Meteorology

1) Temperature

The average monthly temperature recorded at the station of NWRA-A is graphed in *Figure 2.1* and summarized in *Table 2.1*. Though obtained records are very limited, general tendency in the Sana'a Basin is observed. The hottest season is from June to August, and the coldest season is around January and February. The average monthly temperature ranges between about 15 and 25 C.

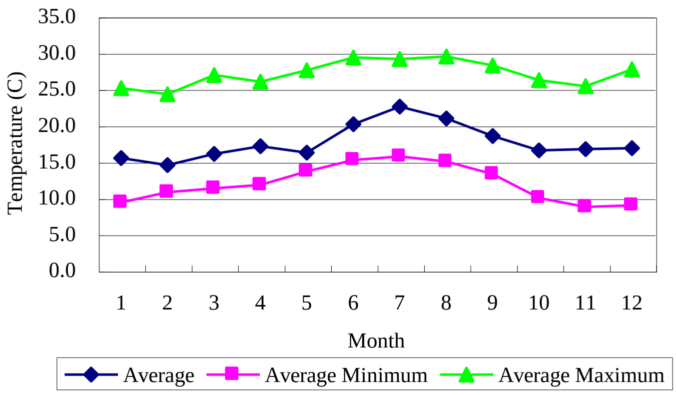


Figure 2.1 Monthly Temperature (NWRA-A, 1989-1997)

Table 2.1 Monthly Temperature (NWRA-A)

YEAR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average	Maximum	Minimum
1989	Average						22.1	23.5						22.8	23.5	22.1
	Minimum						14.9	15.9						15.4	15.9	14.9
	Maximum						28.5	28.6						28.6	28.6	28.5
1990	Average	15.5	16.8	18.6	18.9				23.2	21.4	19.4			19.1	23.2	15.5
	Minimum	8.6	11.7	11.5	12.2				16.7	13.9	11.3			12.3	16.7	8.6
	Maximum	23.8	23.8	27.1	26.2				29.9	28.3	25.8			26.4	29.9	23.8
1992	Average														0.0	0.0
	Minimum										6.6	6.6	6.0		6.6	6.0
	Maximum														0.0	0.0
1993	Average	15.3	15.6		17.2	20.5	23.1	22.8	22.5					19.6	23.1	15.3
	Minimum	8.0	10.4		11.9	14.2	15.8	16.5	15.6					13.2	16.5	8.0
	Maximum	23.5	22.7		24.7	27.4	29.9	30.2	30.1					26.9	30.2	22.7
1996	Average							21.7	22.5	21.8	18.0	15.1		19.8	22.5	15.1
	Minimum							16.2	15.7	14.3	9.6	6.9		12.6	16.2	6.9
	Maximum							29.0	30.1	28.3	25.8	23.6		27.4	30.1	23.6
1997	Average	15.7	11.2	13.6	15.4	12.1	15.4	22.4	15.7	12.5	12.3	18.5	16.9	15.1	22.4	11.2
	Minimum	11.6	10.3	11.2	11.4	13.2	15.1	14.4	12.2	11.7	12.6	12.8	12.0	12.4	15.1	10.3
	Maximum	28.1	26.5	26.8	27.3	27.9	29.7	28.7	28.0	28.2	27.1	27.3	27.8	27.8	29.7	26.5
Average	Average	15.5	14.6	16.1	17.1	16.3	20.2	22.6	21.0	18.6	16.6	16.8	16.9	17.7	22.6	14.6
	Minimum	9.4	10.8	11.4	11.8	13.7	15.3	15.8	15.0	13.3	10.0	8.8	9.0	12.0	15.8	8.8
	Maximum	25.1	24.3	27.0	26.0	27.6	29.4	29.1	29.5	28.3	26.2	25.4	27.8	27.1	29.5	24.3

2) Precipitation

The annual rainfall which is recorded at NWRA-A from 1989 to 2004 ranges from around 110 mm to 300 mm or more as shown in *Table 2.2*. The maximum annual rainfall was recorded at 341 mm in 1998. The figure indicates that rainy or wet seasons are generally from March to May and July to September, although there were some exceptional years.

Table 2.2 Monthly Rainfall (NWRA-A)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
1989				53	3.5	11.5	9.5	21.5	2	0	0	18.5	119.5
1990	0	2.5	40.5	19	3.5	0	31.5	2	25	0	0	0	124
1991	0	5.5	45	11	11.5	0	2.5	35	0.5	0	0	0.5	111.5
1992	2.5	0.5	20	20	64.5	3	10	139.5					260
1993	2.5	9	13.5	83	79.5	6	3	25	30.5				252
1997	5.5	1.5	14.5	29.5	7.5	2	12.5	33.5	0	60.5	33.5	1	201.5
1998	0	0.5	8	19	68.5	0	63	175.5	0	0	6.5		341
1999							9	100.5	15.5	13	7	1	146
2000		0.5	8	30	57.5		9	58.5	2.5	16	2.5	145.5	330
2001	28.5	107.5	31	13	1	0	49	21.5	21	22.5	7	1	303
2002	0	0.5	8	1	1	0	49	21.5	21	22.5	0	0	124.5
2003	0	0	10.5	52.5	12.5	0.5	0	0	0	3	2	146	227
2004	0	13.5	9	23	37	1	6.5	8.5					98.5
2005													
2006													
2007													
Average	3.9	12.9	18.9	29.5	29.0	2.2	19.6	49.4	10.7	13.8	5.9	34.8	230.5
Maximum	28.5	107.5	45.0	83.0	79.5	11.5	63.0	175.5	30.5	60.5	33.5	146.0	
Minimum	0.0	0.0	8.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

Annual precipitation from 1989 to 2004 is graphed as shown in *Figure 2.2*. Though some lacks of measurements are included, it is rather difficult to mention about a long-term tendency.

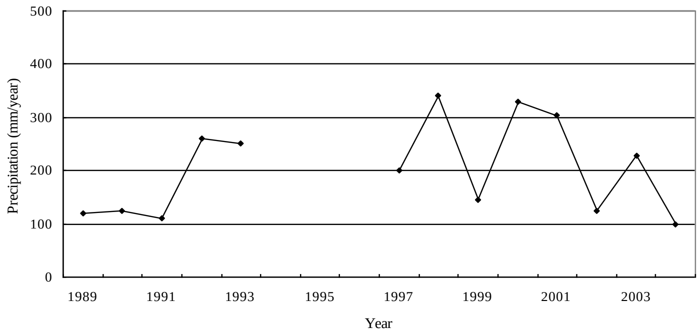
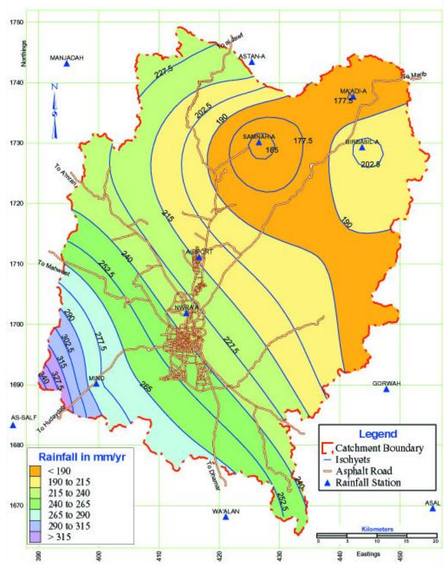


Figure 2.2 Annual Precipitation (NWRA-A)

Figure 2.3 shows the distribution of rainfall in the Sana'a basin provided by NWRA. The northeastern area in the Basin has less than about 200 mm/year rainfall and the central plain area has from 200 to 250 mm. In the southwestern mountainous area, the annual rainfall reaches more than 300 mm. It may be possible that the figure indicates the eastern mountainous area may actually have more rainfall.



Source; NWRA Sana'a Branch (2006): Monitoring Activities in Sana'a Basin. Technical Report (2003-2005)

Figure 2.3 Isohyet Map of the Sana'a Basin

3) Evapotranspiration

1:250,000 Hydrogeological map (Robertson 1990) describes that potential evaporation estimated by the Penman method averages about 2,000mm annually. According to SAWAS (1995), the potential evapotranspiration was an annual total of 2,475 mm based on a meteorological statistics with a maximum in June (average 9.4 mm /day) and a minimum in February (4.8 mm/day). The figures are substantially higher than annual rainfall.

GAF (2007) estimated actual evapotranspiration based on the satellite imagery analysis in SBWMP. According to the report, the total of 113.1 MCM water were transpired in the Sana'a Basin during the period from 1 July 2004 to 30 June 2005.

(2) Runoff

Though wadi runoff is not monitored, two types of method have been used to estimate the runoff volume of wadis in the previous studies. One is the method using a runoff coefficient, or the ratio of runoff depth to precipitation depth, obtained by hydrological observation of main wadis in Yemen. The average runoff coefficient of 0.055 for wadis in Yemen was suggested by WRAY-35 (1995) based on the observed flow volumes from primary watersheds. The volume of runoff in the Sana'a basin is estimated at about 40.9MCM/year with the supposition of the 230 mm of annual rainfall, the 3,240km^2 of the area of the Sana'a Basin and 0.055 of the runoff coefficient.

Another method to calculate runoff volume is the estimation using the SCS method that is the empirical model prepared by the U.S. Soil Conservation Service. TS-HWC Vol. III (1992) constructed a rainfall-runoff model using the SCS method and obtained the figures shown in *Table 2.3*, which indicated the mean total and base flow per day was 74,000 m^3 and 67,000 m^3 respectively in the Sana'a Basin. It means the total outflow of the Sana'a Basin is 27 MCM/year.

Table 2.3 Mean Flow of Sana'a Basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	Annual Total
Total flow	26	29	75	208	110	63	68	129	69	45	41	24	74	26,980
Flood flow	0	0	0	50	4	0	0	29	0	0	0	0	7	2,525
Base flow	26	29	75	158	106	63	68	100	69	45	41	24	67	24,455

Source: TS-HWC Vol. 3 Surface Water Resources, 1992 Unit: thousand m^3/day

In addition, General Directorate of Irrigation (GDI) provided a report of Engineering Data Sheet, which is the summarized report of a survey of 44 existing dams in 2001. It describes the hydrological condition around each dam site including estimated runoff coefficient, which ranges from 0.03 to 0.4, although it is not clear the method of estimation. The estimated mean annual flow of 44 dam sites totaled about 22.3 MCM.

(3) Usage of Surface Water

Surface water is used for recharge, irrigation and domestic purposes through 44 surface dams, 24 dams/pools and 145 springs inside Sana'a Basin. Locations of dams and springs are shown in *Figure 2.4* and *Figure 2.5*, respectively.

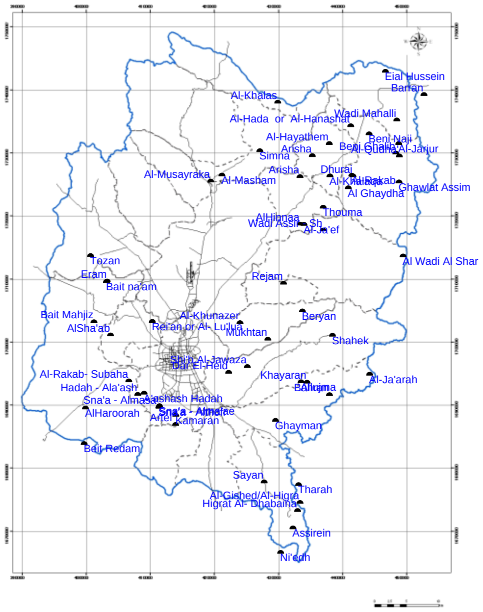


Figure 2.4 Locations of Dams

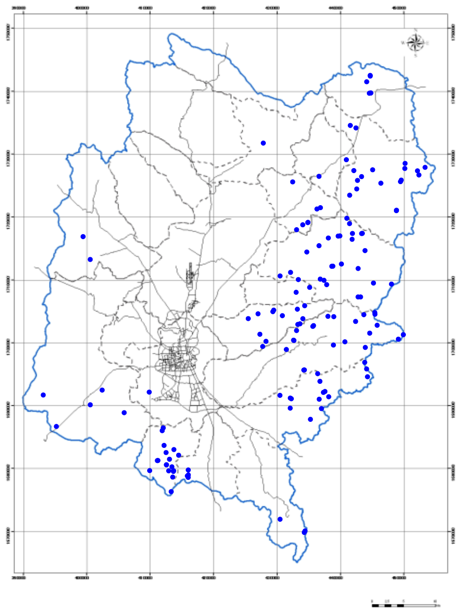


Figure 2.5 Locations of Springs

Most of dams are constructed to recharge groundwater. 15 dams of them are also used for irrigation and only three dams are used for domestic purpose. 15 dams which may be small-scale reservoirs constructed by rural people, are mainly used for irrigation purpose. Total volume of the annual flow or yield of dam sites is calculated to be 24 MCM.

Concerning springs, 51 of 145 springs, 35%, are used for irrigation, 43 springs, 30%, for animal or livestock, and 49 springs, 34%, for domestic water use for rural areas. The total yield of spring is to be 17.2 MCM annually. The volume, however, is not likely an actual annual yielding amount, because the yield of spring is fluctuating seasonally. One third to half of the amount, about 6 to 9 MCM may be an acceptable figure.

(3) Potential of Surface Water

As mentioned in previous section, the annual runoff was estimated to be between 27 MCM and 40.9 MCM depending on the applied methods. While usage amount of surface water was estimated to be 24 MCM/year through dams and 6 to 9 MCM/year from springs. The fact indicates that, more than 75% of surface water resources has been already utilized.

Therefore, it can be concluded that there is no enough potential to more develop the surface water inside Sana'a Basin.

2.2.2 GROUNDWATER

(1) Recharge

Since 1970s, several studies have estimated the amount of groundwater recharge in the Sana'a Basin. Applied method for the estimation is categorized into two types, one is the method based on the Darcy Law, another one is the method using recharge coefficient. *Table 2.4* describes the recharge amount estimated in the previous studies.

Table 2.4 Estimation of Groundwater Recharge in the Sana'a Basin

Study	Term	Organization	Consultant	Method	Estimated Recharge (Mm^3/y)
Water Supply for Sana'a and Hodeida. Sana'a Basin Groundwater Studies	1970-1973	NWSA	Italconsult	Darcy	59
Water Supply for Sana'a Phase 2	1980, 1983	NWSA	Howard and Humphreys & Sons	Darcy	45-28
Sana'a Basin Water Resources Scheme	1986	MAF	Mosgiprovodkhoz	Recharge Coefficient	63
Assistance to the High Water Council in the Preparation of a Water Master Plan	1988-1992	HWC	Individual Experts	Recharge Coefficient	42
Sources for Sana'a Water Supply (SAWAS)	1987-1996	NWSA	TNO Institute of Applied Geoscience	Darcy	35
Sana'a Basin Water Resources Management Study (SBWRM-PPT)	2001	NWRA	Sana'a University, WEC	Recharge Coefficient	46
Water Balance and Hydrological Monitoring (SBWMP)	2007	NWRA	Dr. A.Norman and Eng. W. Mulat	Recharge Coefficient	50.7

Estimated amount using the Darcy Law is based on the transmissivity and assumed simplified aquifer. On the other hand, the recharge coefficients applied for estimation are the empirical values, which are not obtained experimentally. Though there are some assumptions for the estimations, the values calculated, which widely ranges from 28 to 63 MCM annually, are reasonable from the hydrogeological point of view. In this study, the latest figure that is 50.7 MCM/year is adopted as an annual recharge amount inside Sana'a Basin. Because the amount is calculated on the basis of recharge amount estimated each sub-basin as shown in *Table 2.5*, which can be utilized for sub-basin-wise consideration for water resources management.

Table 2.5 Estimated Groundwater Recharge in Sub-Basins

No	Sub Basin	Estimated Recharge (Mm^3)
1	Wadi al Mashamini	0.86
2	Wadi al Madini	2.73
3	Wadi al Kharid	1.76
4	Wadi al Ma'adi	1.71
5	Wadi A'sir	4.27
6	Wadi Khulaqah	1.54
7	Wadi Qasabah	0.83
8	Wadi al Huqqah	1.36
9	Wadi Bani Hwat	5.58
10	Wadi Thumah	1.00
11	Wadi as Sirr	3.81
12	Wadi al Furs	0.79
13	Wadi al Iqbal	2.31
14	Wadi Zahr & al Ghayl	7.11
15	Wadi Hamdan	0.82
16	Wadi al Mawrid	1.54
17	Wadi Sa'Wan	1.41
18	Wadi Shahik	4.12
19	Wadi Ghayman	1.24
20	Wadi al Mulakhy	1.66
21	Wadi Hizyaz	1.92
22	Wadi Akhwar	2.32
Total		50.7

Source; Dr. A.Norman and Eng. W. Mulat (2007), Water Balance and Hydrological Monitoring

The recharge amount applied in the study that is 50.7 MCM/year was estimated using the precipitation data from 1991 to 2003. Although the decreasing precipitation has been pointed out, it is rather difficult to mention about long-term tendency of precipitation as shown in *Table 2.2* and *Figure 2.2*. Therefore, it is assumed in this study that this recharge amount would be continued.

In addition to the recharge by infiltration of precipitation, return flow of irrigation and infiltration of treated wastewater used to be regarded as recharge amount in some studies. Though there is a possibility to be recharged, this amount is not considered as source of recharge in this study. Because the improvement of irrigation efficiency makes the recharge amount small and treated wastewater will be used for irrigation purpose in future and considering being in the safe side.

(2) Groundwater Storage

With regard to the groundwater storage (S_t), two values were estimated with the equation of $S_t = AHS_y$, where, A is the area of aquifer, H is saturated thickness and S_y is specific yield, or effective porosity as described in Chapter 3 in the Supporting Report. The estimated value in TS-HWC (1992) is that the storage is 6,047 MCM and the usable storage is 3,221 MCM in the Sana'a Basin. Then, WEC (2001) has revised the approach and estimated the storage volume of each groundwater province in the Basin. As a result, the storage and the usable storage are estimated at 10,424 MCM and 5,212 MCM, respectively. However, as mentioned in these previous studies, the assumptions used for estimations are fairly rough figures. Therefore, further study is required.

In this chapter, the latest estimated usable storage, that is, 5,212 MCM is adopted, since this volume was revised previous study in the year 1992 by using updated water levels, though the assumptions used for this estimation still remain in rough and ready estimates.

2.2.3 TREATED WASTEWATER

Sana'a Wastewater Treatment Plant (WWTP) is located adjacent to the International Airport with design capacity to treat 50,000 m^3/day of sewage water which comes from the Sana'a City. According to the data from Sana'a Water and Sanitation Local Corporation (SWSLC), who operates the WWTP, the volume of sewage water that have reached the WWTP is 16 MCM (44,000 m^3/day) in the year 2006. However, the WWTP is operating in an overloaded condition in terms of BOD5-load, as explained in Chapter 5 in the Supporting Report and the wastewater improperly treated is discharged to the wadi via a lagoon. This improperly treated wastewater flows by gravity to the downstream through an open channel and farmers are using this water to irrigate their lands and finally it is collected at Al Mashan Dam which is located 12 km downstream of the WWTP. A very small amount of treated water is also used to water trees lining streets and green areas in the city.

Upgrading of WWTP to treat all influent wastewater to an acceptable quality following international standards for reuse in agriculture and watering trees is ongoing. Plans for construction of two new treatment plants are under preparation. One is with daily treatment capacity about 500 m^3/day, with objective to treat sewage brought by tankers from cesspits of the city and other with treatment capacity of 105,000 m^3/day.

Consequently, in an actual condition, the treated wastewater cannot be accounted as a usable water source. In the near future, however finishing the upgrade of present WWTP and construction of new treatment plant, the treated wastewater could be accounted as a water source for irrigation and the expected quantity is a minimum of 18.3 to a maximum of 56.6 MCM/year

2.2.4 ALTERNATIVE WATER SOURCE OUTSIDE SANA'A BASIN

Since the serious depletion of water resources in Sana'a Basin has been well known, the studies on the alternative water sources for Sana'a city from outside of Sana'a Basin have been conducted including desalination as one of the solutions. These alternatives are categorized into four groups and were studied by SAWAS (1996). *Figure 2.6* shows the locations of these alternatives. *Table 2.6* shows the results of the previous studies.

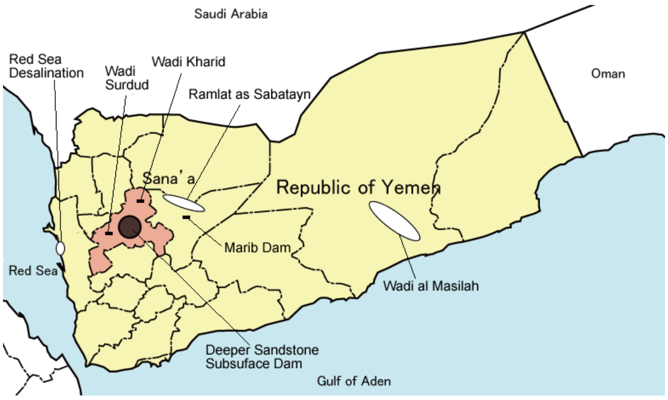


Figure 2.6 Locations of Alternative Water Sources

Table 2.6 List of Alternative Water Sources

Source		Production Capacity *1	Construction Cost	Recurrent Cost	Unit Cost for Water		Cost/ Public *3	Legal Feasibility Appreciation			Restriction
		litter/sec	Million US?$	Million USS$	US$/m³ *1	YR/m³ *2		Source of Water	Transport System	Protected Zone	
1	Wadi Kharid Dam	250	87.2	10.68	1.32	145	5.6	positive	complex	positive	- It will reduce availability of water along this wadi. Use of water of dam is known to be disputed between two tribes
2	Wadi Surdud Dam	500	230.6	32.62	2.03	223	8.7	complex	complex	positive	-This affects groundwater recharge in Tihama area
3	Diversion from Mareb Dam	500	284.4	37.58	2.33	256	10	complex	complex	negative	-Forceful objection from the farmers in the Mareb area can be expected. -It was not able to satisfy the requirement for irrigation in the down stream area
4	Deeper Pre-Jurassic Sandstone	100	60.3	7.68	2.41	265	10.4	normal	complex	positive	-A growing fear among the population that their sources will dry up
5	Desalination (Red Sea)	500	902.9	124.28	7.63	839	32.9	positive	complex	n.a.	- Water has to be lifted nearly 2700m with approximately 150km transmission
6	Ramlat as Sabatayn Area	Feasibility Study is planned by NWRA						-	-	-	
7	Wadi Al Masilah, Hadramawt	not designed yet						-	-	-	- almost 700km transmission in straight line

Note: *1) SAWAS Technical Report No.14, Costs are based on the price level of April 1996.
*2) Exchange rate, 110YR/US$ in the year 1996 is applied.
*3) Public means the tariff of public water supply, 25.5 YR/m³ in the year 1998

Total of expected production capacity that is around 58 MCM/year is possible to cover present water consumption in Sana'a city that is 54.2 MCM in 2005. However, in order to cover the demand in the year 2020 that is 69 MCM, both alternative sources and groundwater resources inside Sana'a Basin should be used.

The construction cost, recurrent cost and unit cost for water were calculated on the basis of the price level of April 1996 with the exchange rate of 110 YR/US$. According to the information from SWSLC, water tariff composed of water supply cost and sanitation cost for the consumed volume from 0 to 10 m^3 was 25.5 YR/m^3 in the year of 1998. Water tariffs of alternative water sources are from 5.6 to 10.4 times of that of public water supply with the source of surface water and groundwater. As for desalination system transferring water from Red Sea to Sana'a city, the difference of tariff is more than 32 times of public water supply. The qualitative appreciation of obtaining the required rights, that is, the water rights, the transport rights and establishing the protection zones was also carried out for each source. Obtaining the transport rights were regarded as "complex" for all alternatives by SAWAS (1996). In addition, some restrictions are noted for each alternative which are the expectation of reduction of groundwater recharge in the down stream, forceful objection from the farmers and so on.

As for water supply project of which maintenance and operation cost is principally borne by the beneficiaries, financial evaluation is generally based on the affordability to pay and the willingness to pay from the view point of possibility to cover the cost by water tariff. Assuming that the water tariff in the year 1996 was set considering these, overload to the beneficiaries was too large to pay for water supplied by alternatives. The cost of the materials has been inflated more than 3 times depending on the sorts comparing that in 1996 and the exchange rate of local currency to US$ has been dropped. In addition, the tariff of electricity for commercial consumption has been increased from 7 YR/kW in 1996 to 17 YR/kW in 2007. Considering these economical change, it could be mentioned that the cost of construction and water tariff should obviously become higher than before. On the other hand, water tariff including sanitation is 63 YR/m^3 and 81 YR/m^3 in 2007 for the consumption from 0 to 5m^3 and from 5 to 10 m^3, respectively. The tariff has become more than twice or three times depending on the consumption comparing that in 1998.

Considering these changes in financial situation, implementation of the alternatives for water supply should be concluded to be not feasible from the view point of financial evaluation for operation and maintenance, even if the adverse impact on the social and environmental aspect is mitigated.

In addition to the studies carried out by SAWAS (1996), NWRA has planned to carry out studies on the feasibility of other two groundwater exploitations outside of Sana'a Basin, namely Ramlat as Sabatayn Area and Wadi Al Masilah, Hadramawt as shown in *Figure 2.6* and *Table2.6*.

As for the Ramlat as Sabatayn, it is expected that there is enough potential to transfer water from the Quaternary deposit, limestone of Amran Group and Mukalla sandstone. This alternative requires transferring water more than 120km long and lifting up more than 1,500 m in height. Since the condition of transmission of water is more difficult than that of groundwater sourced alternative namely, "deeper pre-Jurassic sandstone" in *Table 2.6*, water tariff is estimated at more than 2.41 US$/$m^3$ as of 1996.

Another groundwater sourced alternative namely, Wadi Al Masilah, Hadramawt, which was discovered by Canadian oil company during their oil exploration in 1990s, is expected to have enough potential to supply water to Sana'a city. However, this alternative requires transferring water more than 700 km with lifting up it around 2,000 m. Therefore, water tariff is also estimated to be more than that of the "deeper pre-Jurassic sandstone" alternative.

Therefore, it is preliminarily mentioned that feasibility of these two alternatives are also very low.

Consequently, these alternative water sources could not be one of the solutions to supply water to Sana'a city unless the financial aspect is solved first in a proper way.

2.3 PRESENT WATER USE

2.3.1 DOMESTIC WATER USE

(1) Urban Water Supply

1) Public Water Supply

The main source of the public water supply for Sana'a City, which is operated by SWSLC, is groundwater abstracted from three main well fields called Eastern well field, Western well field and Sana'a well field. SWSLC posses around 130 wells, of which around 80 wells are functioned and the remaining are not functioned due to decrease of the production (decreasing of the water level), technical problems and failure of drilling.

Production of water for Sana'a City water supply for the past nine years is shown in *Table 2.7*.

Table 2.7 Production and Consumption of Water (1988-2006)

Year	No. of wells	Water Produced	Water Consumed
1998	56	19,146,980	13,231,847
1999	62	17,289,380	12,201,750
2000	63	17,304,271	11,343,467
2001	64	16,779,443	10,336,823
2002	65	18,468,664	11,771,810
2003	68	20,320,782	12,868,174
2004	78	21,843,914	13,222,526
2005	77	24,347,334	13,785,339
2006	78	24,083,969	14,744,341

Source: Sana'a Water and Sanitation Local Corporation Unit: cubic meters

During the period of 1998 and 2006, production of water has increased by 26% and number of wells operating has increased by 39%. The production amount in the year of 2005 is reported to be 24.4 MCM of which 12.5 MCM is billed amount of domestic consumption and supplied for 672,141 inhabitants with unit consumption of 50.8 l/c/d.

2) Private Water Supply

Estimated population of Sana'a city for 2005, based on 2004 census data, is 1.84 million inhabitants and the population covered by the public network is 672,141 inhabitants. Around 1.17 million inhabitants were not connected to the public water supply system. These inhabitants were obtained water from private water sources, namely private piped network, water tankers and treated water in containers. Consumption of domestic water from private water supply was estimated in the year of 1997 adopting an average per capita consumption of 70 l/c/d as described in Chapter 5 in Supporting Report.

Water consumption from private water supply is estimated as shown in *Table 2.8*, adopting an average per capita of water consumption of 70 l/c/d.

Table 2.8 Domestic Water Consumption from Private Water Supply

Source	Year	Total Estimated Population (inhabitants)	Population served (inhabitants)	Average per capita water consumption (l/c/d)	Water consumption MCM/year
(1)	1997	1,123,942	292,225	70	7.45
	2005	1,640,091	539,401	70	13.78
(2)	2005	1,841,562	1,169,421	70	29.89
	2006	1,937,783	1,241,642	70	31.70

Source: (1) Dar Al-Handasah (2000): Population Based on 1975, 1986, 1994 Census, before modification of district boundaries. Population for 1994 was 954,448

(2) Study Team. Population based on 2004 Census, after modifications of district boundaries. Population for 1994 was 1,003,627

(2) Rural Water Supply

Planning and execution of rural water supply projects are made by General Authority for Rural Water Supply Projects (GARWSP), the responsible body for rural water supply. However, no suitable data or study was available regarding water use condition for rural water supply.

WEC (2001) has carried out the estimation of water consumption by water-use zone with the per capita consumption of water of 21 l/c/d for rural area, after the estimation of the population inside Sana'a Basin by districts and water-use zones. However, GARWSP adopted an average per capita of water consumption of 40 l/c/d and 2.5% of population growth rate for the rural area.

Therefore, in this study, unit water consumption and population growth rate used by GARWSP are adopted and water demand is estimated based on the population of each sub-basin. *Table 2.9* shows the estimated domestic water consumption for rural area.

Table 2.9 Estimated Domestic Water Consumption for Rural Areas

Sub-Basin		2004		2005		2006	
		Population	Water Consumption	Population	Water Consumption	Population	Water Consumption
1	Wadi Al Mashamini	5,346	78,051	5,480	80,002	5,617	82,002
2	Wadi Al Madini	13,674	199,641	14,016	204,632	14,366	209,747
3	Wadi Al Kharid	9,067	132,384	9,294	135,694	9,526	139,086
4	Wadi Al Ma'adi	2,360	34,451	2,419	35,312	2,479	36,195
5	Wadi A'sir	4,449	64,951	4,560	66,575	4,674	68,240
6	Wadi Khulaqah	1,645	24,024	1,687	24,625	1,729	25,240
7	Wadi Qasabah	4,511	65,866	4,624	67,513	4,740	69,201
8	Wadi Al Huqqah	11,545	168,564	11,834	172,778	12,130	177,097
9	Wadi Bani Huwat	14,647	213,848	15,013	219,194	15,389	224,674
10	Wadi Thumah	2,008	29,319	2,058	30,052	2,110	30,803
11	Wadi As Sirr	34,529	504,120	35,392	516,723	36,277	529,641
12	Wadi Al Furs	9,937	145,080	10,185	148,707	10,440	152,425
13	Wadi Al Iqbal	25,552	373,057	26,191	382,383	26,845	391,943
14	Wadi Zahr & Al Ghayl	39,299	573,758	40,281	588,102	41,288	602,805

Sub-Basin		2004		2005		2006	
		Population	Water Consumption	Population	Water Consumption	Population	Water Consumption
15	Wadi Hamdan	7,355	107,383	7,539	110,068	7,727	112,820
16	Wadi Al Mawrid	10,566	154,259	10,830	158,115	11,101	162,068
17	Wadi Sa'wan	18,841	275,082	19,312	281,959	19,795	289,008
18	Wadi Shahik	27,327	398,975	28,010	408,949	28,710	419,173
19	Wadi Ghayman	17,874	260,967	18,321	267,492	18,779	274,179
20	Wadi Al Mulaikhy	7,277	106,251	7,459	108,908	7,646	111,630
21	Wadi Hizyaz	10,498	153,274	10,761	157,106	11,030	161,034
22	Wadi Akhwar	16,424	239,790	16,835	245,785	17,255	251,930
Total		294,733	4,303,095	302,101	4,410,672	309,653	4,520,939

Unit: Population: inhabitants, Consumption: cubic meters per year

Source: Population of 2004: calculated based on 2004 Census results and for 2006 was estimated adopting population growth rate of 2.5%, which is adopted by GARWSP

Water Consumption: calculated adopting average per capita water consumption of 40 l/c/d, which is adopted by GARWSP for water supply projects

Note that the results of the above table should be considered as a rough estimation of quantity of water abstracted to cover the rural population independent of the source of water. Detailed information such as total number of population benefited by the public water supply system and/or private water supply, location of each water supply projects carried and so was not available. However, according to the NWSSIP, the percentage of rural population with access to safe water accounts only to 25% for entire Yemen. Applying this rate for Sana'a Basin in the year of 2005, it results in 75,526 inhabitants with access to safe water, which means 1.1 MCM of water abstracted to serve the population through the public water supply system.

2.3.2 AGRICULTURAL WATER USE

Annual water consumption for irrigation purpose, which was estimated by WEC-ITC (2001) by calculating the actual evapotranspiration (ETa) through analysis of cropping pattern based on the satellite imagery analysis, was calculated 151.4 MCM adopting 40% as the irrigation water efficiency. The well inventory (2002) has estimated at 217.5 MCM for the annual water abstraction through interviews to the owner of wells and on-site measurement. Approaches and methodologies for the estimation of these studies are different. Then GAF (2007) has estimated at 139.47 MCM applying the 60% as irrigation water use efficiency, for annual water consumption of irrigation purpose by same methodology as WEC-ITC (2001) by sub-basin.

As for irrigation water use efficiency, adopted value is different study by study. In this study, the irrigation water efficiency of 40% is adopted considering following conditions.

According to MWE (2006), the main irrigation methods used inside Sana'a Basin are furrow and small basin methods and farmers use surface irrigation by applying a sheet of water to the fields up to knee height, therefore the field application efficiency is very low and might reach 45%. While the conveyance used for irrigation are iron and plastic pipes with considerable amount of water leakage and earth channels crossing tracks with long distance causing infiltration, evaporation and run off losses. Consequently, the scheme efficiency is very low for surface irrigation and might be between 30 to 40 %.

According to FAO, the field application efficiency for surface irrigation such as border, furrow and basin is 60% and it may be lower if the level of farmers discipline is not satisfied.

Therefore, irrigation efficiency of 60% adopted by GAF (2007) is relatively high to apply to the irrigation activities in Sana'a Basin

Irrigated area and quantity of water consumed by agriculture for each sub-basin is shown in *Table 2.10*.

Table 2.10 Irrigated Area and Water Abstraction of each Sub-Basin

Source		WEC-ITC (2001)		Well Inventory 2002		Modified GAF (2007)	
Year		2000*		2002		2004/2005**	
Sub-Basin		Irrigated area	Abstraction	Irrigated area	Abstraction	Irrigated area	Abstraction
1	Wadi Al Mashamini	-	-	78	0.5	69	**0.89**
2	Wadi Al Madini	663	1.5	412	2.6	352	**4.53**
3	Wadi Al Kharid	659	4.2	408	3.6	238	**3.03**
6	Wadi Khulaqah			285	2.4	181	**2.33**
4	Wadi Al Ma'adi	187	0.8	455	2.2	100	**1.29**
5	Wadi A'sir	1,108	11.7	516	6.9	593	**7.65**
7	Wadi Qasabah	3,181	15.0	226	2.1	186	**2.40**
8	Wadi Al Huqqah			1,935	14.8	1,176	**14.48**
13	Wadi Al Iqbal			2,871	15.9	1,538	**34.87**
9	Wadi Bani Huwat	5,561	22.7	6,888	55.9	4,826	**33.71**
10	Wadi Thumah	393	2.0	286	2.1	126	**12.08**
11	Wadi As Sirr	3,461	33.4	3,874	39.7	2,603	**16.56**
12	Wadi Al Furs	1,198	11.9	1,302	13.2	856	**5.74**
14	Wadi Zahr & Al Ghayl	2,387	27.6	1,524	11.1	1,297	**16.30**
15	Wadi Hamdan	774	7.1	312	1.8	789	**10.16**
16	Wadi Al Mawrid	1,081	5.5	811	8.5	739	**8.76**
17	Wadi Sa'wan	870	2.7	1,442	7.5	1,055	**10.05**
18	Wadi Shahik	650	1.3	1,454	10.5	1,032	**10.30**
19	Wadi Ghayman	893	2.6	590	3.8	533	**5.50**
21	Wadi Hizyaz			279	2.7	206	**2.64**
22	Wadi Akhwar			419	7.3	191	**2.45**
20	Wadi Al Mulaikhy	314	1.4	211	2.4	269	**3.48**
Total		23,380	151.4	26,577	217.5	18,953	**209.20**

Unit: area in hectare, abstraction in million cubic meters

* Estimated adopting irrigation efficiency of 40%, ** Estimated adopting irrigation efficiency of 40%

2.3.3 INDUSTRIAL WATER USE

Water supply for industries from public network is very few according to information from SWSLC. Water for most of the industries is supplied by their own well and it is supposed that the water abstraction is unregulated and unrecorded. Consequently, information regarding industrial water consumption is very scarce. Due to lack of information, TS-HWC (1992) and WEC (2001) have estimated the water requirement for industrial sector by using "Gross Water Requirement Method" which depends on (a) average water requirement per unit of physical output in various industrial sub sectors and (b) the physical outputs of the different industrial products.

In this study, present water demand for industrial sector, which is shown in *Table 2.11*, was estimated based on the results of the study carried out by WEC (2001) which used an alternative approach involving the use of "gross value of production (GVP)"and the "gross water requirement method". Due to unavailability of recent data regarding GVP of industries within Sana'a Basin, estimation of water required up to 2005 was estimated based on results of 1995.

The condition of the calculation is mentioned in section *5.5* "Industrial Water Use" in Supporting Report.

Table 2.11 Estimated Water Consumption for Industrial Sector in 2005

Industrial sub-sector	Manufacturing		Mining and quarrying		Total Water Requirement
Year	Gross Value Output	Water Requirement	Gross Value Output	Water Requirement	
1995	14,484.291	3.29	485.192	0.00157	3.29
1996	14,894.196	3.38	532.741	0.00172	3.38
1997	15,315.702	3.48	584.949	0.00189	3.48
1998	15,749.137	3.57	642.274	0.00208	3.58
1999	16,194.837	3.67	705.217	0.00228	3.68
2000	16,653.151	3.78	774.329	0.00250	3.78
2001	17,435.849	3.96	821.563	0.00265	3.96
2002	18,255.334	4.14	871.678	0.00282	4.14
2003	19,113.335	4.34	924.850	0.00299	4.34
2004	20,011.661	4.54	981.266	0.00317	4.54
2005	20,952.210	4.75	1,041.124	0.00336	4.76

Unit: Gross value: Million Yemeni Rials,
Water requirement: million cubic meters

2.3.4 TOURISTIC WATER USE

No studies have been carried out to estimate the water requirements for tourism sector. Due to unavailability of data, water consumption for 2005 has been estimated under many presupposed conditions as shown below and estimated water consumption of touristic sector is shown in *Table 2.12*.

- Occupancy rate of beds assumed as 40%
- Five and four stars hotels provide in general more water consuming accommodations than hotels of lower standard. Average per capita of water consumption assumed for five and four stars hotels is 350 l/c/d and for three to one star hotels, average of 180 l/c/d was assumed[1]. Consumption of water by traditional hotels is expected to be lower than other hotels and unit consumption was assumed at 120 l/c/d.
- All hotels of Sana'a City and Sana'a were included in estimation presupposing that most of hotels of Sana'a are located around the City.
- According to water usage condition survey carried in this study, five stars hotels were not connected to public water supply network and it is supposed that four stars hotels also were not connected to the public network. Number of hotels connected in to the public network is unknown

Table 2.12 Estimated Water Consumption for Touristic Sector in 2005

Classification	Total Hotels (no)	Total Number of Beds (no)	Beds Occupied (no)	Unit Water Consumption (l/c/d)	Total Water Consumption (MCM)
Traditional	44	3,653	1,461	120	0.06
One Star	126	4,420	1,768	180	0.12
Two Stars	45	2,570	1,028	180	0.07
Three Stars	25	1,250	500	180	0.03
Four Stars	19	650	260	350	0.03
Five Stars	3	921	368	350	0.05
Total	262	13,464	5,386		0.36

2.4 WATER BALANCE

2.4.1 WATER BALANCE ENTIRE SANA'A BASIN

Since the imbalance between groundwater recharge and water abstraction was pointed out, more than decade has been already past. Water balance in Sana'a Basin is calculated in this study based on the existing data and present water use that is described in section 2.2 and 2.3 in this Chapter. The abstraction amount is almost six times of recharge amount as shown in *Table 2.13*.

Table 2.13 Water Balance in Sana'a Basin (2005)

Urban water use*		Rural water supply	Irrigation	Industry	Tourism	**Total**	Recharge	**Balance**
Public	Private							
24.3	29.9	1.1	209.2	4.76	0.36	**269.6**	50.7	**-218.9**

*: It is composed of both domestic and non-domestic
Unit: million cubic meter

Such imbalance means that non-renewable water resources are consumed every year. If these annual amount is accumulated, non-renewable water resources will continue to be depleted.

2.4.2 WATER BALANCE IN EACH SUB-BASIN

The water balance in the Sana'a Basin was calculated by the previous studies. The two types of detailed water balance evaluation in sub-basins have been provided recently by the parts of SBWMP, one is the hydrological approach adopted in Norman and Mulat (2007), and another one is based on the satellite imagery analysis, GAF (2007).

Water balance studied by Norman and Mulat (2007) is calculated by the recharge minus the abstraction from well. The balance studied by GAF (2007) is that using irrigated area and the actual evapotranspiration estimated by the satellite imagery analysis, the amount of water for agriculture use, which was supposed to be abstracted all by wells, were calculated assuming the irrigation efficiency of 60%. Since this water balance is obtained only using the water use for agriculture, consumption for other purposes was added. *Table 2.14* describes the calculated water balance by two previous studies

Table 2.14 Water Balance in Sub-Basins by Hydrological Approach

	Sub-Basin	After Norman and Mulat (2007)						After GAF (2007)			
		Recharge (Mm^3)	Abstraction (Mm^3)	Return Flow (30%) (Mm^3)	Consumed Volume (Mm^3)	Revised Balance (Mm^3)	Comsumed Ratio /Recharge	Rainfall (Mm^3)	Agriculture Water Use (Mm^3)	Total Water Use (Mm^3)	Water Use/Rainfall
1	Wadi Al Mashamini	0.9	0.85	0.26	0.6	0.3	0.66	22.6	0.6	0.7	3.1%
2	Wadi Al Madini	2.73	2.92	0.88	2.04	0.68	0.75	62.3	3	3.2	5.1%
3	Wadi Al Kharid	1.76	3.36	1.01	2.35	-0.59	1.33	26.7	2	2.2	8.2%
4	Wadi Al Ma'adi	1.71	2.67	0.8	1.87	-0.16	1.10	22.5	0.9	0.9	4.0%
5	Wadi A'sir	4.27	6.93	2.08	4.85	-0.58	1.14	52.4	5.1	5.2	9.9%
6	Wadi Khulaqah	1.54	2.12	0.64	1.48	0.06	0.96	13.6	1.6	1.6	11.8%
7	Wadi Qasabah	0.83	2.12	0.64	1.48	-0.65	1.78	16.2	1.6	1.7	10.5%
8	Wadi Al Huqqah	1.36	17.36	5.21	12.15	-10.79	8.91	31.4	9.7	9.9	31.5%
9	Wadi Bani Huwat	5.58	60.87	18.26	42.61	-37.03	7.64	67.4	32.4	51.8	76.9%
10	Wadi Thumah	1	3.25	0.98	2.28	-1.27	2.27	16.2	0.8	3.1	19.1%
11	Wadi As Sirr	3.81	39.06	11.72	27.34	-23.53	7.17	54	16.5	17.2	31.9%
12	Wadi Al Furs	0.79	13.6	4.08	9.52	-8.73	12.02	8.5	5.7	5.9	69.4%
13	Wadi Al Iqbal	2.31	17.46	5.24	12.22	-9.91	5.29	61.9	13.1	13.5	21.8%
14	Wadi Zahr & Al Ghayl	7.11	16.51	4.95	11.56	-4.44	1.62	132.1	10.9	12	9.1%
15	Wadi Hamdan	0.82	7.47	2.24	5.23	-4.41	6.36	18.9	6.8	7.6	40.2%
16	Wadi Al Mawrid	1.54	35.4	10.62	24.78	-23.24	16.04	48	5.8	90.9	189.4%
17	Wadi Sa'wan	1.41	8.82	2.65	6.17	-4.76	4.37	21.9	6.7	7.2	32.9%
18	Wadi Shahik	4.12	10.41	3.12	7.29	-3.16	1.77	69.9	6.9	8.3	11.9%
19	Wadi Ghayman	1.24	4.23	1.27	2.96	-1.72	2.39	41.6	3.7	3.9	9.4%
20	Wadi Al Mulaikhy	1.66	2.96	0.89	2.07	-0.41	1.25	22.8	2.3	2.4	10.5%
21	Wadi Hizyaz	1.92	3.17	0.95	2.22	-0.3	1.16	21.9	1.8	1.9	8.7%
22	Wadi Akhwar	2.32	8.44	2.53	5.91	-3.59	2.55	34.7	1.6	1.9	5.5%
Total		50.7	270	81	189	-138.2	-4.02	867.2	139.5	253.1	29.2%

Source; Modified Norman and Mulat (2007); Modified GAF (2007)

As shown in *Table 2.14*, difference between recharge and abstraction is different sub-basin by sub-basin. This tendency implies that these high imbalanced sub-basins would be early affected by severe water scarcity unless appropriate measures are taken.

REFERENCES

[1] Digital National Water Master Plan (2004) Ministry of Water and Irrigation, The Hashemite Kingdom of Jordan