Estimation of Groundwater Resources in Kathmandu Valley, Nepal

— from the watertable fluctuation and the natural discharge —

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カトマンズ盆地の地下水賦存評価

Abstract

The fluvio lacustrine deposits of the Kathmandu Valley, Nepal are divided into four zones in terms of aquifer distribution. Deep confined aquifer in the south, GRI, medium depth interbedded aquifer, GRII, shallow unconfined aquifer in the north, GRIII and an unconfined aquifer of thin sand and gravel deposit widely distributed on the surfaces of the terraces and other locations.

Surface sediment deposits of fine to medium grain size referred to as surface gravel deposits, supply considerable quantity of water for residents of the valley through “*Dharas*” (stone spouts) and wells at superficial depths. The discharge is reported to double during monsoon period. General quality of water from these sources is considered good with some exceptions.

For some years now, underground water source is believed to contribute about 40% of the city water supply. This is aggregated even further by pumping of the water in the private household with overdrafting going on for sometime. This overdrafting can be observed from the declining trend of the water levels in the tube wells. The total dynamic reserve of the valley is 12,730 m³/day. The average amount of infiltration from the rainfall is 17.2%.

The discharge from “*Dharas*” adds to 1380 m³/day. Hence if the ground water is properly managed, overdrafting may not be necessary. Multipurpose projects specially in the northern zone should help induce artificial recharge. Otherwise, Kathmandu may face a potential disaster in the near future.

Key Words: Kathmandu, unconfined aquifer, discharge, overdrafting, artificial recharge.

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要旨

ネパール国カトマンズ盆地には礫層を主体とした鮮新・更新統が広く発達している。この礫層は、盆地北部では不圧地下水の帯水層で、南部では被圧地下水の帯水層を形成し、その中間の中央部では半被圧帯水層となっている。これらの帯水層には15m程度の井戸が掘削され、主として飲雑用水として利用されている。盆地全体の地下水流動量は1,380 m³/dayであるが、雨期にはほぼその2倍に増大する。しかしながら、カトマンズ盆地の水利用量の40%をしめる地下水使用量の増加によって、水位低下などの障害が心配されてきた。そこで、特に北部についてはマルチパーパス計画を行うべきである。

I. Introduction

I-1 Background

Kathmandu valley is a large intermontane basin lying in the central part of Nepal with coordinates 85°11'–85°34' E Longitudes and 27°32'–27°49' N Latitudes as shown in Fig. 1.

Valley basement and surroundings consist of rocks of Phulchowki Group of Kathmandu Complex. The rock types consist of limestones, phyllite, sandstones etc. Only a few formations of the Phulchowki Group are exposed in the valley. The northern rim of the valley consists of granite and migmatites which have intruded into the rocks of Phulchowki Group. Thick fluvial lacustrine deposits of Neogene to Quaternary in age fill the valley. The fluvio lacustrine deposits of the valley are believed to lie unconformably on the Paleozoic Kathmandu Complex and also partly on granite (YOSHIDA M. and IGARASHI Y., 1988).

Sharma and Singh (1966) compiled the groundwater exploratory drilling results in the Kathmandu Valley and confirmed that potential zones for development of ground water are confined to the northern part of the valley (KARMACHARYA, 1990). The aquifer zones in the northern area of the valley have enough volume and permeability for future water supply (DHOUBHADEL T., 1988).

In 1990, the authors investigated the flow and

quality of groundwater from the dug wells and *Dharas* (stone spouts) distributed in the Kathmandu valley limited to the surface sediments upto 15m depth, as a part of Karmacharya's master thesis work.

I-2 Geomorphology and sediment distribution

The valley occupies a large area of about 585 sq. Km.. It consists of three large cities, Kathmandu, Patan and Bhaktapur and numerous other small towns and villages. It is surrounded by high mountains of lesser Himalayas ranging in altitudes from 2000m to 2765m. the highest being Phulchowki Range (2765m). Besides these, many spurs intrude into the valley dividing it into many smaller valleys. Drainage pattern is nearly of centripetal type with the streams from all directions flowing towards the centre of the valley joining the main Bagmati River, which drains out of the valley through Chobhar gorge in the south. The geomorphic surface consists of number of terraces.

The fluvio lacustrine deposits of the valley have been divided into eight stratigraphic units as follows: Lukundol Formation, Pyangaon Terrace Deposits, Chapagaon Terrace Deposits, Boregaon Terrace Deposits, Gokarna Formation, Thimi Formation, Patan Formation and Lower Terrace Deposits (YOSHIDA M. and IGARASHI Y., 1984). The Lukundol Formation consists of clay, silt and sand beds with lignite layers and is exposed on

Fig. 1 Water table contour map prepared from dug wells and "Dhunge Dharas" distributed in Kathmandu Valley. The contours are in met.above MSL.

the southern region of the valley (TULADHAR R., 1982). Many vertebrate fossils have been reported from this formation.

Pyangaon, Chapagaon and Boregaon terrace deposits are distributed in the southern most end of the valley and consist of fine grained to pebble and cobble size sediment considered less permeable due to clay layers in them. The boundary between them are often obscure. Gokarna Formation

is distributed on the north of the valley and consists of arkosic sand, silty clay and peat and yields many pieces of carbonized fossil wood. Thimi and Patan formations are distributed around Kathmandu city and Patan city and consist of gray to light brown coloured sand, silt, clay, peat and gravel. The lower terrace deposits are exposed mainly along the Bagmati river and its tributaries (YOSHIDA and IGARASHI, 1984).

Total thickness of the above sediments exceed 455m with the thickness increasing from north to south. The northern part of the basin consists of predominantly granular deposits of deltaic deposition. Central part of the valley consists of peat, clay, sand and gravel deposits while the southern side of the valley consists thick clay layers. The sediments gradually increase in grain size towards the margin of the valley. High rainfall, centripetal drainage and nature of the sediments all favor dependable shallow groundwater resource and should be so for deep aquifers as well. Groundwater from shallow aquifer has been under exploitation for centuries and recently deep tube wells have been constructed in many parts of the valley. But the groundwater systems are yet to be studied in detail, the management and control yet to be exercised. This report attempts to shed light on the present situation regarding the exploitation and its consequences in future.

II. Aquifer setting

II -1 Aquifer distribution

Kathmandu valley has been divided into four zones in terms of aquifer distribution. According to Binnie and partners consultants, aquifer system in Kathmandu Valley can be divided into a) Deep confined aquifer in the southern zone, GR. I b) Medium depth interbedded aquifer in the central northern zone GR. II and c) Shallow unconfined aquifer in the northern most part, GR III as shown in Fig. 2 (GAUTAM R., 1988). Besides these three, thin sand and gravel deposits on the surface act as shallow unconfined aquifer and are widely distributed on the valley terraces and other locations. This zone was referred to as the surface gravel deposits by Binnie and partners consultant, 1973 (KARMACHARYA, 1990). Dharas and wells are located in this shallow aquifer. The southernmost part of the valley is referred to as the no aquifer zone due to mostly thick clay deposits. The number of aquifer horizons increases towards north and north east and hence the northern

aquifer belt is predominantly of interbedded aquifer type.

Though number of aquifer horizons exist in the north, two horizons lying at the depths of 3-37m and 55-70m. in borehole no.2, 38-120m and 131-165m. in borehole 3 and 70-116m and 133-166m in bore hole no.4 are prominent. The location of the boreholes are shown in Fig.2. In the central part, the aquifer horizons are in the form of lenses and layers. These layers in many cases pinches, bulges and are often not continuous. In the extreme south, there are no clay free granular zones. The central part of the basin consists of two aquifer horizons (Boreholes 5, 12, 18, 19, 23 and 25.). The upper aquifer horizon increases in thickness towards north and north-east while it is only 5 -9.5m in the centre part. The thickness of the lower aquifer horizon increases from north towards the centre with the thickness varying from 17 to 108m. The lower aquifer horizon is believed to be more or less continuous in east-west direction as indicated by lithological sections. In general, the number of aquifer horizons are found to decrease from north to south. The maximum cumulative thickness of the aquifer horizons in the Kathmandu Valley is found to be 145m. at Sanothimi and minimum is 17m. near Pashupatinath temple (GAUTAM R., 1988).

II -2 Water level depth

Detailed investigations were carried out by the authors on shallow ground water in the surface gravel deposits which is exploited through 'Dharas' and dug wells. Altogether forty-seven 'Dharas' and dug wells were studied. Twenty-two observations were made on 'Dharas' on terrace, nine on the slopes and four on the low lying areas. Seven dug wells on the terraces and five in the low lying areas were observed.

'Dharas' in the central part of the valley are

Fig. 2 Aquifer Divisions and Piezometric surface map of Kathamandu valley (after Gautam R., 1988)

mostly located at depth ranges of 1-5m. below ground level. A few 'Dharas' as at Naya Bazaar and Chabel (No.33 and 28 respectively) are exposed nearly on the surface. The sediments in the vicinity of the 'Dharas' consist mostly of sandy clay, silty clay, pebbles with sand, clay etc. In areas where clay is exposed, 'Dharas' are located at depths upto 5m. In 'Dharas' near the valley periphery, water flows directly as natural seepage. The flow direction is governed by the slope direction. In the central region, 'Dharas' are not natural seepages but are made to flow in excavated pits. The depth at which the water flows is considered as the water level depth in the area.

In the wells, depth to water table lies between

1-6m. below ground level. In a well at Raj Tirtha (No.38), on the bank of River Bagmati, water table lies at 1m below ground level which overflows during monsoon. The fluctuation of water level between pre-monsoon and post monsoon period is 1 to 2m. The water table map based on the depth of the spring and wells shows the flow towards the centre from the periphery much alike the drainage pattern on the surface (Fig. 1).

Bore hole at Boudha (B. H. 27) has the minimum screen depth with 2.5m, the maximum being 283m below ground level (bgl) at Lagan tole (B. H. 16). Most of the tube wells tap multi aquifers. Generally the top screens are located at shallow depths in the northern part. The static water level

depth varies from 1.5m bgl. at Chobhar (B. H. 32) to 25 m bgl. at Bansbari (B. H. 28). The static water level lies above the ground level at Gokarna (B. H. 4), Tahachal (B. H. 13), and Lagan Tole (B. H. 16) leading to flowing conditions. Depth to water level increases towards the periphery and decreases towards the centre of the valley.

The position of static water level in relation to depth of an aquifer indicates that these levels have risen to different levels above the aquifer at various locations, thus classifying the aquifers as confined (GAUTAM R., 1988). No such rise has been recorded in the tube wells close to the foothills around the valley. The confined aquifer occupy area south of Maharajgunj, west of Boudha extending up to the rim of the valley.

The piezometric surface elevation conforms to the topographic gradient decreasing towards the centre of the valley. Hence the flow is from periphery towards the centre of the valley (Fig. 2).

II-3 Yields

The discharge from the 'Dharas' is highly variable with reference to topographic position and season. In the study area this rate varies from less than $1.6 \times 10^{-5} \text{ m}^3/\text{s}$ (Tin Dhara) to $3.737 \times 10^{-3} \text{ m}^3/\text{s}$ (Matatirtha). Discharge is high on slope and low on terraces and low lying areas with about $8.33 \times 10^{-5} \text{ m}^3/\text{s}$ (KARMACHARYA, 1990). The discharge is reported to double during monsoon and post monsoon period. In the dug wells, water is withdrawn manually for domestic use and hence amount could not be calculated.

In the confined aquifer zone, the discharge from tube wells ranges from $2.0 \times 10^{-3} \text{ m}^3/\text{s}$ at Chobhar (B. H. 32) to $4 \times 10^{-3} \text{ m}^3/\text{s}$ at Manohara (B. H. 31). Free flow discharge ranges from $5.0 \times 10^{-4} \text{ m}^3/\text{s}$ at Kirtipur (B. H. 35) to $4.0 \times 10^{-3} \text{ m}^3/\text{s}$ at Lagan Tole (B. H. 16). In case of uncon-

fined aquifer, the discharge rate ranges from $8.0 \times 10^{-3} \text{ m}^3/\text{s}$ at Bansbari (Well no. 28) to about $1.1 \times 10^{-2} \text{ m}^3/\text{s}$ at Boudha (well no. 2) and Gokarna (well no. 30) (GAUTAM R., 1988).

Southern part of the valley around Sunakothi, Harishiddhi, Lubhu is considered no aquifer zone as clay is predominant. Nevertheless some potential cannot be ruled out even in this region.

II-4 Quality

Most of the water samples from the 'Dharas' appear colourless, odourless, clear and potable except for samples from locations such as Naxal and Naya Bazaar which are turbid and not potable due to suspended particles. Water temperature ranges from $16^\circ - 23^\circ\text{C}$. In samples from Matatirtha and Naudhara (Godavari), the difference between water temperature and air temperature is upto 10°C , recording low in waters. Also, in many cases, samples from different 'Dharas' in the same location differed in temperature by as much as 4°C . At Harishiddhi and Kalimati areas, most of the samples from dug wells are turbid, and yellowish in colour as they are located in yellowish clay formation. Water sample from Raj Tirtha gave foul odour of Methane.

Chemical parameters of water samples from the three aquifer divisions are given in Table 1. The physical appearance of few samples shows the water to be slightly coloured and hazy containing suspended materials. Colour units of water in confined aquifers are in the range of 23-391 which in case of unconfined aquifer is 8 (GAUTAM R., 1988).

III. Groundwater Potential

III-1 Exploitation of groundwater

Before the introduction of city water supply, people used to depend on dug wells and 'Dhunge Dharas' exploiting the surface aquifers. These sources for daily use of water were well main-

tained. With the introduction of city water supply, many of the wells and 'Dharas' were either turned into mere historical monuments or into rubbish dumps. In the past two decades, with rapid rise in urbanization and population, Water Supply and Sewerage Corporation, henceforth will be referred to as WSSC, has been unable to meet the demand for water (Table 2). Hence once again these old wells and 'Dharas' have gained their lost importance. But in many cases, the discharge from 'Dhar-

as' has drastically reduced mostly due to deep foundations of modern buildings which interrupted the flow.

III-2 Groundwater resource evaluation

Recharge sources of the aquifers in the study area are mainly two-a) rainwater and b) surface water. Infiltration can take place in the northern zone through alluvial fans and granular zones on the surface. However infiltration through fans is

Table. 1 Chemical Parameters of water samples from the three aquifer divisions In Kathmandu Valley.

Parameters	Gr.I	Gr. II	Gr. III	Potable Water Limits	
				Desirable	Permissible
Turbidity (JTU)	75 - 79	3 - 15	8 - 9	5	25
Total Hardness (mg/l)	90 - 250	25 - 60	12 - 18	100	500
Total Alkalinity (mg/l)	360 - 640	37 - 116	21 - 32	-	-
Free CO ₂ (mg/l)	125 - 220	8 - 41	5 - 12	-	-
TDS (mg/l)	384 - 600	80 - 180	62 - 86	500	1000

Source: Binnie and partners, 1988
(After Gautam R., 1988)

Table. 2 Table showing the water demand, supply and the growth in population in Kathmandu Valley.

Year	Water demand (m ³ /d)	Present supply (m ³ /d)	Deficit	Population
1981	90,000	46,000	44,000	369,000
1986	106,000	83,000	23,000	442,000
1991	126,000	126,000	-	537,000
1996	186,000	154,000	32,000	656,000
2001	272,000	154,000	118,000	802,000
2006	396,000	154,000	242,000	983,000
2011	577,000	154,000	423,000	1,205,000

Source: WSSC, Kathmandu, Nepal
(After Gautam R., 1988)

limited because of smaller areal extent and steep topography. Recharge takes place mainly in rainy season which on average lasts for three months. The recharge to the aquifer in this region has been calculated on the basis of water table fluctuation (dynamic resource) and the computation is shown below:

III -3 Dynamic reserve of shallow unconfined aquifer zone (GRIII)

Area of the unconfined aquifer $\times$ specific yield factor $\times$ water table fluctuation.

Area of the shallow unconfined aquifer zone
 $= 8\text{km}^2 = 8,000,000 \text{ m}^2$

Specific yield factor $= 20\%$
 (for sand and gravel)

Avg. water tab. fluctuation $= 1.33 \text{ m}$.
 (Avg. recorded at Sundarijal tube well)

Dynamic reserve
 $= 2,128,000 \text{ m}^3/\text{yr} = 5830 \text{ m}^3/\text{day} \text{---} -1$

In the area between Bishnumati and Manohara rivers, there are quite a few granular zones on the surface and at depth. Binnie and partners (1988) classified this zone as interbedded aquifers and have considered them as semiconfined aquifers (GAUTAM R. 1988). Gautam calculated the ground water reserve of the medium depth interbedded aquifer zone (GRII) treating it as an unconfined aquifer as in the following:

Area of the zone $= 42\text{km}^2$.

Specific yield $= 20\%$

W. table fluctuation $= 0.29 \text{ m}$

(avg. value of well no. WHO3 at Bansbari)

Thus dynamic reserve $= 243,6000 \text{ m}^3/\text{yr}$. or
 $6674 \text{ m}^3/\text{day} \text{---} -2$.

In the case of deep confined aquifer zone (GR I) in the south, dynamic reserve has been calculated on the basis of piezometric surface fluctua-

tion as follows:

Area of the confined aquifer zone
 $= 107 \text{ km}^2 = 107,000,000 \text{ m}^2$

Avg. storage coef. $= 1.64 \cdot 10^{-3}$

Water level fluctuation $= 0.47 \text{ m}$ (BH12)

Dynamic reserve
 $= 82,476 \text{ m}^3/\text{yr} = 226 \text{ m}^3/\text{day} \text{---} -3$.

Thus the total dynamic resource of the valley
 $= 12,730 \text{ m}^3/\text{day}$.

(1+2+3)

Static water reserve or the amount of water available for emergency use was calculated. These reserves are equal to total ground water that can be extracted by lowering the piezometric head to the top of the aquifer. It is calculated as:

Area of the confined aquifer $= 107 \text{ km}^2$

Available drawdown (mean piezometric head-w. l. fluctuation) $= 123.21 \text{ m}$.

Avg. storage coef. $= 1.64 \times 10^{-3}$

Hence total static reserve
 $= 123.21 \times 107,000,000 \times 1.64 \times 10^{-3}$
 $= 21,620,890 \text{ m}^3$ (GAUTAM R., 1988).

But while the static reserve as calculated by Gautam gives the total amount of water available for abstraction, withdrawal of all that water could have catastrophic results such as land subsidence and pollutants from surface or near surface sediments contaminating the entire aquifer permanently. This quantum of resource can be exploited judiciously depending on the necessity and subjected to its replenishment.

Therefore the total reserve would add up to 12730 m^3 + part of the static reserve.

The amount of recharge to ground water has been calculated by water balance method involving surface input, outflow and evapotranspiration

as shown below:

$$\begin{aligned}
 &\text{Total drainage area of the valley} \\
 &\quad = 5.4 \times 10^8 \text{ m}^2 = 540 \text{ km}^2 \\
 &\text{Avg. annual rainfall} = 1400 \text{ mm.} = 1.4 \text{ m} \\
 &\text{Total rainfall within the valley} \\
 &\quad = 1.4 \times 5.4 \times 10^8 = 7.56 \times 10^8 \text{ m}^3 \\
 &\text{Annual runoff out of the valley} \\
 &\quad = 4.96 \times 10^8 \text{ m}^3 \\
 &\text{Losses due to evaporation} \\
 &\quad = 0.24 \text{ m/m}^2 = 1.296 \times 10^8 \text{ m}^3 \\
 &\text{Total infiltration to the G. water reservoir} = \\
 &\text{-----} 7.56 \times 10^8 - (4.96 \times 10^8 + 1.3 \times 10^8) \\
 &\quad = 1.3 \times 10^8 \text{ m}^3/\text{yr.} \\
 &\text{Percentage of infiltration from rainfall} \\
 &\quad = 17.2\% \text{ (Gautam, 1988)}
 \end{aligned}$$

III-4 Water demand

It was reported that a typical American uses 0.20m³/day-0.30 m³/day of water per day. A person requires about 3 litres of potable water per day to maintain essential fluids of the body (FETTER C. W., 1990). Besides this, more water

is consumed for facilities such as offices, hotels, factories, hospitals, schools etc. which comes under special demands.

Table 2 shows WSSC estimated the population of Kathmandu valley to be around 442,000 for 1986 and the water demand for the total population was 106,000 m³/day. The actual supply was 83,000m³/day, which indicates deficit of 23,000m³/day. Of the 83,000m³/day, ground water resources contributed 25,000m³/day. The total dynamic reserve calculated comes up to only 12,730m³/day. Thus overdrafting has already taken place. The above table does not include withdrawal from private wells which adds up to even more groundwater withdrawal.

The effect of overdrafting could be observed from the declining trend of the water level in the tube wells (Table 3). The maximum decline has been upto 10.7m in some wells in the span of last two decades. Table 2, shows that WSSC hoped to increase the production to meet the estimated demand in 1991. According to recently published

Table. 3 Fall in the piezometric surface and water level in the boreholes due to over exploitation.

Tubewell owners	SWL (m bgl) Year drilled	SWL (m bgl) in 1988	Fall in water level (m)
Hotel Kathmandu	24.4 (1978)	35.10	10.7
Bottlers Nepal Ltd.	Artesian (1985)	3.05	—
British Embassy	8.23 (1972)	9.80	1.57
Hotel Malla	4.60 (1975)	6.70	2.1
Hotel Yak & Yeti	Artesian (1975)	20.00	—
Hotel Annapurna	Artesian (1977)	10.00	—
Bir Hospital	6.10 (1986)	9.10	3.0
Hotel Everest	4.30 (1978)	13.70	9.4
Jawalakhel Distillery	35.60 (1976)	42.70	7.1

Source: Binnie & partners, 1988
(after Gautam R.,1988)

data in a daily newspaper, Kathmandu Valley consumes 130,000 m³ of water per day but WSSC barely manages to supply 60,000 m³. Apart from that WSSC estimates 40% loss due to leakage and misuse (Kantipur, Nepali national daily, July 5, 1993). As a result, many individuals and establishments have drilled shallow and deep tube wells to meet the water demand. Many people do not keep any sort of records and hence the amount of withdrawal from these private wells are unknown. As stated above WSSC pumps out nearly about 40% of the total water supply or

25,000m³/day from deep tube wells in the northern sector. This overdraft could not only cause land subsidence but dry up the aquifer as well. Kathmandu valley may face potential disaster unless the government comes up with effective remedial measures soon.

Discharge data from the 'Dharas' in Table 4a, b and c shows that total discharge comes to about 1,380m³/day. This discharge was measured during the driest month of the year hence gives the lowest flow. As reported, the flow easily doubles

Table. 4a Hydrogeological parameters of *Dhunge Dharas* distributed around the Kathmandu Valley boundary.

Dhara no.	Location	Depth of seepage (m bgl.)	Temperature° C		Discharge (m3/s)
			water	air	
1	Sundhara, Kath.	5.00	23.00	29.00	0.000270
10	Nagbahal, Patan	2.70	19.00	24.00	0.000291
11	Aalko Dhara, Patan	5.90	21.00	26.00	0.001280
12	Washa Hiti, Patan	0.60	20.00	27.00	0.000308
14	Durbar square, Patan	3.30	19.50	25.00	0.000430
15	Sundhara, Patan	0.40	20.00	26.00	0.000385
16	Tahakhel Dhara	4.00	21.00	28.50	0.000130
18	Pulchowk Dhara	4.00	19.00	27.00	0.000166
21	Panipokhari	1.00	21.00	28.50	0.000020
22	Gairi Dhara	2.00	20.00	29.00	0.000089
23	Naxal, near R. Palace	3.00	19.00	29.00	0.000058
24	Naxal, south of N. temple	2.50	22.00	29.00	0.001416
28	Chabel	n. surface	20.50	25.00	0.000148
29	Gaushala, SE of R. Road	1.10	21.00	26.00	0.000200
33	Nayabazaar	n. surface	20.50	29.00	0.000072
35	Min Bhawan	1.00	20.00	23.00	0.000063
39	Kohiti	3.00	18.00	23.00	0.000250
40a	Maruhiti (diff. channels)	2.00	19.50	29.00	0.000800
40b	Maruhiti	2.00	19.50	29.00	0.000133
40c	Maruhiti	2.00	19.00	29.00	0.000160
40d	Maruhiti	2.00	19.50	29.00	0.000103

Table. 4b Hydrogeological parameters of *Dhunge Dharas* in the central part of the Kathmandu Valley.

Dhara no.	Location	Depth of seepage (m bgl*.)	Temperature ° C		Discharge (m ³ /s)
			water	air	
26	Baudha	near surface	21.0	25.0	0.000137
27	Baudha	near surface	22.0	25.0	0.000333
20	Bansbari	near surface	21.0	25.0	0.000108
19	Budanilkantha	near surface	20.0	22.0	0.000182
30	Bais Dhara	near surface	23.0	27.0	0.000533
31	seep. north of B.Dhara	on slope	23.0	27.0	0.000167
32	B.I.D.	near surface	21.0	26.0	0.000063
36	Swayambhu	5.50	20.5	30.0	0.000100
37	Chawni	near surface	20.5	28.0	0.000070
17	Teen Dhara,Dhoboghat	2.00	19.0	25.0	0.001110
45	Teen Dhara,Naikap	1.67	21.5	28.5	0.000020
46	Gurju Dhara,Balambu	0.73, 1.12	22.0	26.0	0.000375
47	Mata Tirtha	3.00	16.5	25.0	0.003730
2	Nau Dhara, Godavari	1.00	16.0	26.0	0.000708
3	God.Kund	1.00	18.0	28.0	0.001440
4	Washa Hiti,Thaiba	5.00	19.0	26.0	0.000083
5	Dhusa Hiti,Jalgaon	1.15	19.5	25.0	0.000036

* bgl refers to below ground level

Table. 4c Hydrogeological parameters of the dug wells in the Kathmandu Valley.

Well no.	Location	Depth of water level bgl. m.	Temperature ° C		Seasonal Fluctuation
			water	air	
6	Harishiddhi	2.28	19.00	27.00	
7	Harishiddhi (Sanal Tole)	3.36	18.00	27.00	1.00
8	Harishiddhi (Pokcha Tole)	5.35	18.50	27.00	1.00
9	Near Patan Gate	2.64	18.50	23.00	2.00
13	Kumbheswor Temple	1.00	20.00	26.00	1.00
25	Boudha (south)	near surface	20.50	25.00	
34	SE of Tin Kune	2.44	21.00	23.00	
38	Raj Tirtha well	0.63	18.50	28.50	
41	Near Thamel Chowk	2.12	19.00	26.00	
42	Kalimati	0.40	23.00	27.00	
43	Kalanki	2.05	20.00	27.00	
44	Dhunga Adda	2.98	19.50	30.00	

during monsoon in which case the discharge would be about $2,700\text{m}^3/\text{day}$. This amount is for 45 'Dharas' studied and the actual number of these spouts could be three times more. Moreover the 'Dharas' studied were all in the vicinity of Kathmandu and Patan and does not include the ones in Bhaktapur, Sankhu, Thimi and many other smaller villages. Again they were only some of the natural seepages that has been tapped, and many more may be just flowing back to the river. Hence if detailed investigation is carried out and ground water is properly tapped, overdrafting from the deeper aquifers should not be necessary. As seen above surface sediments alone possess large potential for water supply.

Another possibility is to recharge the underground reservoir. It has been observed that natural recharge by vertical infiltration is very small, and certainly insignificant in relation to quantity of surface water movement.

Also artificial recharge can be done only in restricted areas due to presence of clay layers. Construction of check dams along the stream beds, multipurpose ponds in the north should help in recharging the groundwater and serve as recreational spots. Precaution, however, should be taken as not to contaminate the underground water from the already over polluted streams of Kathmandu Valley.

IV. Conclusions and recommendations

1) Kathmandu valley consists of complex aquifer system with unconfined aquifer in the north, semi confined interbedded system in the centre and confined aquifer in the south.

2) Surface sediment deposits can supply considerable amount of water through dug wells and 'Dharas'.

3) Withdrawal of water from age old 'Dharas' and wells is extensive even in the extreme south which is considered as non aquifer zone.

4) Groundwater system if properly managed has enough potential to supplement the city water supply.

5) For the lack of data, water potentiality study covers limited portions of the valley and hence more detailed study should be conducted so as to cover the entire valley of Kathmandu.

6) Multipurpose projects, specially in the northern zone should help induce artificial recharge.

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