UNICEF

NEPAL

WATER RESOURCE AVAILABILITY

By

S. Radojicic

1975

WATER SUPPLY AND SANITATION SECTOR STUDY - NEPAL

WATER RESOURCE AVAILABILITY

by

S. RODOJICIC

UNICEF Hydrodeologist

1975

C O N T E N T S

SUMMARY

I. In Nepal there are real feasibilities the water supply of people to be settled by developing two water resources: surface and ground waters.

Hydrogeologically, two regions are clearly noticeable in Nepal: the mountain complex and the Terai plain. In the mountain complex, there can be developed streams from surface waters and springs from ground waters. Exceptionally, in some river and structurs valleys of this complex, under-ground waters can be developed by dug and tube wells. In the Terai Region, only ground waters can be developed for the water supply by dug, shallow and deep tube wells.

Taking into acount some specific physiographic, climatic, geological, hydrologic and consequently, also ecologic features, in Nepal five regions can separated; all of them stretching WNW - ESE. They are: High Himalayas, Midland, Mahabharat Rang Churia Hill and Terai. The first 4 mentioned regions correspond to the above mentioned mountain complex.

1.1. High Himalayas:

This region covers the furthest northern belt of Nepal. Its average width makes about 40km and the elevation rages form 3,000 m to 8,848 (Mount Everest). The climate is alpine. The snow line is at the elevation of 5,000 m and about 14% of the total area of Nepal is always under snow. The rainfall is comperatively low: 500-1,000 mm in western and far western parts and 500-2,500 mm in central and eastern parts of the region. Because of severe conditions, the life is mainly limited up to the elevation of 3,000 m and there can hardly be found a settlement above this altitude line. The vegetation is limited up to 4,000 m and in a belt from 4,000 - 4,500 m only grass is found.

Two water sources may be used for the water supply of the people of this region who are small in number: streams and springs:
Streams mainly fed by snowfalls are clear almost during the whole year, they are perennial and they can be used for the water supply providing a simple treatment in applied.
Springs drain fissured aquifers formed in folded and faulted igneous and netamorphic rocks (granite, gneiss, migmatite, various schists and lenses and beds of marble and crystalline dolomite) and local aquifers formed in weathering zones. The recharge of both aquifers mainly originates from the snowfalls. The spring water is, therefore, slightly mineralised and suitable for the domestic use.

The scarce settlements of this region may be successfully provided with water mostly by simple gravity water supply systems.

1.2. Midland:

This region covers the most part of the central part of Nepal and it consists of lowlying hills, rivers and tectonic valleys with an average altitude of 2,000 m. In the valleys which are open southwards, the climate

/....

is moist sub'ropical and in the higher areas, it is temporate. This is the reachest region in Nepal as far as the rainfall is concerned. The rainfall ranges from 1,000 to 2,500 mm in the far western and eastern parts of the region and from 2,000 to 4,000 mm in the western and central parts, the maximum rainfall being in the Pokhara area - 4,500 mm.

Because of the favourable physiographic, climatic, geological and other conditions, the soil development is intensive which arose the great interest of people to live in this region: about 60% of the total population of Nepal lives over there. Because of favourable climatic conditions and safety (landslides, rock falls, erosion), the settlements are mostly situated on the top of hills or un the upper parts of their slopes. The only exception in this sense are major rivers and tectonic valleys.

In this region the main water sources are streams, big rivers and springs, and, in structure valleys, also porous aquifers which may be developed by dug and tube wells.

The rivers and streams are mostly perennial..They are mainly fed by rainfalls and during the monsoon and immediately after it, their waters are muddy which rather complicates and makes most expensive their development for the water supply. (settling tanks and other treatments are required, therefore). Besides, they are located low in comparison to the settlements, so that pumps or hydraulic rams with head of 30 to 300 m must be applied. Or, if one wants to avoid the water pumping, a long distance pipe lines are required.

Ground waters are found in geological formations characterised by fissured and porous aguifers.

Geologically, this region coincides with the major fault zones. Consequently, there can be found numerous river and tectonic valleys which were later on filled with loose deposits and saturated with ground waters which may be developed by dug and tube wells. These valleys are: Kathmandu, Pokhara, Dang, Surkhet, Mariphant, Benena, Panchkhal and some other smaller ones.

The fissured aquifers are mainly found in metamorphosed rocks whose degree of metamorphism decreases going from the north towards the south: various schists and gneiss with lenses and beds of crystalline limestone and dolomite in the central part and slates with lenses and beds of dolomite in the southern belt of the region. These aquifers are drained by numerous springs whose discharge greatly varies. The springs associated with fault zones, dolomit and limestone shoukd be expected to to be of the greatest discharge. Springs being mostly fed directly by the percolation of rainfall, the great variations between the minimum and maximum discharge may be expected. It should be born in mind when sellecting springs for the water supply. From the water supply point of view, springs should have the most suitable quality of water, then should follow porous aquifers in river and tectonic valleys, and finally, stream water. Accordingly, in sellecting water sources for the water supply schemes, this sequence should be generally respected.

1.3. Mahabharat Range

This is the first high hill range facing the vast Indo-Gangetic plain. Its width varies and in western Nepal its boundary towards Midland is not clearly defined. The elevation varies between 1500 and 3500 m, the average one being about 3,000 m. The climate istemporate. The summer rainfall is dominant and most of the winter precipitation is in the form of snow. The rainfall ranges from 2,000 and 3,000 mm in central and eastern parts, and from 1,500 and 2,000 mm in western and far-western parts.

The geological composition also varies. In the eastern part of the range granite, gneiss and quartzite dominate; in the middle and western part cherty dolomite with slates and in the far western part granite and gneiss are dominant. So, the eastern and far western parts of the range, being composed of very hard rocks, are higher in altitude, steeper in slopes and, consequently, less populated; very few villages are located over there. In middle and western Nepal, there are more villages which have the same prolems as those ones in the Midland with somewhat more favourable conditions only in areas where dolomite is found.

The thick forest is the benefit so that numerous springs may be found particularly on the northern slopes where most of the villages are situated. There are no data on the discharge of springs, its variations and quality of water. However, on the basis ofthe geological composition of water bearing fromation and aquifer recharge, the suitable composition of water from the water supply point of view should be expected.

1.4. Churia Hills

Churia Hills represent the southernwards and lowermost belt of the mountain complex. They continuously stretch from the eastern to the western border of Nepal. Its average width makes about 20 km and the elevation varies between 300 and 1,500 m with an average of 1,000 m. Humid tropical climate prevails at lower altitudes and moist subtropical at higher altitudes. The rainfall varies between 1,500 and 2,500 mm with an anomaly of 3,500 mm in the Butwal area.

The Hill slopes steeply dip in the south and gently in the north. The northern slopes bear vegetation and some springs, where as the southern face is dry.

Geologically, the Hill is composed of gravel, sand and clay beds dipping northwards. Being porous and exposed, no ground water is retained in this area. So, drinking water is very limited and people greatly suffer because of it. Hence, there are few villages only. The exception

/....

are "dun valleys" which are filled with Recent and quaternary fluvial loose deposits, saturated with ground water at the depth of 9 to 12 m. Ground water is fresh and fit for the water supply and it can be developed by dug and drilled tube wells, providing proper well protection is made.

The ground water development might be difficult in the peripheral parts of dun because of very coarse deposits (cobble, boulder). Hence, the percussion drilling is recommended, whereas in the central part of the dun confined water is possible along with phreatic one and other drilling methods can be applied.

The nearby streams cannot be used for the water supply at all, because they are not perennial.

1.5. Terai Region

Between the Churia Hill on the north and Nepal-Indian border on the south, there is about 30 km wide flat belt of the Terai, with the elevation of 60 to 300m. Climate is humid tropical. The rainfall varies from 1.500 to 2,000 mm.

Terai is the most densely populated area in Nepal. About 38% of the total Nepal population live in this region. They mostly deal with the agriculture and they lime in villages which are well organised (compact communities). They drink water from open dug wells of different depth; some villages mearby the Indian border are provided with hand pump. Both dug wells and pumps tap shallow phreatic aquifer. The very extensive ground water explorations made first of all for the irrigation purposes, especially in western Terai, suggest that in Terai anormous quantities of ground water are accumulated in alluvium deposits. It was found that the phreatic aquifer is distributed in the whole Terai and that in the middle part also exist confined aquifers. Both aquifers systems contain water of good quality fit for the domestic use and irrigation purposes. It can be easily developed by dug and tube wells of different depth: by deep tube wells for large quantities of water and by shallow dug and tube wells for small communities.

Hydrogeologically, three zones can be separated in Terai. All of them stretch continuously from the eastern to the western border of Nepal.

The first zone, so called Bhabhar Zone.is in the northern part of Terai, in the foot of the Churia Hills. Actually, it is a phreatic aquifer composed of very coarse, loose deposits (boulder, pebblr,gravel) saturated with ground water whose water table is at different depth: at the northern edge of the zone it is at the depth from 7 to 9 m, in the central part of the zone at the depth from 5 to 15 m and at the southern edge of the zone immediately below the ground surface or at the ground surface itself. The southern border of the zone is clearly marked by a line of numerous springs.

/....

The middle zone, Marshy or artesian zone, contains two systems of aquifers: the deep, confined aquifer with artesian conditions and shallow phreatic aquifer.

The confined aquifer system is composed of numerous individual aquifers composed of gravel and sand, In some areas, this system starts even at the depth of 30 m, but in whole Terai it can be noticed at the depth which does not exceed 60 m. As a rule, wells tapping this aquifer system are of the very large discharge and they are suitable not only for the water supply of large communities but for the large scale irrigation schemes also.

The phreatic aquifer is immediately below the ground surface. It is composed of sand silt and clay and it is very suitable for the water supply of small communities by shallow tube wells equipped with hand pumps.

The southern zone, mostly called southern flat zone, mainly stretches along the Nepal-Indian border. It also contains two aquifer systems: the deep confined aquifer with subartesian conditions and the shallow, phreatic aquifer. The aquifers mainly consist of fine sand, silt and clay Generally, they are poor in water. To settle the water supply of large communities numerous individual aquifers should be tapped by deep wells. As for small settlements, there might be sufficient if only the top, phreatic aquifer is tapped by shallow tube wells equipped with hand pumps.

* * *

For the well drilling in the Bhabhar zone, heavy duty percussion rigs should be supplied and in the other zones the rigs based upon the other drilling methods can be applied.

R E C O M M E N D A T I O N S

1. HYDROGEOLOGICAL AND SANITARY SURVEY

1.1. Mountain Complex

The Mountain Complex includes 4 regions: High Himalayas, Midland, Mahabharat Range and Churia Hills.

111.1. To make water supply feasibility stuies of the rural communities, with the Remote Area and Local Development Dept., to form a research team consisting of a sanitary engineer, an assistant sanitary engineer (with the adequate experience in hydrometry) and a hydrogeologist in order to enable the planning, design and construction of water supply schems in the mountain complex. The task of the team should be to examine and establish on spot per each rural community as follows: the water requirements, present water supply status, present sanitary conditions, the most suitable water source for the future water supply scheme, type of future water supply system, the access to the community, the equipment and

/....

supplies required and the cost of the future water supply system and the per capita cost.

Besides, the team is also expected to select typical springs considering all hydrogeological and climatic conditions to make the long term observations of the discharge and quality of water. In each district at least 2-3 springs of different hydraulic mechanism should be selected for this purpose.

1.1.2. The survey should first be made in communities given the priority by the RA and LDD and afterwards in those ones connected by good communications.

1.1.3. The national personnel should be provided with one year training by an international sanitary engineer and hydrogeologist. It should be both the class and on-the-job training. The training programme should included types of aquifers, ground water dynamics, types of springs, discharge measurements, water sampling, water quality testing and determination of sanitary protection zones.

The training might also include more personnel than the number of personnel for the feasibility stydy.

1.1.4. The team to work in the field should be provided with as follows: a light 4-wheel drive diesel vehicle (jeep type), a 4 wheel drive diesel pick-up, camping equipment (tents, folding beds, sleeping begs, etc.), cooking facilities, scientific equipment (current meter, conductivity meter, geological compass, stopwatch field hammer, pocket pen-type thermometer, pocket magnifying glass, measuring tape,surveying altimeter, and pocket altimeter), topographical maps and aerophotoes. To procure this equipment, the assistance of external agencies is meeded.

1.1.5. The well trained team is supposed to be able to complete surveying at least 200 communities a year. If voluntiers are provided, then a rather larger number of communities might be completed.

1.1.6. The annual expenses of such a team make N.Rs. 79,140 - If a team completes the survey scheme will make only N.Rs. 396.

1.2. Terai Region

1.2.1. It is recommended with the RA and LDD to form a team for operational and research purposes consisting of a hydrogeologist, assistant hydrogeologist, a snitary engineer. The task of this team should be as follows: to study all documentation concerning the Terai Region, to select productive artesian wells and small dia. test wells which might be used for the rual water supply providing a simple adaptation is made, then to make hydrogeological and sanitary survey and sanitary survey in areas lacking data at persent; on the basis of collected and processed data to

/....

divide Terai to separate areas according to the optimal depth of wells on which the future water supply programme for rural communities will be based. Besides, the team should also study the access to the communities and to suggest the transport of drilling rigs to well sites located, to design typical wells for particular areas. In addition, the same team is expected to take part in the realisation of the shallow tube well drilling programme (pilot project) suggested, and the next large scale tube well programme for the whole Terai Region.

1.2.2. The national staff to be engaged in this survey should be provided with one year training by the international staff mentioned under 1.1.3. The training programme should include as follows: methods of drilling, well dydraulics, well design well discharge testing, water sampling, water quality testing and detrmination of sanitary protection zones around a well. In addition, this programme should also include on-the-job training which can be successfully made in the Ground Water Section Ministry of Food and Agriculture. The profession staff should be provided with the fellowship abroad.

1.2.3. For the field work, the equipment mentioned under 1.1.4 should be provided, plus a tube well water sampler, water level indicator and tube pressure gauge.

1.2.4. The well trained team is expected to be able to survey 300 rural communities in one year period.

1.2.5. The annual expenses of such a team make N. Rs. 80,100.- and the cost of survey per one community NRs. 267.- only.

2. SYSTEMATIC HYDROGEOLOGICAL SURVEY OF THE MOUNTAIN COMPLEX

2.1. To form a team with the Ground Water Section, Department of Irrigation, Hydrology and Meteorology, which should start with the systematic hydrogeological investigations of themountain complex. The task of this team should be as follows: to collect and process all geological and structural data with the Bureau of Mines and Geological Survey, all existing data on water sources which are used for the water supply (with the WSSB, WSSD, and RA & LDD), to interprete aerophotos, to make field survey in order to be able to make a set of hydrogeological maps. The set should include three maps: the water sources inventory map, water quality map and summery hydrogeological map.

2.2. The national staff to be engaged on this job should be provided with a six month training which should include methods of map preparation. The internationally recruited hydrogeologist, expert in the preparation of maps mentioned, should be provided for such a training.

/....

3. SHALLOW TUBE WELLS PILOT PROJECT

3.1. To select the most suitable drilling equipment for shallow well drilling and to estimate the capital cost of water supply of rural communities in the Terai Region, before an implementation of a large scale water supply programme forthe whole Terai, a two-year pilot project implementation is suggested. It should cover the shallow well drilling and hand pump installation in the marshy zone and southern flat area of the Terai Region.

3.2. A typical public shallow tube well should be of the following features: min. diameter 6 inches, 4-inch PVC casing and screen installed, the fitler-pack installed between the well wall and screen, the upper 5-6 m of this space to fill with bentonite or grout, with a concrete slab at the surface, as well as drain and pit for waste water. The well should be equipped with a hand pump with a cylinder and raising main placed into the well.

3.3. Three types of drilling rigs are suggested for the well drilling: one cable tool rig, one continouos augar drilling and one jet drilling rig.

3.4. To successfully implement the project, on-the-job training should include three drilling crews which might to be partly trained by an international drilling superintendent and partly by the technical staff of the Ground Water Section, Ministry of Food and Agriculture.

3.5. The well approx. 15 m deep, drilled by a calbe tool rig, constructed and equipped as under 3.2. should cost about N.Rs 6,000.- If such a well may meet requirements of 200 inhabitants then it follows that the per capita cost makes N. Rs. 30.-

3.6. The project is suggested to be carried out by the RA & LDD, and the selection of areas to coincide with the priority of water supply of rural communities in the Terai Region already established.

WATER SUPPLY AND SANITATION SECTOR STUDY - NEPAL

WATER RESOURCES AVAILABILITY

INTRODUCTION:

In the period from September 22 to October 9, 1975, the Reporter was in Nepal as a member of the WHO/IBRD/UNICEF Mission participating in the preparation of the Water Supply and Sanitation Sector Study of Nepal. Regarding his field of activity, the Reporter was fallen to work out a part of the studey referring to the ground water exploration and development and to collect basic data on the exsiting grovernment agencies involved in this field activity. As some parts of Nepal lack real conditions for the entensive ground water development, this Reports also briefly deals with possibilities of surface water development from the water supply point of view.

The water resources assessment presented in this Report has been based upon data collected during numerous contacts made with the personnel in the Water Supply and Sewerage Department (WSSD) under the Ministry of Water and Power, the Remote Area and Local Development Department, (RA & LDD) under the Ministry of Panchyat, the Ground Water Section (GWS) of the Ministry of Food and Agriculture, the UNICEF and WHO personnel in Kathmandu, then on data from numerous reports and studies (see references) and, finally, it has been based upon personal impressions got by the Reporter during his field trip Kathmandu-Pokhara-Butwal-Bhairawa from Oct. 1 to Oct. 4, 1975. The Reporter is much grateful to the personnel of all above mentioned institutions for their assisstance and kindness.

1. SURFACE WATER OCCURRENCES

Rivers represent the main source of surface water in Nepal. All rivers in Nepal are tributaries of the Ganges River in India and they flow generally in a north-south direction (see a map attached).

There are four main rivers in Nepal (ref. 7), the Mahkali, the Karnali, the Sapta Gandaki (Narayani) and the Sapta Kosi. They all have their headwaters in the high Himalayas and thanks to snow and glaciers they are of a sustained flow.

The Kankai Mai, the Kamla, the Bagmati, the Rapti and the Babai are secondary rivers originating from the middle hills. Their discharge greatly varies and it is followed by the high flooding during the monsoon (July-September). However, they never get dry completely. A large number of small rivers with their source area in the Churia Hills and Terai are mainly seasonal, i.e. they do not flow in the dry period.

According to data obtained in the Department of Irrigation, Hydrology and Meteorology, Ministry of Food and Agriculture, in a year of 1972 there

/....

were 41 regular gauging stations and 39 partial-record stations and miscellaneous sites (ref. 2) for the low flow discharge measurements.

Table 1 shows the drainage area, and the average, maximum and minimum discharge of the rivers at which regular gauging stations exist. From the same Table it is evident that the maximum river discharge is, as a rule, in the period of July-August-September, i.e. during the monsoon season. Few exceptions show that monsoon can also take place in June and it can last even in October.

The minimum discharge takes places in different time of the long dry season: sometimes it is in February, more frequently in March-April and most often in May-June. The seasonal variations in the discharge are best suggested by the maximum-minimum discharge ratio.

For the Karnali River Basin, the maximum-minimum discharge ratio is as follows: the Karnali River at Asara Ghat 59.8, the Karnali River at Chisapari 76.6, the Karnali River at Bheni-Chat 103, the Bheri River at Jamu 96.4, etc. The greatest ratio in this basin is of the Babai Nadi at Bargadaha (815.4) whose catchment area is in the Churia Range and it is almost exclusively fed by the rainfall.

In the Narayani River Basin, the following ma ximum-minimum discharge ratio is characteristic: the Trisuli River at Betrawati 84.5, the Seti Khola at Phoolbari 118.5, the Kali Gandaki River as Setiheni 126.5, the Kali Ghandi River at Katagaon 176.8, etc. The greatest ratio is of the Burhi Gandaki River at Arughat Bazaar (3065) and the Andhi Khola at Dumrichaur (1590).

In the Sapta Kosi Basin, the lowest maximum-minimum discharge ratio is of the Bhote Kosi at Bahrabise 45.9, the Tamkosi River at Busti 48.8 and the Likhu Khola at Sangutar 60.7. The other values vary from 80.9 to 225.8 with the exception of the Rosi Khola at Panauti where the ratio makes 1671.

The greatest maximum-minimum ratio can be noticed in the Baghmati River Basin where the rainfall is themain source of feeding. The lowest ratio is of the Bishmumati Khola at Budhanilkantha (730) and of the Thado Khola at Darkot (1227). The largest ratio has the Baghmati River at Ghobhar (43,800), and the Nakhu Khola at Tika Bhairab (18,100).

Similary, the maximum-minimum discharge ratio of the Rapti River at Jalkundi makes 2,381.

* * *

The analysis of the Hydrograph of theKarnali River at Chasapani (ref. 11) indicates that 78% of the total quantity of water flows out during the rainy season of three months as the surface run-off, 12% of water is supplied by snow during the summer and 10% comes form the ground water.

/....

TABLE 1 : AVERAGE, MAXIMUM MINIMUM DISCHARGE OF SOME MAJOR RIVERS IN NEPAL

River Basin	River & G.S. Location	Drainage Area (sq.km)	Average discharge cu.m./sec. /period/	Maximum discharge cu.m/sec /date/	Minimum discharge cu.m./sec /date/	Remarks
1	2	3	4	5	6	7
	Karnali R.at Asara-dgat	19.260	489.6 /1961-72/	5,050 /10.9.1971/	84.4 /27.2.1967/	Records good
	Karnali R.at Beni-ghat	21.240	579.5 /1965-72/	9,600 /10.9/1971	93.2 /10.3.1967	Records good except above 5.000 cu.m/sec
	Seti R.at Bangga	7.460	315.4 /63-72/	7.030 /10.9.71/	27.7. 8/12.3.67/	Records good except above 2000 cu.m/sec
KARNALI	Bheri R.at Jamu	12,290	428.5 1963-72	5;61o 21.7.70	58.2 11.4.66	Records good
	Karnali R.at Chisapani	42,890	1333 62-72	16.400 10.9.71	214 10-13.3.67	"
	Sarda R.at Kalimati	688	9,279 1972	77.2 14.9.72	0.62 13-15.6.72	"
	Babainadi at Bargadaha	3,000	66.14 67-72	2.120 20.8.69	2.60 6-8.6.67	Records poor
	Kali Gandaki R.at Setibeni	6.650	270.2 1964-72	2240 13.7.70	17.7 10.4.69	Records good
NARAYANI	Andhi Khola R at Dumrichaur	476	29.82 1964.72	1.590 17.6.1970	1.00 29.5.1965	"
	Kali Gandki R at Kota gaon	11,400	503.2 1964-72	6720 5.10.1968	38.0 4-7.4.70	Records good except for 65, 66 and 67
	Seti Khola R at Phoolbari	582	48.54 1964-72	711 7.8.1970	6.00 1-4.3.69	Records good
	Chepe Khola R at Palung tar	308	26.32 1964-72	556 10.7.67	2.00 14-15.5.70	"

/....

1	2	3	4	5	6	7
	Burhi Gandaki R at Arughat Bazaar	4,270	150.8 1964-72	5210 2.8.68	1.70 6,7May 68	Record pair
	Phalankhu Khola at Betrawati	162	15.99 1971-72	510 10.9.71	0.40 12,13 June 72	Records poor
	Trisuli R at Betrawati	4,110	155.3 1967-72	2020 7.7.72	23.9 22,26.3.69	"
NARAYANI	Tadi Khola at Pipal tar	2,060	40.97 1969-72	1500 28.7.72	1.40 14,15-5-70	Record good except those above 250 cu.m. /sec.
	Rapti R at Rajaya	579	30.54 1963-72	1050 26.8.68	1.10 4-8,3,71	Rdords good
	Lothar R. at Lothar	169	9.141 1964-72	464 13.6.71	0.56 13-14,6,65	"
	Burhi Rapti at Chitrasari	184	15.65 1964-72	400 17.7.70	1.00 13-14,6,72	Records goog except those above 60 cu.m/ sec.
MAHAKALY	Surna gad at Patan	188	6.861 1966-72	373 20.7.70	0.20 10-16,6,66 25-28,5,69	Records fair.
	Bhote Kosi at Bahrabise	2,410	73,08 1965-72	446 1.8.66	9.70 29.3.71	Records poor
	Balephi Khola Phalamesangu	629	48.79 1964-72	1,125 9.8.70	5.30 21.3.71	Records fair
SAPTA KOSI	Sunkosi at Pashuwar Ghat	4,920	212,5 1964-72	3,410 28.7.72	22.0 19.3.65	"
	Rosi Khola at Pananti	87.2	2.405 1964-72	117 24.8.66	0.07 11-13.6.70	Records good eecept those above 10 cu.m/ sec.
	Tamakosi R. at Busti	2,753	155.5 1971-72	873 4.9.72	17.9 20-23.3.71	Records fair
	Khimti Khola at Rasnalu village.	313	17.43 1964-71	420 3.6.71	1.86 Apr. May 1966	Records fair except those above 100 cu.m/sec.

/....

TABLE 1.

1	2	3	4	5	6	7
	Sunkosi at Khurkot	10,000	485.5 1968-72	6600 9.8.70	47.4 6.4.70	Records fair
	Likhu Khola at Sangutar	823	55.82 1964-72	428 22.6.64	7.05 13.4.66	"
SAPTA KOSI	Dudh Kosi at Rabawa Bazaar	4,100	221.6 1964-72	2450 20.7.70	18.5 4.5.69	"
	Sunkosi at Kampughat	17,600	710.0 1966-72	9,390 5.10.68	116 22-24.3.72	"
	Tamur R. at Mulghat	5,640	307.5 1970-72	4,100 26.9.72	33.0 20-22.3.71	"
	Bagmari near Sundarijal	16.0	1.011 1963.72	33.1 4.9.66	0.02 30-31.5.70	Records poor
	Bishnumati Khola at Budhanilkantha	4.43	0.276 1969-72	7.30 19.8.70	0.01 11-16.3.70	Records good except those above 3000 cu.m./sec.
BAGMATI	Nakhu Khola Tika Bhairab	42.5	1.116 1963-72	181 24.8.66	0.01 25-26.6.69	Records poor
	Bagmati R. at Chobhar	585	14.15 1963-72	876 28.7.72	0.02 8-9.6.64	"
	Thado Khola at Darkot	13.8	0.755 1964-72	98.2 28.7.72	0.08 dry season 1967	Records fair
	Kulikhani at Kulikhani	126	3.904 1963-72	572 16.7.70	0.11 4.6.67	Records poor
WEST RAPTI	Marikhola at Nayagaon	1,980	59.59 1964-72	880 22.8.64	4.48 23-25.4.70	Records good
	Rapti R. at Jalkundi	5,150	99.65 1964-71	2,500 20.8.69	1.05 31.5.68	"

The Bagmati River hydrograph that about 80% goes from the surface run-off and the remaining part goes for the ground water.

* * *

The total hydropower for hydroelectric power is estimated to be 83,000 megawatts (MW) in which the Karnali Basin contributes 32,000, the Gandaki Basin 21,000 and the Kosi Basin 22,000 MW (ref. 5 & 11). The present installed hydroelectric capacity is only 33 MW and Nepal's per capita consumption of 9 MW is among the lowest in the world.

* * *

From the water supply point of view, the following facts are worth mentioing:

- the streams of the High Himalayas are mainly fed by snowfalls and, therefore, they are more or less clear during the whole year and they can be used for the water supply in the areas where ground waters cannot be developed providing a simpl water treatment is made:
- the riversform the middle hills are mainly fed by the rainfalls and, therefore, they are very muddy during the monsoon and immediately after it, which rather complicates and make more expensive the utilization of them for the water supply; they should be, therefore, used only in case there is no other water source;
- the rivers originating from Ghuria Hills and Terai are seasonal and muddy and, therefore, they cannot be used for the long term water supply.

2. GROUND WATER OCCURRENCES

Hydrogeologically, Nepal might be divided into two main regions; the mountain complex and the plain (terai).

2.1. Mountain complex covers more than three fourth of the Nepalese territory and it includes all mountains from 'hria Hills on the south which border on the Indo-Gangetic plain, to the highest Himalayas on the north whose height ranges from 300 m (the foot of Churia Range) to 8848 (Mount Everest). With the exception of few river and tectonic valleys filled by the Miocene-Pliocene and Quaternary slightly consolidated and unconsolidated deposits saturated with under ground water (porous water bearing formations and/or porous aquifers), the whole complex is built up of geologically consolidated formations (solid rocks) which are only partially saturated with ground water (fissured water bearing formation). The complex is mainly composed of metamorphic rocks (gneiss, various schists, crystalline limestone and dolomite, quartzite, phyllite and slates), then follow sedimentary formations (sandstone, shale and in a less degree, congolomerate and limestone), and finally igneous rocks (granite facies dominating). These rocks are of very poor primary porosity and only the secondary porosity caused by the post genetic processes and movements is of practical improtance as far as the ground water accumulation is concerned. It means that faults, fractures, joints and slip planes represent ways for the waters percolation, movement and drainge.. As the quantity of accumulated water in an area besides geological factors depends also upon other numerous factors such as topographic, climatic, hydrologic,

/....

vegetative, etc., hydrogeological conditions of this complex are presented for each zone in particular. Such a classification was made by C.K.Sharma (ref.11) whosepatated 4 zones within this complex: High Himalayas, Midland, Mahabharat Range and Churia Hill.

2.1.1. High Himalayas:

They cover the northest belt of Nepal and their average width is about 40 km. Their elevation ranges 3000 m up to 8848 m (Mount Everest). The climate is alpine (tundra) with short and cool summer and severe and dry winter, The lowest temperature at the highest meteorologic station (Teng Boche - 3867 m) was - 11.4°C on 28 th of January, 1970 and the highest one was 17.2°C on 21st of August, 1970. In areas higher than 5000 m (snow line), the temperature is below freezing throughout the year and there is abundant snowfall.

The rainfall is comperatively low: 500 - 1000 mm in western parts and far werstern parts of the zone and 500 - 2500 mm in central and eastern parts. (below the snow line, of course). Because of hard conditions, life is mainly limited up to 3000 m and one can hardly find any village above this height. The vegetation is limited to 4000 m and above this line grass is found up to 4500 m.

Geologically, the area is built up of granite, migmatite and various schists with lenses and beds of marble and crystalline dolomite (cherty) in the soutern belt of the zone. Because of intensive tectonic monements, rocks rather folded, faulted and fissured, so that besides streams, springs represent the main water sources there. Springs drain fissured aquifers and local aquifers formed in the weathering cover. (characteristic mechanical weathering). As they are richy fed by snowfall their average discharge makes 25 - 30 l/sec. There are no data on the variation of spring discharge. It is supposed, however, that they might be perennial providing the forest conservation along with the drinking water development is made.

Snow water from small streams is clean and it can also be used for the water supply. No chemical and bacteriological tests were made. The quality of spring and stream water is believed to be suitable because there are paractically no sources of pollution, Generally, settlements are scarce in this zone and they are located higher than the water sources, so that the gravity water supply systems seem to be best.

2.1.2. Midland Zone:

Between two mountainous ranges, the High Himalayas on the north and Mahabharat Range on the south, lies about 30 km wide belt of law-lying hills and rivers and tectonic valleys, having an average altitude of 2000 m. In the valleys open southwards,the climate is moist sub-tropical, and in the higher areas (over 2000 m), it is temperate. This is the richest zone in Nepal as far as the rainfall is concerned. It ranges from 1000 to 2500 mm in far-western part and eastern part of the zone and from 2000 to 4000 mm in western and central part, the maximum rainfall being in Pokhara area (4500 mm).

Because of favourable climatic, topographic, vegetative conditions and

/....

intensive soil development, about 60% of the total number of inhabitants lives there. It is also favoured by the suitable geological composition because the zone is built up of soft formations subject to the mechanic and chemical desinategration (the other one being more expressed). With the exception of river and tectonic valleys, the whole zone is composed of more or less metamorphosed rocks, the degree of metamorphism decreasing going from the north towards the south. In the northern part are various schists and gneiss with lenses and strata of crystalline limestone and dolomite. In the contral part are phyllites with chlorite schist, quartzite, limestone and dolomite and in the soutern belt are slates with lenses and beds of (cherty) dolomite. The southern boundary between Midland and Mahabharat Range in Western Nepal is not completely definite so that one cannot say where the Eocene sedimentary formation (sandstone and shales), corresponds to the formation making numerous interrupted synclinales in Tansen area stretching west-eastwards.

This zone also coincides with the major fault zones. It can be noticed that numerous rivers in basins of Karnali-Narayani and Spta Kosi make eastern or western bends following the weak points - faults and thrust lines and fold axes. Kathmandu, Pokhara, Dang and Surkhet are typical tectonic valleys located in this zone.

The main water sources which can be developed for the water supply of settlements are, of surface water, numerous streams and, of ground water, springs which drain fissured aquifers and porous water bearing formations in river and structure valleys where ground water can be developed by dug and drilled tube wells.

Most of rivers and streams are perennial and they are mainly fed by rainfalls. During the monsoon and immediately after it, their water is muddy, therefore, which rather complicates and makes more expensive their utilization for the water supply (settling tanks and other treatments are required). The most of settlements are located at the top of the hills or in the upper parts of their slopes because of more favourable climatic conditions and better stability of soil, which means high above the river streams and rather far away, which represents an aggrevating circumstance. Consequently, in areas lacking suitable springs, centrifugal pumps or hydraulic rams with head varying between 30 and 300 m (!) must be applied to utilize surface water. Or, if pumps and rams are preferred to be avoided, a long distance pipe line is required (Tansen and Bandipur are typical examples). In some parts of Western Nepal, during the dry season both surface and ground water is insufficient for people and cattle, so that people is obliged to make pools to collect rain water over there.

Because of the insufficient porosity of most rocks of the metamorphic complex, the srpings of this zone are somehow connected with fault zones and lines, with limestone and dolomite masses and their contacts with schist, phyllite or slates, and, finally, with the weathering cover. As they are mainly fed by the percolation of rainfalls, it should be supposed, because

/....

there are no constant observation measurements, that their discharge greatly varies. It is important, therefore, to make difference between perennial and seasonal (intermittent) springs and between primary and secondary springs in this zone. The more so, because the water supply of the largest number of settlements in this zone is based just upon the spring tapping. According to data obtained by the RA and LDD, 49 completed schemes and 88 water supply schemes presently in different phases of construction represent gravity systems based upon the spring water tapping. According to data got by the WSSD (see table 2), of 71 water supply schemes completed up to now, 36 ones use spring water, and of 14 systems under construction, 3 systems are based upon the spring water.

It is supposed, therefore, that the largest part of 106 new gravity systems (ref. 14) to be implemented in the period from 1975 to 1980, and 100 schemes (ref. 15) for which the UNICEF seeks funds, will be based upon springs also.

As for the ground waters in the river and structure valleys of this zone, the extensive explorations were made in Katmandu Valley only (ref.3 and 11). This valley of eliptic shape, 25 km in E + W lenght and 19 km in N - S width, is deepest where the Bagmati River flows and Kathmandu city is located because of the centripetal dipping. There are deposited lacustrine Neogens (?) - Quaternary sediments whose material originates from the nearby mountains. In the northern part of the valley, detritus (boulder and pebble) of Sheopuri granite was deposited and towards the centre of the valley fine sand predominates. In the southern part of the valley, material derived from the southern hills is found (boulder and pebble). In the central part of the depression, black clay about 210 m thick containing iron phosphate (vivianite) and humus overlies water bearing sands, The water is associated with methane gas and dydrogene sulphide. Deep water bearing formation contains several isolated aquifers up to 458 m deep. Water is confined. In the central part of the valley, above black clay is phreatic ground water whose depth varies between 1 and 4.5 m at most of the places and in several places it is between 4.5 and 12 m. This water is more mineralised than confined and it especially contains more chloride. However, confined water is also not suitable because of the high iron content, the iron being possible derived from virianite or marcasite which are generally found to be associated with peat or black clay (re. 11, page 122). Fe content varies between 0.32 and 9 ppm, which means beyond standards accepted all over the world. Mn content is also higher in some tube wells than the internationally accepted one (it ranges from 0.26 to 0.8 ppm). In the peripheral part of the valley, the position is more suitable as far as the quantity and quality of water is concerned but the water bearing formation is mainly composed of boulder, cobble and gravel which cannot be easily drilled.

In the other valleys, explorations have not been made so far. The Quaternary deposits are, however, supposed to contain ground water in the sufficient quantity and of suitable quality whcih can be developed by shallow

/....

TABLE 2: a/ WATER SUPPLY SYSTEMS COMPLETED (under WSSD)

S. No. 1	District 2	Place 3	Water source spring or stream 4	Discharge of source 5	System production 6
1.	Baitadi	Baitadi	spring		20,000 gpd.
2.	Dati	Silgarhi	stream	90 gpm.	45,000 "
3.	Surkhet	Birendra Nagar	"		50,000 "
4.	Jajarkot	Jajarkot	"		30,000 "
5.	Salyan	Salyan	"		33,000 "
6.	Dang	Tulsipur	spring	200 gpm (min)	82,500 "
7.	"	Ghorahi	"		30,000 "
8.	Pluthan	Tiram Golvang	"		4,700 "
9.	Mustang	Rakhu	"		84,000 "
10.	Gulmi	Jubhung	"		36,000 "
11.	Kashi	Pokhara	stream		600,000 "
12.	"	Gijyan	"		20,000 "
13.	"	Khudi	"		28,800 "
14.	"	Bhimad	"		4,000 "
15.	Gulmi	Thorga	?		14,000 "
16.	Parbat	Falebas	spring		20,000 "
17.	Shyanja	Satanu Dashai	stream		16,000 "
18.	Palpa	Tanson	spring & stream		84,000 "
19.	"	Deule Archal	?		5,800 "
20.	Rupandehi	Butwal	stream		450,000 "
21	Tanahu	Archale Chaur	"		20,000 "
22.	"	Damanli	"		5,800 "
23.	Tanahu	Bandipur	"		135,000 "

/....

1	2	3	4	5	6
24.	Gorkha	Manakamana	Stream		2,200 gpd.
25.	Chitawan	Diyalo Bangalo	"		20,000 "
26.	Malwanpur	Hetanda	spring & stream		300,000 "
27.	"	Bhimfedi	stream		50,000 "
28.	Bara	Amlekhgunj	"		100,000 "
29.	Kathmandu	Tokha	"		40,000 "
30.	"	Jhorhode	spring		4,200 "
31.	"	Topical	stream		40,000 "
32.	"	Jitpur	spring		6,600 "
33.	"	Balambu	"		36,000 "
34.	"	Kirtipur	"		30,000 "
35.	"	Chovar	"		52,500 "
36.	"	Sundharighat	river		400,000 "
37.	"	Sankhu	spring		80,000 "
38.	"	Farping	stream		10,000 "
39.	"	Kathmandu	"		5,000,000 "
40.	Laltpur	Lalitpur (panga)	spring		660,000 "
41.	"	Bungmati	stream		34,000 "
42.	"	Ketini	spring		35,000 "
43.	"	Harishidhi	"		14,000 "
44.	"	Godavari	stream		34,000 "
45.	"	Thecho	spring		158,000 "

/....

1	2	3	4	5	6
46.	Bhaktapur	Baktapur	spring		800,000 gpd.
47.	"	Karkimanthali	"		35,000 "
48.	Shindhupalehon	Chantara	stream		69,100 "
49.	Kavrepalanchok	Sanga	spring		13,000 "
50.	"	Kalleri	"		2,500 "
51.	"	Lamagaun	"		5,400 "
52.	"	Kavre	"		1,800 "
53.	"	Banepa	"		150,000 "
54.	"	Mahendrajhoti	"		3,500 "
55.	"	Dhulikhel	"		30,000 "
56.	"	Panauti Bazaar	"		93,000 "
57.	"	Panauti Sunthan	"		10,500 "
58.	Dolkha	Dolkha	"	36 gpm	3,000 "
59.	Ramechap	Ramechap	"	5 gpm	10,000 "
60.	Shindhuli	Madi	stream		60,000 "
61.	Okhaldhunga	Okhalchunga	spring		60,000 "
62.	"	Rumjatar	stream		60,000 "
63.	Khotang	Lamidanda	spring		11,500 "
64.	Shankhuwa Shawa	Chainpur	"		40,000 "
65.	Dhankuta	Hile Bazar	"		15,500 "
66.	"	Diyale	spring		4,000 "
67.	"	Muga	"		40,000 "

/....

1	2	3	4	5	6
68.	Dhankuta	Dhankuta	stream		47,700 gpd
69.	Sunshari	Dharan	"		462,000 "
70.	Ilam	Ilam	"		34,600 "
71.	Tehrathum	Tehrathum	spring		14,400 "
TABLE 2: b/WATER SUPPLY SYSTEMS UNDER CONSTRUCTION					
1.	Dadheldhura	Dadheldhura	stream	0.25 l/sec	60,000 gpd.
2.	Achham	Ridikot	"	20.1/sec	332,640 l/d
3.	Dailekh	Dailekh	"	28.3 l/sec	231,581 l/d
4.	Pynthan	Lund	"	......	20,160 gpd
5.	Anghakhanchi	Balkot	spring	120 gpm	60,000 "
6.	Gulmi	Righa	stream	13 gpm	33,000 "
7.	Baglung	Baglung	"	6.2 l/sec	
8.	Lamjung	Beshishahar	"	50 gpm	10.5 pgm
9.	Chitavan	Bharatpur	"	180 cu.m/sec	360,000 gpd
10.	Kavnepalanchok	Falate	spring	24.0 gpm	15.6 "
11.	Shindhupalehok	Chautara	?		
12.	Dolkha	Hamdu	spring	11,520 gal/day	13,000 gal/day
13.	Bhojpur	Bhojpur	?		
14.	Dhankuta	Chuliban	stream	63. gpm	195,000 gpd

/....

and reasonable deep wells. The lithological composition of water bearing formations can be guessed by the composition of nearby mountains from which they originate. The larger river and structure valleys are Dang, Surkhet, Pokhara, Mariphant, Banepa and Panchkhal.

2.1.3. Mahabharat Range:

This is the first high hill range facing the wast Indo-Gangetic plain. Its width varies and, as it has been already mentioned, in Western Nepal its boundry with Midland is not clearly definitive (see the map attached where it is, therefore, discountinuously protented). In the other parts of Nepal, the average width of this range makes about 20 km and its altitude varies between 1500 and 3500 m, the average one being about 3000 m. This range is very important for Nepal from the meteorological point of view: first, it blocks the hot dusty wind of the Indo-Gangetic plain from entering the Hidland area and, second, it entraps most of the clouds coming from the south-eastern side of India and cause heavy precipitation in the Terai region.

The climate is temporate with cool and short summer and cold winter with night teperature below freezing. Summer rainfall is dominant and most of the winter precipitation is in the form of snow. In central and eastern part, the rainfall ranges from 2000 to 3000 mm and in western and far western part from 1500 to 2000 mm. Geologically, it is of similar composition as Midland only the soft members of metamorphic complex are rather less distributed there (schist, phyllite and slate). So, in the eastern part of the range dominate granite, gneiss and quartzite, in the middle and western part cherty dolomite with some slates and in the far western part granite and gneiss. The southern boundary with Churia Hills represents the main thrust boundary between the metamorphic complex and the Miocene-Pleistocene series going from Acan (India) through Nepal to Kashmir. Eastern and far western parts of the zone composed of very hard rocks are higher in altitude, steeper in slopes and, consequently, less population; very few villages are located over there. In middle and western Nepal there are more villages which have the same problems as those ones in the Midland with somewhat more favourable conditions in areas where dolomite is found.

The thick forest is the benefit in this range so that numerous springs can be found, particularly on the northern slopes where most of the villages are located. The southern slopes of the range are much steeper because of the above mentioned dislocation.

There are no data on the discharge of springs and its variation. Data on the quality of water are also lacking. It is believed to be good because it has been drunk by ages without any consequences.

2.1.4. Churia Hills:

They represent the southerwards belt of the mountanous complex. They stretch continuously from the eastern to the western boundary of Nepal and their average width is about 20 km.

/....

Their altitude varies between 300 and 1500 m with an average of 1000 m. Humid tropical climate prevails at lower and moist sub-tropical at higher altitudes. Rainfall varies from 1500 to 2500 mm with an anomaly of 3,500 mm in Butwal area.

The hillslopes steeply dip in the south and gently in the north. Northern slopes bear vegetation and some springs, whereas the southern face is dry. Geologically, Churia Hills corresponds to the Miocene-Pleistocene basin composed of gravel, sand and clay beds dipping northwards. Being porous and exposed, no ground water is retained in this area (fast drainage). Drinking water is very limited and people suffer because of it. Hence, there are not many villages over there except in "dun valleys" (inner terai) which are filled with Recent and Quaternary loose deposits (gravel, sand, clay), saturated with ground water at the depth of 9 to 12 m. Water is fresh and fit for the water supply and it can be developed by hand dug and drilled tube wells. The max. depth of the Quaternary deposits is estimated to be about 300 m in the central part of the duns. A great many villages are situated in both valleys, Rapti dun (east) and Deokhuri (west). People use dug wells tapping shallow water which are not properly designed (no proper linig and concrete slab on the top), the percolation being, therefore, common both from sides and top which increases the chloride and nitrate content and bacterias. Hence, waterborn deseases are common. The second layer is therefore, recommended to be tested for the water supply over there.

The ground water table fluctuates from the surface to 12 m. The ground water development might be difficult in peripheral parts because of very coarse deposits (cobble, boulder). Hence, the percussion drilling is recommended, whereas, in the central part of the duns confined water is possible and other drilling methods might be applied. The nearby streams cannot be used for drinking because they are not perennial.

2.2. TERAI REGION:

Between Churia Hill on the north and Indian border on the south lies a flat of Terai about 30 km wide with the elevation of 60 to 300 m. Climate is humid, tropical with very hot summers (50oC) and mild winters.

The summer rainfall comes from the east and it varies from 1,800 mm in the east to 900 mm in the west. In the winter, some rainfall comes from the west so that western part of Terai gets more rain than the eastern one. Hence, the total rainfall is nearly equal within the whole area (1500 to 2000 mm).

Terai is the most densely populated area in Nepal. About 38% ofthe total population of Nepal live in this region. They mostly deal with agriculture and they live in villages which are well organised (compact communities). They mostly drink water from dug wells of different depth; some villages nearby the Indian border are provided with hand pumps. Both dug

/....

wells and pumps tap shallow phreatic aquifer.

Geologically, the Terai is a part of the vast Indo-Gangetic basin which was created in the Pleistoce after the arise of Churia Hill (ref. 11). The contact between Churia Hill and Indo-Gangetic basin is a deep, reverse dislocation of about 3,000 m displacement. The basement consists of hard Precambrian crystalline rocks of Indian shiekd, and in the Nepalese Terai occurs at a depth of 6,000 to 7,000 m. By the aeromagnetic survey, it was found that the Gangetic basin is separated into few compartments by north-south faults. The faults are located east of Kathgodam (India), western part of the Karnali, west of Bagmati and west of the Kosi. Because of them and the east-west running dislocation between Churia Hill and Indo-Gangetic basin, the depth of the basement is different: it lies at shallow depth in the east Nepal(about150 m) and in central and west Nepal it is 6,100 m. The basement dip towards the Himalayas. Some explorations indicate that below the Gangetic alluvium (top formation) lies the Churia formation (Siwalik rocks) and that the Eocene is absent. If the thickness of Churia formation is about 4600 m, then it follows that the thickness of alluvium in the central and west part of Nepal is about 1500 m. Such a thick alluvium composed of differently granulated loose deposits saturated with water represents a huge ground water basin..

Regional surface and subsurface explorations made in Terai suggest that the alluvium material originates from nearby mountains. In the first phasis of sedimentation the largest contribution was made by major rivers such as the Kosi, Gandaki, Karnali and Mahakali and later on, when other rivers came into existence, they also started to deposit their material (Recent fluvial deposits). Hence, there are two generations of deposits in Terai whose general mechanism of sedimentation is presented hereinafter in short.

During the formation of Indo-Gangetic basin (Pleistocene), the major rivers started to fill the basin up. Most of them were of the long course before they came out of hills carrying and depositing into the basin fine gravel, sand and caly mainly. The coarser material was deposited near the mouth (in front of hill) and finer far away (Indo-Nepal border). The material is well sorted and it makes a good aquifer. The area between two fans (between two major rivers) was also filled up by finer deposits mainly.

Under the heavy load of incoming detritus, during the main sedimentation, the Indo-Gangetic trough was slowly sinking and, as an isostatic balance, the nearby Churia hills had started rising. The sinking of Terai and rising of mountainous part was confirmed by some geological findings (invarse sequence of sediments) and the sinking was also confirmed by the archeological investigations.

Superimposed on the general sedimentation of older alluvium is the local river effect of recent alluvium. Recent rivers originate either in th Churia Hill or in the Mahabharat range. Those ones from the Churia Hills

/....

deposited clastics, made of sandstone, and shale mainly, poorly sorted. These sediments were also deposited in fan shape. In such areas good aquifers are limited.

Rivers from the Mahabharat range carried detritus of harder rocks (quartzite, gneiss, dolomite, and the others, see the geological composition of Mahabhar range). Deposits are well sorted and they are corser than major river deposits. They form good aquifers. The coarse material (boulder, cobble and gravel) was deposited first (on the northern belt of Terai) and then gradually followed finer material (in the central part of Terai) and the finest material was deposited in the southern belt of Terai.

* * *

Having in view facies changes and different hydraulic mechanism of ground waters formed in the sedimentary complex, the Terai region can be hydrogeologically separated into three zones: northern, so called bhabhar zone, middle or marshy (artesian) zone and southern zone - flat lands (ref.11).

The zone mentioned are presented separately for Eastern Terai, central and Western Terai (see attached map).

2.2.1. Eastern Terai:

Eastern Terai is situated between the rivers Sapta Kosi and Mechi. According to the administrative division, three districts correspond to : Sunsari, Marang and Jhapa. The most important towns are Biranagar, Dharan and Bhadrapur.

The elevation at the southern end of the Terai is about 60 m and in the northern part, it ranges from 230 to 430 m. In this area the Churia Hills is not well developed and the rocks of the Churia formation are found at the foot of the Mahabharat range.

The rainfall ranges from 2,500 mm in the foothill to 2,000 mm in the southern part of the Terai. The relative humidity varies between 65% in March and 91% in January.

The Bhabhar Zone starts from the base of the bill and most of rivers pass through it while they originate from the Mahabharat range or the hinterland. As soon as the major rivers reach the Bhabhar zone, their discharge is reduced, and the minor rivers vanish immediately and after crossing this zone water reappears in the river bed. Being highly porous it acts as a recharge zone for the ground water of the Terai.

Generally, the Bhabhar zone is composed of boulder, pebbles and gravel of hard quartzite and gneiss of the Mahabharat range and clastics of sandstone of the Churia hill are sporadically found. On the top of these deposits, the clay layer 1 - 2 m thick can be noted. The water table varies from 30 to 90 m, below the surface. The drilling should be performed by a heavy duty persussion rig. In the southern part of this zone, the water table rises to the ground surface which is marked by the spring line. It indicates the beginning of the middle zone. At the Tarhara farm, in two dug wells the following sequence was found: 0-1,8 m top soil; 1,8-3,4 m fine sand and from 3,4 to7,6 coarse gravel, pebble and cobble. A dug well can produce 40 gmp with few inches drawdawn which suggests the transmissivity of the aquifer of the order of 100,00 gpd/f. This andicates that in the southern tip of Bhabhar zone the high capacity wells can be constructed.

The Middle Terai Zone starts from the spring line mentioned and it stretches southwards to Dhubi Bazaar. This zone consists mainly of sand, clay, gravel and cobble. In the top aquifer (phreatic), the water table is sometimes nearly at the surface and in the other places it is 3 to 4.6 m. The confined aquifer system with artesian conditions starts in this zone at a depth of 25 m. Because of belowout, the careful and precise control of the density and viscosity of the drilling mud is required.

The Flat Land Zone stretches from Dhubi Bazaar up to the Indo-Nepal border. The area is flat and it mostly consists of sand, silt and clay which make a poor water table aquifer. The Biratnagar town water supply draws water from this aquifer.

2.2.2. Central Terai

The Central Terai covers the area between the Narayani River in the west and the Kosi River in the east. Two dun type valleys are found: Trijuga in the east and Chitwan (Rapti) valley in the west.

Administratively, this area includes the following districts: Saptarr, Siraha, Udayapur, Dhanisha, Mahotari, Sarlahi, Rauthat, Barsa and Chitwan. There are few important towns: Rajbiraj, Siraha, Janakpur, Jaleswar, Malangwa, Gaur, Kalaiya, Birganj and Bharatpur.

The Central Terai can be divided into 4 zones: Dun Valley (Inner Terai), Bhabhar zone, Middle Terai and Flat Lands.

Dun Valleys.- As it has been already mentioned, there are two valleys of this type: Trijuga in the easternmost and Chitwan in the extreme western part. In both valleys, at northern and southern edges dominate boulder and pebble and deposits while in the exial part, where the rivers are located, the finer deposits like gravel, sand, clay are found.

These clastics consist mostly of Churia sandstone. The confined aquifer seems to be limited. The depth of water table ranges from 3 to 9 m.

Bhabhar Zone.- It is well developed in the middle part of the Central Terai. There are deposited boulders and boulders and cobble of Churia sandstone, except in the influence area of the Bagmati rivers where boulders of granite, quartzite and gneiss are suspected. The depth to the water tabel ranges from

/....

30 m at the northern edge to 9 m at the middle edge and nearly at the ground surface in the southern part. Most rivers originating from the Churia Hills after entering this zone gradually sink at the northern edge and they again appear at the southern edge of this zone. The southern edge of this zone is marked by a seepage line at an altitude varying between 122 and 153 m. In this part of Bhabhar Zone, there has been drilled one well only (at Dharapani, 96 m deep). Its geological log suggests the poorly sorted material. The water level is found at 24.4 m depth; the transmissivity is 6929 gpd/ft and the cons radius is 262 m. This example, however, should not be characteristic for the whole zone.

The Middle Terai is south from the seepage line and the water table of the phreatic/aquifer is only 1-2 m below the surface. The area mainly consists of sand, gravel and clay. At Malangwa, Parsa, Janakpur, the northern part of Siraha and south of Jaleswar, the confined aquifer can be found approx. at 60 m. The thickness of quifer ranges from 6 to 30 m. The artesian condition is absent only in Birgunj and Rajbiraj areas. Table 3 shows some main data on the wells drilled in the Middle Terai zone.

The Soutern Flat Land consists of clay, silt and fine sand at the top saturated with ground water. These aquifers might not be feasible for the heavy ground-water development.

In the Birgunj area (ref. 6), in an area of about 200 sq.km., the phreatic aquifer has found to be present everywhere. The water level is a few meters below the ground surface. It varies considerably with the incidence of rainfall. Water level measurements on 14 wells tapping the phreatic aquifer show that the annual average fluctuation is about 3 m. According to the values of electrical conductivity and the total dissolved solids (TDS) got from 23 wells, the quality of water should be quite satisfactory. The conductivity ragnes from 280 to 350 micromhos and the TDS from 185 to 560 ppm.

2.2.3 Western Terai

Western Terai is not a continuous strip. It is, therefore, presented here as Lumbini, Bheri and Seti-Mahakali zones.

2.2.3.1. Lumbini Zone

The Lumbini zone is situated west of the Narayani River (see map) and it includes three districts: Nawal Parsi in the east, Rupandehi in the middle part and Kapilvasti in the west. The Terai belt is about 120 km long and 40 km wide.

Climate is tropical and the temperature rnages from 7°C in December to 36°C in May. The rainy season generally starts in June and it ends in September. Rainfall is about 1200 mm in the middle Terai.

Hydrogeologically, the Lumbini zone can be divided into Dun Valley, Bhabhar zone, Marshy land and Southern flat ladd (ref.11).

/....

TABLE 3: some basic data of the wells drilled in the Middle Terai Zone (after C.K. Sharma)

Location	Static Water level/ft/	Pumping dischage /gph/	Drawdown /ft/	Well depth /ft/
Kalaiya	14	45,600	23	360
Parwanipur	15	45,000	18	420
Jitpur	15	40,200	33	200
Pachaule	13	46,800	14	350
Chainpur	16	47,000	13.5	330
Ramporatokni	28	48,000	13.5	390
Parsoni	24	48,000	13.5	390
Khutwa	22	48,000	13	390
Chosini	11	43,500	20	230
Barewa	22	42,000	18	430
Biratnagar	21	54,725	11	252
Shivnagar	11	56,409	10	240
Chainpur	20	58,000	12	320
Salimpur	30	41,046	16	324
Lakshmipur	9	62,696	10	350
Kaurera	14	54,405	10	330
Bishanpur	24	35,000	18	340
Khutanne	14	52,000	12	330
Simra	7	61,186	10	-
Average	17.2	48,970	15.4	

/....

The Dun-type valley is located in the eastern part of the Nawalparasi area and it is a continuation of the Rapti valley. The marginal sediments of this valley (boulder and pebble) are derived from the Churia Hills (sandstone) and in the central part of it fluvial deposits brought by the Narayáni River are found dominating. Generally, the area is good for the ground water development in the central part, whereas in the boulder-pebble belt of the foothill, the ground water development may not be feasible.

The Bhabhar zone is discontinuously found along the foot of the Churia hills. The zone is highly permeable (boulder, pebble) and most of the rivers flow underground and they reappear at the southern edge of this zone. The water table depth ranges from 15 to 18 m at the northeen edge, from 9 to 12 m in the middle part and nearly at the ground surface at thesouthern edge which is generally marked by a spring line. Several wells have been drilled to a depth of 91 m, yielding 350 gpm at cca 3.7 m drawdown. The zone consists of gravel, pebble and boulder (few horizons each one 9 to 15 m thick). The transmissivity ranges from 190,000 at the northern edge to 815,000 gallons per day per foot/gpdf/. The quality of water is good (law mineralised). The fluctuation of water table ranges from 2 to 3 m in general and the maximum makes 5.5 m at Manigram before the onset of rain. After the rains, the water table recuperates within a month.

The Middle section or marshy land of the Lumbini zone starts from the spring line and extends 10 to 15 miles towards south. The lithology of individual strata gradually changes: the boulder-pebble zone transits into gravel and snad beds in the middle part of the area and, finally into silt and clay in the southern end which causes a reduction of porosity and permeability going to the south. The transmissivity varies between 236,000 and 50,000 gpd/f. Wherever the ground surface is law, compared to the head overflowing conditions are found. In marshy areas the water table is found either 2 m below the surface or on the top. Therefore, the water - logging condition was developed creating toxic conditions and affecting agricultural yield.

The southern flat area contains strata composed mostly of fine sand, silt and clay. The water table in phreatic aquifer is found within 6 m.

* * *

As for the chemical composition, there are two groups of water in the Lumbini Zone: shallow water tapped by dug wells and deep water tapped by deep tube wells. About 200 dug wells have been checked and data obtained show the following variations:

	Average	
Ca 25 to 200 ppm	79.3	ppm.
Mg 30 to 150 ppm	36	"
Na + K 50 to 150 ppm	111	"

/....

HCO_3 250 to 600 ppm .... 423 ppm.
So_4 40 to 80 ppm .... 53 "
CI 59 to 250 ppm .... 116 "
Dissolved solids 300 - 900 ppm ..... 757 "
Total hardness 200 - 300 ppm ...... 295 "
Alkalinity 299 - 300 ppm .... 244 "
Non-carbonate hardness 0 - 50 ppm .. 43.3 "
Sp. Conductance 400 - 200 (micromhos) 771 (micromhos)
PH 7-8 .... 7.5

In deep wells water contains almost twofold less amount of major chemical constituents as compared to dug wells.

2.2.3.2. Bheri Zone:

This zone lies in the western part of Nepal, to the east of the Karnali River (see a map). The Rapti River flows in the estern part and the Babai River in the central part of the zone. It includes the districts of Banke and Bardiya with the district seats of Nepalganj and Gularia.

Hydrogeologically, this zone can be divided into Bhabhar, Marshi and Southern flat land.

The Bhabhar zone is developed in the interinfluence area of the Babai and Karnali rivers and also in the north of Shumserganj in Rapti area. It is composed of boulder, pebble and sand.

The Marshi land is very limited in the middle part of Bheri Zone. The water bearing formation consists of unsorted pebble, sand and clay. The high pressure artesian condition is found at Thukuli and Madaha.

The Soutern flat land is well developed in the Bheri Zone but its main part lies in the Indian territory. It is mostly composed of alluvial clay and silt. Table 4 shows some main data on deep aquifers in the Bheri Zone.

TABLE 4: Geohydraulic Characteristics of Aquifers in Bheri Zone (after Sharma)

Zone	Location	Screened interval /ft/	S.W.L. (Head) + above - below /ft/G.S.	Specific capacity gal/ft.	Transmissivity g/day/ft
1	2	3	4	5	6
Bhabhar	Dhakela	126-124	-24	8.0	56.000
	Madaha	190-211 & 220-230	+ 2	3.0	18.000
Artesian	Udai	209-216	+35	19.0	20.000
	Thukuli	412-430	+21	54.0	49.000

1	2	3	4	5	6
Non-artesian	Agriclfarm	100-111	- 34	0.82	36.000
	Vodarpurva	191-211	- 27	0.56	17.000
Soutern flat land	Panchayat training c.	141-260	- 15	16.0	20.000
	Jumunaha	410-430	- 16	29.0	132.000
	Taratal	267-285	- 24	27.0	84.000
	Kanthapur	390-429	- 33	10.0	135.000

The chemical composition of water of deep well shown in Table 4 is as follow (ppm):

Ca .... 8 - 68

Mg ....18 - 79

HCO_3 ....194 - 422

SO_4 ....nil - 162

Cl ....5 - 8

Hardness ....143 - 244

Alkalinity ....159 - 346

PH ....7.6 - 8.6

Spec. conductance /micromhos/ ....293 - 683

CO_3 .... 0 - 14

Total dissolved solide ....220 - 552

Solium & Potassium .... 3 - 64

Non - carbonate hardness .... 0 - 1

2.2.3.3. Seti-Mahakali Zone:

Seti and Mahakali zones lie in Far-Western Nepal, between the Karnali River on the east and the Mahakali River on the west. This zone includes the districts of Karnali and Nanchanpur.

The Bhabhar zone is discontinuously exposed at the foot of the Churia Hills. It consists of boulder, cobble, pebble and sand. It is very porous, the recharge is heavy and most of the rivers running through this zone are found

/....

to be recharging the aquifer. The water table is at around 15 m below the ground surface with the summer fluctuation between 6 and 9 m.

The contact between Bhabhar and Marshi Land is marked by a spring line.

The Marshy Land extends up to the Indo-Nepal border in the Dhangargi section Nearly five layers of confined water under the high pressure (+10.7 m at Geta and +19.2 m at Ganeshpur) are found in this area. The transmissivity ranges from 25,000 to 50,000 gpd/ft. Table 5 shows some main data on the hydraulic characteristics of aquifer of Seti-Mahakali Zone. Numerous chemical analyses of water taken from deep wells show that the quality of water is suitable both for the irrigation and drinking purposes.

The Southern Flat Land is of limited extent in the Seti-Mahakali Zone. It lies along the Indo-Nepal border and it is composed of sand and silt saturated with ground water. The water table ranges from 9 to 14 m. below the ground surface.

3. FEASIBILITY OF TAPPING GROUND WATER IN THE TERAI BY SHALLOW TUBE WELLS

In Terai there are two sources of water which may be taken into account for the water supply over there. They are big rivers and underground water. Samll streams originating from Terai and Churia Hills are seasonal and they cannot be taken into account. As the big rivers are far away from each ather, comperatively small number of settlements could be provided with water. On the other hand, the river water is muddy and as a rule, it is polluted, so that the large investment should be made to utilize it. Accordingly, the underground water is the most suitable water source, it is abudant, it can be found at the small depth and it is of good quality and it should be only properly tapped.

3.1. Hydrogeological Conditions:

On the basis of above chapter, the following conclusions on the underground water occurence in Terai can be made:

In the Eastern Terai are developed three zones with specific hydrogeological features. The Bhabhar zone consists of boulder, pebble and gravel saturated with the ground water which is of free water table. The water table is in the middle and northern part of the zone, at the depth of 30-90 m, and it gradually decreases going southwards, at the souther edge, however, being immediately on the ground surface (spring line).

The Middle Terai Zone (marshy zone)contains two types of aquifer: the confined aquifer with artesian conditions and the shallow phreatic aquifer which is composed of gravel, sand and clay. The water level in the phreatic aquifer is between 3 and 4.6 m and in some places it is on the ground surface. The confined aquifer system starts at a depth of 25 m.

The Flat Zone Land is composed of sand, silt and clay saturated with ground water which has the free water table in the sub-surface zone.

/....

TABLE 5: Geohydraulic Characteristics of Kailali & Kanchanpur (after Sharma)

Zone	Location	Screened interval /ft/	S.W.L.(Head) + above - below /ft/G.S.	Specific capacity (gal/ft)	Transmissivity g/day/ft
BHABHAR	Durgauli	50 - 80	- 11	18	232,000
	Mahendranagar	52 - 105	- 8	10	140,000
ARTESIAN	Ganeshpur	263 - 279	+ 62	4	45,000
	Gandraiya	219 - 240	+ 14	5	33,000
	Dhangarhi Patia	197 - 217	+ 22	6	54,000
NON-ARTESIAN	Bichuwa	48 - 59	- 6	10.2	185,000
	Bijaypur	275 - 285 307 - 317	- 6	2,5	37,000
SOUTHERN FLAT ZONE	Punarbas	275 - 304	- 45	8	
	Basanta	155 - 175	- 18	5	12,000
	Pachni (Calcutta)	291 - 311	- 13	14	197,000

<u>In the Central Terai</u> four hydrogeologial units can be found going from Churia Hills to the Indo-Nepal border.

So called Dun Valleys (Inner Terai) are filled by the Quaternary loose deposits which are at the norther and souther edge of the valley represented by boulder and pebble and in the cenrtal part by gravel, sand and clay. The aquifer is mainly phreatic and the water table is at the depth of 3 to 9 m.

As in the whole area from the eastern to the western border of Nepal, the Bhabhar zone consists of boulder and pebble saturated with ground water at the depth of 30 m at the norther edge of the zone, 9 m in the central part and at the surface itself at the southern edge of the zone which is clearly marked by a spring line.

In the middle Terai zone, the water bearing formation consists of

/....

gravel, sand and clay. The confined aquifer system starts at the depth of about 69 m and the water table in the top phreatic aquifer is at the depth of - - 2 m only.

In the southern Flat Land, the shallow, phreatic aquifer consists of fine sand, silt and clay and the water table is few meters below the ground surface.

The Western Terai represents a discontinuous region consisting of Lumbini, Bheri and Seti Mahakali zones.

In the Lumbini Zone four hydrogeological units can be separated.

The Dun valley consists of boulder and cobble in its marginal northern and southern part and of fluvial gravel, sand and clay in the central part. Ground water is at the reasonable depth.

The Bhabhar zone consists mainly of boulder and pebble saturated with ground water which is found at the following depth: at the northern edge at of the zone at 15 - 18 m, in the central part at 9 - 12 m, and at the southern edge at the surface (spring line).

The Marshy Land is characterised by the gradual lithological changes from gravel-sand in the northern part to silt-clay in the southern part. At the greater depth is the confined aquifer system and at the sub-surface is the phreatic aquifer with the water table whose depth ranges from 2 m to the surface itself.

The Southern Flat Zone contains aquifers composed of fine sand, silt and clay and the water table in the top aquifer is at the depth to 6 m.

The Bheri Zone consists of three hydrogeological units.

The Bhabhar Zone is composed of boulder, pebble and sand saturated with ground water at the depth varying between 7 and 15 m.

The Marshi Land contains confined and phreatic aquifers. Aquifers are composed of gravel, sand and clay and the water table in the phreatic aquifer is close to the ground surface.

In the Southern Flat area, the phreatic aquifer is composed of sand , silt and clay and the water table varies from 4.6 to 10 m below the ground surface.

In the Seti-Mahakali Zone three hydrogeological units can be separated.

The Bhabhar zone consists of boulder, pebble and sand and the water table is below 15 m. The Marshy Land contains confined aquifers with artesian conditions above which lies the top, phreatic aquifer with the water table at the depth of 2 - 3 m.

Finally, the Southern Flat unit with the phreatic aquifer consists of sand and silt and the water table varies here between 9 and 14 m.

* * *

As there is a comperatively small number of big towns in Terai for which the large quantity of water should be provided by deep wells, there remains an open question of numerous small rural communities whose requirements for water may usually be met by providing a water source whose discharge makes few litres per second only. These communities may be provided with water in three ways:

1. By the existing exploratory well (about 200) and small dia. research wells (about 200). Most of them are overflowing and they are close to settlements, so that the only thing which should be done is to convey water to settlements by the piping . Some of thses wells are observatary. They can also be used for the water supply providing the certain adaptation is made to enable measurements of pressure and discharge and the water samplaing. Some of test wells are in the phreatic aquifer and the other ones are in the confined aquifer with subartesian conditions. They can be used providing either hand or diesel pumps are installed relative to the size of the settlement.

2. By improving some of the large number of dug wells. According to some information obtained, there is a lot of dug wells properly lined, so that only a concrete slab and pit for the waste water conveyence should be made and a hand pump installed, by the sanitary and technical survey to be made on the spot, it will be decided which wells may and should be successfully improved.

3. By drilling the new shallow tube wells in whose Terai except in the Bhabhar zone where the special equipment is required for the construction of wells. Some preliminary observations show that the shallow phreatic aquifer can be found in the whole central and southern part of Terai which is most densely populated; the similar case is also in the central parts of dun valleys (Inner Terai). The water bearing formation is mainly soft and drilling can easily be made by light rigs. Judging by the depth to the water table, the far largest number of wells should be 10 to 20 m deep, exceptionally 30 m. It is understood that the upper 5 to 6 m of the aquifer cannot be tapped because of sanitary reasons (this part should be protected). Taking into consideration the seasonal water table fluctuation and the paln according to which a large number of minor irrigation schemes will be made, also based upon shallow wells, i.e. the phreatic aquifer which might cause an additional lowering of the ground water table, it follows that the average depth of well will make cca 15 m. All wells should be provided with hand pumps whose cylinders should be in wells. It will increase the price of wells, i.e. the per cpita cost, but in such a case the continuous water

production even under the most unfavourable hydrogeological cinditions will be provided.

3.2. Drilling Method and Equipment Required:

As it is a question of small diameter shallow well drilling, light drill rigs lounded on light 4 wheel drive vehicle may be the most suitable ones. It has already been mentioned that the settlements in Terai are rater compact. Because of the lack of roads, it will be difficult to transport drill rigs to the well locations in the central part of the settlement. The drill rig should be, therefore, easily transportable even by oxcart or man power. Generally, settlements cannot be easily reached because of bad and infrequent roads. With the exception of magistral roads, they are surface roads which cannot be used in the rainy season at all. Providing of machine tools for the temporary road construction should be considered, therefore, Bulldozers and graders are too heavy. The most suitable might be a tractor with a bulldozer blade which can be used both for the local transport and short provincery road construction to the village and inside the village.

As for the transport of drill rig to the long distance, the four wheel drive 1 - 2 t pick-up or 6 persons and the space for the transport of material may be the most suitable. All engines should be diesel-driven because of economy.

Which drilling rig might be the most economic one as far as the well drilling in Terai is concerned? Although it is a question of shallow wells, the drilling by hand tools is not suggested by purpose. On the basis of experience got in numerous undeveloped countries, it can be said that there is no adequate interest and affinity for such a kind of drilling. In case Nepal is an exception, then go ahead - there are quite favourable conditions for the application of this type of drilling in Terai from the hydrogeological viewpoint.

Drilling rotary rigs are rather more complicate for handling and more expensive than the other type of rigs. Drilling mud should be used which means that bentonite of good quality should be provided and the constant control of the quality of fluid should be made: on the other hand, the well development is more complicate because it is not easy and simple completely to take away the mud cade. Such a drilling requires the well skilled and experienced drilling crew, However, it is a problem because the Nepalese have no experience in the shallow tube well drilling. It is suggested, therefore, to use the cable tool type rig first, then the continuous auger drilling and finally jet drill rigs. The adventage is in their being cheaper, easier to be handled and maintenanced and, besides, the drilling staff can be more easily trainedto use them. The cost of such rigs with the complete toll for the drilling is appox. as follows:

cable tool rig 20,000 - jet boring rig 15,000 and continuous auger drilling 12,000 US dollars.

One can find cheaper rigs, of course, but the ones suggested above are of such a capacity that they can meet the requirements for the well drilling in whole Terai and Inner Terai with the exception of areas where the aquifer is composed of boulders and pebble. In case of last mentioned, the heavy duty cable tool rig should be applied. Fortuantely, there are few settlements in these areas only so that a small number of wells required can be made of rigs and the experience drilling crew. To drill these wells the local contactors (2) or contactors from India can be engaged.

3.3. Well Design Construction and Cost:

Each tube well equipped with the hand pump should meet the requirements for water of 200 to 250 people relative to the density of population. Because of the certain import upon the people, the distance between two adjacent wells should not exceed 100 to 150 m.

The public wells should provide the continuous exploitation within a long period and the maintenance should be as easily as possibly (well clearance, pump repair, etc.). In contrast to the hitherto experience, it is suggested, therefore, to drill large dis wells (final dia. 6 inches), to instal 4 inch PVC casing and screen (chemically very resistant, hard enough for shallow wells, and besides, cheapest and lightest), to instal filter-packing and the protection of the upper part of well (up to the depth of 5 to 6 m relative to the local conditions) by bentonite or grout. Of course, at the surface should be made a concrete slab, drain and pit for the waste water conveyence (5 - 10 m far away from the well relative to the permeability of the top layer).

Generally, most of future tube wells will tap the phratic aquifer which is composed of silt, various grained sand and, in some areas, finer gravel. Regarding the filter pack suggested, it can be foreseen that the screen slot of 0.5, 1.0 and 1.5 mm and the filter packing with fractions of 0.5 - 1, 1 - 2 and 2 - 3 mm respectively, will meet all requirements in Terai and Inner Terai. As for the scope of providing each of srreen slot size mentioned, the answer should be given by a team of experts whose task, besides other things, should be to study all the existing hydrogeological documentation and to make additional investigations in the field lacking the data. For the beginning, for the slot size 0.5, 1.0 and 1.5 mm, the ratic of 1:2:1 might correspond, i.e. of the total quantity of screen, 25% should be of 0.5 mm slot size, 50% of 1.0 mm slot size and 25% of 1.5 mm.

For the well development, in addition to the above mentioned equipment a light compressor should be also provided. It may be sufficient for three drilling rigs suggested above.

* * *

The price of a shallow well provided with the hand pump greatly differs.

* * *

According to K. Jagtiani (Ref. 6), the well 50 ft deep, 4 inch dia. drilled by jet boring equipment and equipped by a pitcher pump, costs N.Rs. 500. Providing a well covers 200 inhabitants, then the per capita cost makesN.Rs.2.50 only. The price mentioned does not include the price of platform, drain and soaking pit.

* * *

According to A. Moller (ref. 8) the well 60 ft deep, with a drilling dia. of 4 inches and casing/screen dia. of 3 inches, drilled by a direct rotary rig, is priced NRs. 3,800.- If to this price, it is added the installation of a hand pump (with a cylinder and raising main inside the well) and the construction of concrete foundation at N. Rs. 2,200.- then the total price of the well makes N.Rs. 6,000.-,i.e. per capita cost of Rs.30.-

According to the same author, the price of lining of an existing dug well with concrete rings makes N.Rs. 2,400.- If the price of hand pump and construction of the concrete slab making N.Rs. 2,200.- is added to this price, then the total cost of the improvement of an existing dug well makes N.Rs.4,600.- The per capita cost is N.Rs.23.0 in such a case.

According to G. Stern and K. Anderson (Ref.12), the price of a shallow tube well to be used for the irrigation makes N.Rs.3,500.- If a pump set isinstalled into (as suggested by A. Moller at N.Rs. 2,200.) then the total price of the well makes N.Rs. 5,700.- or N.Rs. 28.5 per capita.

* * *

The highest price of a well 15 m deep is obtained if the local unit price for the drilling (table 6) and casing/screen (table 7) is applied:

- drilling 6 inch dia., 15 m à 410 N.Rs.	N.Rs.	6,150.0
- 4 inch steel casing, 11 m à N.Rs. 196.8	"	2,164.8
- 4 inch steel slotted pipe 4 m à 393.6	"	1,574.4
- gravel packing, 250 N.Rs. per well	"	250.0
- hand pump set with cylinder into the well	"	1,500.0
- pump installation	"	200.0

Total well cost : N.Rs. 11,839.2.-

The per capita cost 11,839.2 : 200 = 59.20 Nepalese rupees.

* * *

/....

TABLE 6 : WELL DRILLING COST:

Well depth/m/	Drilling dia.(inch)	Unit price (N.Rs/ft)	Type of drilling
10	2	30	Hand auger & machine
20	2	40	"
10	4	60	"
20	4	80	"
50	4	100	Machine
100	4	160	"
10	6	100	Machine & hand auger
20	6	150	Machine
50	6	160	"
100	6	200	"
50	10	200	"
100	10	250	"

TABLE 7 : WELL CASING AND SCREEN COST:

Steel casing pipe (made in India)		Slotted iron pipe coated with brass (INDIA)	
Dia. (inch)	Unit price* (N.Rs/ft)	Dia. (inch)	Unit price* (N.Rs./ft)
2	20	2	40
4	60	6	120
6	140	6	280
8"	200	8	400
10"	250	10	500

* Transport and all texes included.

* * *

Finally, here is also a price of a well 15 m deep, dia 6 or 8 inches, drilled by a cable tool rig, with an installed 4-inch PVC casing and screen and a hand pump set with a cylinder and raising main into the well.

It is support thata drillin crew may finish 5 wells a month,i.e. 40 wells a year.

/....

e/	One assistand driller, annual gross salary 12 x 250....	N.Rs. 3,000
f/	Two skilled labours for drilling, annual gross salary 2 x 12 x 150	N.Rs. 3,600
g/	One driver (for pick-up), annual gress salary 12 x 200..	N.Rs. 2,400
h/	One driver for tractor (for 3 drilling units) annual gross salary for one drilling unit 12 x 200 :	N.Rs. 800
i/	One driver helper (for tractor and for 3 drilling units), annual gross salary for one drilling unit 12 x 150 :3	N.Rs. 600
j/	One mason, for 3 drilling units, annual gross salary for one drilling unit 12 x 350 : 3	N.Rs 1,400
	Personnel total	N.Rs.22,000.-

The rate per one well 22,000 : 40 .... N.Rs. 550.-

3. Well casing and screen (PVC without custom duties)

a/	4-inch PVC casing, 11 m à 63.36 N.Rs. (US $ 6)	N.Rs. 697.00
b/	4-inch PVC screen, 4 m à N.RS. 168.96 (US $ 16)......	N.Rs. 676.00
c/	One bottom plug N.Rs. 21.12 (US $ 2)	N.Rs. 21.00
	Total under 3:	N.Rs. 1934.00

4.	Gravel packing, 250 N.Rs. per well	N.Rs. 250.00
5.	Diesel, oil, etc. N.Rs. 300 per well	N.RS. 300.00
	Total well construction 1-5	N.Rs.3,655.00.-
6.	Well protection (concrete slab, drain, pit).........	N.Rs. 250.-

7. Hand pump set

a/	hand pump body	US $ 48.0	
b/	galvanised iron pipe, 13 m à $4.4	US $ 57.2	
c/	steel rod, 13 m à 1.2 dollar	US $ 15.6	
d/	brass cylinder	US $ 54.0	
e/	reducing brush barrel	US $ 8.4	
f/	barrel nipple	US $ 2.4	
g/	brass foot vlave	US $ 4.8	
	Total 7/	US $ 190.4	N.Rs. 2.011

Total well cost 1 - 7 ....N.Rs. 5,916.-

The per capita cost 5,916 : 200 = N.Rs. 29.6 .-

../....

It should be emphasied that the above mentioned is a rough estimation only. The actual price of the well and the most effectiveness and suitability of drilling equipment as far as Terai is concerned, a y realised only after a two-year project whose implementation is suggested herewith before any large scale water supply project for rural communities in Terai based upon the shallow tube wells and hand pump programme.

4. GOVERNMENT AGENCIES INVOLVED IN THE WATER RESOURCES EXPLORATION AND EXPLOITATION

At present there are three grovernment organisations sharing the responsibility within the water supply and sanitation sector. They are: the Water Supply and Sewerage Board (WSSB), Water Supply and Sewerage Dept. (WSSD), and Remote Area, and Local Development (RA & LDD). Besides the Sector is the Nepal Resettlement Co. whcich, besides other things, also provides people moving into the new areas with minimum facilities regarding the water supply.

The other organisations worth mentioning regarding the activity of the Section are, first of all, the Ground Water Section within the Irigation, Hydrology and Meteorology Dept. under the Ministry of Food and Agriculture and the Bureau of Mines and Geological Survey under the Ministry of Industry and Commerce which is of indirect importance as far as the ground water exploration and development are concerned.

4.1. Water Supply and Sewerage Board:

The Water Supply and Sewerage Board is a semi-autonomous government organisation established in 1973 with the responsibilities of as follows (7):

a/ the maintenance of the exsiting water supply and sewerage systems in the Kathmandu Valley and Pokhara, and

b/ the implementation of " the Water Supply and Sewerage Project for Greater Kathmandu and Pokhara", a project assisted with a credit from the International Development Association of the World Bank.

This organisation is headed by the Board of Directors, whose chairman is the Secretary to the Ministry of Water and Power, and the other members are the representatives from the Government Ministries of Finance, Panchayat, Health and the Naticanl Planning Commission.

This organisation is to be additionally dealt with. It is worth mentioning, however, that this organisation lacks the unit provided with the relative equipment and technical personnel either for the surface or underground water resources. The definition of water sources in the terms of

/....

quantity and quality is left to the foreing and local consulting and executive organisations.

4.2. Water Supply and Sewegare Department:

The Water Supply and Sewerage Department was established in 1972 under the Ministry of Water and Power with the responsibility for the water supply in medium size and large communities with the population exceeding 3000 including zonal and district headquaters and excluding only those ones under the WSSB juridiction (Greater Kathmandu, Bhaktapur and Pokhara). It is also responsible for the sewerage in urban centres. In addition to the head office in Kathmandu, for the actual execution of the project, temporary field offices are established (the construction period varies between 2 and 4 years depending uponthe size of the project). After the completion, the project is usually overtaken by the local authorities for the operation and maintenance. As it can be moticed from Table2, up to now 71 water supply projects were completed in the Hills based upon spring and stream waters and 9 systems in Terai based upon the deep well water. They are: Birgunj, Janakpur, Biratnagar, Bhadrapur, Mahendranagar, Dhangarhi, Nepalganj, Rajbiraj and Bhairawa. The water supply systems under construction in the Hills are listed in the other part of Table 2 and those in Terai are Kalaiya, Gaur, Jaleswar, Malamgwa, Tamlihawa and Tikapur. All projects mentioned have been planned to be completed by July, 1978. The number of new projects to be constructed within the next five year plan (1975-80) are: minimum programme 90, maximum programme 110 schemes. The responsible staff in the WSSD could not tell us which settlements were included into the water supply programme.

In the Department there is no special unit for the ground water exploration and there is also no professional and subprofessionall staff. The certain unmber of engineers attended a course on ground waters so that problems concerning ground waters are not quit unfamiliar to them, In the Department there is one direct rotary rig (Winter Weiss Portadrill) by which the drilling up to 1500 ft can be made. It should be, however, completely overhauld. Up to now about 20 deep wells have been drilled by it exclusively for the exploratory purposes. Of the technical staff, there is one driller only (who has been ill for a long time) and few unexperienced helpers.

For the productive wells, at present, are engaged the Indian contractors, mainly from the Hindustan Tube Well Co., Patna, India. The certain number of deep wells was drilled by the Groundwater Section of the Dept. of Irrigation, Hydrology and eteorology. The Reporter was told in the WSSD that the GWS might drill wells only in areas where their drilling rigs were because of the limited equipment, manpower and thier extensive programme covering the irrigation purposes.

The WSSD intends to establish the ground water unit but within the next 5 year paln only (1980-85). The drfinition of water sourse in the quantity

/....

and quality terms is made by contactors. The simple tests are made by their laboratory sometime.

Generally, there are no national standards for drinking water in Nepal. There are also no laboratory facilities to carry out water analyses. In the Kathmandu Valley there is the Bacteriological Section of the Central Health Laboratory which carried the routine water test which is submitted to the WSSB for information and necessary action. The water samples are generally collected from public taps and at the request from private taps. The frequency of water sampling is three times a week in the Kathmandu area, twice a week in Patan and once a week in Bhaktapur.

4.3. Remote Area and Local Development Department:

The Remote Area and Local Development Department was established in 1971 in the Ministry of Panchayat with the responsibility for the water supply of rural communities of under 3000population. Its head office is in Kathmandu. To implement the water supply schemes more successfully, 4 main regional centres in the eastern, central, western and far western region were formed. They are in Biratnagar, Kathmandu, Pokhara and Nepalganj. The centers mentioned have actually been established to maintain close contact with district and village panchayats from whome initiative starts and through which water supply schemes are executed afterwards. The four regional centres conduct the technical service, assessment and research works.

The countrywide Community Water Supply and Sanitation Programme assisted by the UNICEF and WHO is implemented through the RA and LDD.

Generally, all up to now completed district and village level projects have been based upon spring water and they correspond to the category of gravity systems. Within the last five years, for example, about 500 water supply schemes at the village level were completed (1970-75) of which, within the Community Water Supply and Sanitation Programme mentioned, 49 gravity systems. Under different phases of construction are still more 88 water supply schemes of which 69 ones will be transferred into the next 5 year plan (1975-1980). According to the new Rural Water Supply Programme assisted by the UNICEF/WHO the implementation of new 106 schemes have been planned, which means in total 175 schemes in the 1975-80 period. In the 1975-76 the priority is given to so called Small Area Development Projects (SADR) licated in the districts of Jumla, Tibrikot, Dailekh (in Far Western Region), Mustang, Parbat (Western Region) and Sankhuwa Shaba (Eastern Region). All new schemes (106) are in Intensive Development Areas which in addition to the SADP already mentioned also includes the following districts: -

- in Far Western Region: Bajhang, Dandeldhura, Rukum, Rolpa, Dolpo, Mugu, Humla, Bajura and Doti;
- in Western Region: Lamjung, Manang and Arghakhandu;

/....

- in central Region: Rasuwa-Nuwakot, Dolakha and Makwanpur and
- in Eastern Region: Taplehung, Khotang and Dhankuta.

All areas/districts mentioned are in the mountain complex and more or less it is a question of gravity type water supply systems. For Terai, the construction of 105 tube wells has been planned It should start in 1977/78. The priority was given to districts of Bardia and Dang in the Far Western Region and Sarlahi District in Central Region. The priority might be changed because of existing 400 wells of which numerous might be immediately included into the rural water supply programme.

* * *

At present there is no special research unit within the RA & LDD for the determination of water sources. As it has been already mentioned, the initiative starts from the village and district panchyats which submit their request to the RA & LDD and with the consent of the UNICEF and WHO and applying special criteria, it includes rural communities in the water supply programme. The discharge of water sources is first estimated by the local people (teacher and village leaders), then by suboverseers and finally by overseers which submit their findings to the design section in regional centres. Engineers from regional offices do not take part in the research phasis at all because they are few only and they are engaged in other deals. Somewhat more then 50% of their activity goes for the water supply problems, that is to the construction phase mainly. The quality of water sources is not determined as a rule! The only exception is a case where the quality of water is under suspicion. If one knows what a capability of a newly trained overseer is and how he can estimate the complex hydrogeological mechanism of a spring, for example, then one can understand upon how risky data one rather expensive water supply system might be based. Although the RA and LDD lack the manpower, as the other departments in the Sector also do, (there is a lot of vacancies), at least two research teams must be formed (one for the mountain complex and the other one for Terai) including experienced experts for water resources. The expenses of a research team in comparision to the total price of a water supply are negligible, the more so if it is taken into account that such a team can determine at least 200 water sources per year.

Here is a rough estimation of expenses to be made by such a team in the mountain complex:

1. Personnel

a/ One sanitary engineer, annual gross salary 12 x 600 ....N.Rs. 7,200
b/ One assistant sanitary engineer (experienced in hydrometry),
annual grass salary 12 x 450 ....N.Rs. 5,400

/....

c/ One hydrogeologist, annual gross salary 12 x 600 .... N.Rs. 7.200
d/ Two light vehicle drivers, annual gross salary
2 x 12 x 200 .... N.Rs. 4.800

TOTAL under /1/ N.Rs. 24,500

2. Equipment

a/ One light 4-wheel drive vehicle (jeep type) .... N.Rs. 70,000
b/ One 4-wheel drive pick-up for passangers and load .... N.Rs. 75,000
c/ Camping equipment, 3 sets (for two persons) each
N.Rs. 4,000 .... N.Rs. 12,000
d/ Cooking equipment 3 sets (for two persons) each N.RS. 500... N.Rs. 1,500
e/ Scientific equipment (one current meter pygmy type Rs. 40000, One conductivitymeter Rs. 4000, one stop wacth Rs. 400, one field hammer Rs. 100, one pocket pun-type thermometer Rs. 200, one pocket (Brunton) transit Rs. 600, one pocket magnifying glass Rs. 200, one measuring tape Rs. 200, one surveying altimeter Rs. 4,000, one pocket altimeter Rs. 500) .... N.Rs. 14,200

TOTAL under /2/ N.Rs. 172,700

Depreciation time for equipment: 5 years.
Annual rate: 172,700 : 5 = N.Rs. 34,540.-

3. Material such as diesel, oil, spare parts, office paterial, etc per year .... N.Rs. 20,000

TOTAL 1-3 N.Rs. 79,140.-

The cost of survey for one water supply scheme 79,140 : 200 = 396.-!

In addition to the above mentioned, the cost of survey in the Terai should also include the following equipment: one tube water sampler Rs. 1,500, one electric water level meter Rs. 800, and one tube pressure gauge with several adaptors Rs. 2,500.- The team for the survey of Terai should include: one hydrogeologist, one assistant hydrogeologist and one sanitary engineer. The stress is upon ground waters here because they can be developed by tube wells. The well trained team is supposed to be able to survey at least 300 rural communities a year in Terai, so that the unit price of survey may be lower than that one for the mountain complex.

4.4. Ground Water Section:

The Ground Water Section, which is within the Department of Irrigation,

/....

Hydrology and Meteorology under the Ministry of Food and Agriculture, in the only organisation in Nepal which can make systematic ground water investigations. At the timebeing, the activity of this Section mainly takes palce through the Ground Water Exploration Projects in the Terai only, for irrigation purposes. Because of the limited capacity and extensive investigation programme, they hardly can take part in water supply programmes.

The Head Office in Kathmandu and 4 field offices are in the Terai: as Bhairwa (Butwal), Nepalganj, Dhangari and newly opened, at Parmajia.

The Central Office, headed by the Project -in- charge has the Adminstration Division(Adminstration, Account and Store) and Laboratory Division (Geological Lab. and Chemical Lab). One filed office has the Drilling Division and Administrative and Maintenence Division. The Drilling Division includes Rig's Unit, Constractors Rig and Elec. Logger Unit, Road and Survey Unit and Pumping Test Unit.

The Administrative and Maintenance Division includes Administration, Store, Workshop, Account and Well Survey Unit. The Field Office includes also the Well Observation Unit.

Of the equipment, they have two combined, direct rotary percussion rigs, Speed Star type, capacity of drilling appox. to 1500 ft (both in good condition), then an Indian percussion rig, Well Master PR-2500, capable to 500 ft. (also in good condition) and the other one Indian percussion rig (300 ft) which will soon be put at their disposal. Steps will be made the rig from the WSSD also to be given to them. Besides, they also have one bulldozer, one grader, and 9 trucks and 18 jeeps. Workshops are well equipped and they can make all kinds of rapairs. They just lack spare parts because it is a question of imported equipment.

In the chmical Laboratory are analysed FE, Ca, Mg, Na + K, HCO_3, SO_4 Cl, CO_3, TDS, hardness, alcalinity, specific conductance, PH, SAR, HCO_3 hazard. They need about 200 analyses per year but the Laboratory can make 200 to 400.

The Geological Laboratory makes core analyses and sieve analyses. Including all professional, subprofessional, technical and non-technical staff, there are 215 employed on full time basis and during the working season, workers on part time basis are also engaged whenever necessary. Of the professional staff, there are 17 hydrogeologists, 6 chemists, 3 civil engeineers and i mechanical engineer. Of the subprofession and lower staff, there are two overseers, 9 drillers, 11 mechanicians, 2 assistant (for the pumping tests), 9 assistant drillers, 5 heavy equipment operators, 6 assistant mechanics, 3 pumping test assistants, 25 drivers and 33 helpers.

* * *

/....

There are no facilities in Nepal to train engineers to degree level. Most of the engineers take their degree (first) at Indian Universities and higher degrees they take either in India or other countries (USA, USSR, UK) Geologist of B. Bc.degrees are trained at the Tribhuwan University in Nepal Kathmandu.

The subprofessional staff is trained by the Technical Training Institutes at Kathmandu, Balaju, Butwal and Netaura; all under the Institute of Engineering jurisdiction.

There are no facilities for drillers and pump operators training. Their drillers were trained in Pakistan and they now train new drillers. Pump operators are mechanicians.

* * *

The Reporter was told in the Ground Water Section that they could not take part in the well drilling for the water supply on a large - scale basis because they were very busy drilling wells for irrigation purposes. However, in case an agreement is made between the Ministry of Panchayat and the Ministry of Food and Agriculture, they can provide lab, facilities for water sample analyses, some professional and subprofessional staff to be engaged for the RA & LDD water supply programmes, as well as training facilities.

* * *

As it can be noticed from all above mentioned, the activity of the Ground Water Section takes places in the Terai Region only. It means that the mountain complex has not been treated hydrogeologically at all. It is an amission the more so because 62% of the total population lives over there. The hydrogeological investigation of the mountain complex may be rather simplier and cheaper than in the Terai Region. There is no subsurface exploration. There should be started with the systamatic complition of a set of hydrogeological maps. First , in the areas of priority, which means densely populated areas and areas where agriculture, industry and tourism are under development, then gradually to cover the whole country. The main maps to be made are: the inventory map, the water quality map and summery hydrogeological map which should inclmde water bearing formations, main structural elements and some important hydrogeological occurrences. The main facilities exist: topographic maps (scale 1 inch: 1 mile = 1:63,359) and one inch : 4 mile = 1:253,437), aerophotos and technical personnel which meeds a short training only. Geological maps available with the Geological Survey and Bureau of Mines may make easier the compitation of hydrogeological maps. There should just be provided the equipment for the field work (mainly the same equipment as listed in the above chapter). It may be realised by the external assistance. The most logic is to make three investigations through the some what extended Ground Water Section which already has the

/....

personnel and certain technical facilities, as well as the hydrogeological experience. The Ground Water Section has already accepted such an idea.

4.5. Nepal Resettlement Co.

The Nepal Reselltement Co. is a semi-government company (but under the complete control of the Government) established to extend minimum facilities for life to people moving to Terai. People move to Terai either from the hill regions of Nepal or from surrounding countries (Burma, India). They are given land under favourable conditions and they are provided with favourable facilities fro the house construction, water supply, education, etc. For the water supply purposes, up to recently they had one direct rotary rig (Wabco Holemaster 1500) and one percussion rig (Speed Star). The first one was in good working condition and the othee one was completely out of order. However, both rigs have recently been sold to a just established private company.

4.6. Contractors Service Available in Nepal

There are few contractors in Nepal and they mainly deal with the drilling of exploratory and productive wells.

The Nepal International Drilling Co.

Was established in 1974. It has two drilling rigs bought from the Nepal Resettlement Co. It has one foreign engineer and drillers. Up to now they have drilled few wells for hotels in Kathmandu.

N.B. Tube Wells & Co. (Nepal) Ltd.

Is an Indian company. It has 4 rigs but they are not in Nepal. Whenever the agreement is made, they bring rigs to Nepal. In the period from 1967 to 1972, this Company made 60 wells for the ground water section, i.e. for the ground water exploration project in the Terai Region. They were exploration wells, but the Company can also make large dia productive wells.

M.S. Hindustan Tube Well Co. Patna India

Is a contractor usually engaged by the WSSD for the drilling of the deep productive wells. This company is able to make complete determination of water sources in terms of quantity and quality.

In addition to above mentioned, in Terai and especially in its border part there are numerous Indian private contractors which offer their service for sinking shallow wells and installation of hand pumps under very favourable conditions and guarantee.

Kabul, November, 1975

Stevan RADOJICIC
UNICEF Hydrogeologist

R E F E R E N C E S

1. Departmnet of Irrigation, Hydrology and Meteorology, Ministry of Food, Agriculture and Irrigation, Nepal. — Climatological Records of Nepal, 1970 Jore Ganesh Press PVT, Ltd. Balaju, Kathmandu, 18 February 1973.

2. " — Surface Water Records of Nepal. Supplement No.7, 1972. Jore Ganesh PressPVT, Ltd., Balaju, Kathmandu 27 June, 1974.

3. Engineering Science, Inc. Kathmandu. — Draft Preliminary Engineering Report on Gre.ter Kathmandu Water Supply Kathmandu, 1974.

4. International Bank for Reconstruction and Development International Development Association — Nepal Water Supply and Sewerage Project, April 1974.

5. " — Agriculture Sector Survey of Nepal. The General Report (two volums) December, 1974.

6. Jagtiani K. — Report on Drinking Water Supply, UNICEF May, 1974

7. Ministry of Water & Power and Ministry of Panchayat with the Collaboration of WHO — Project Formulation for Development of Water Supply and Excreta Disposal. Draft. Kathmandu, 29 August, 1975.

8. Moller A. I. — Assessment of the Ground Water Potential in the Terai Region, Nepal and Recommendations for shallow tube Well Drilling Programme. Draft. WHO September - October 1974.

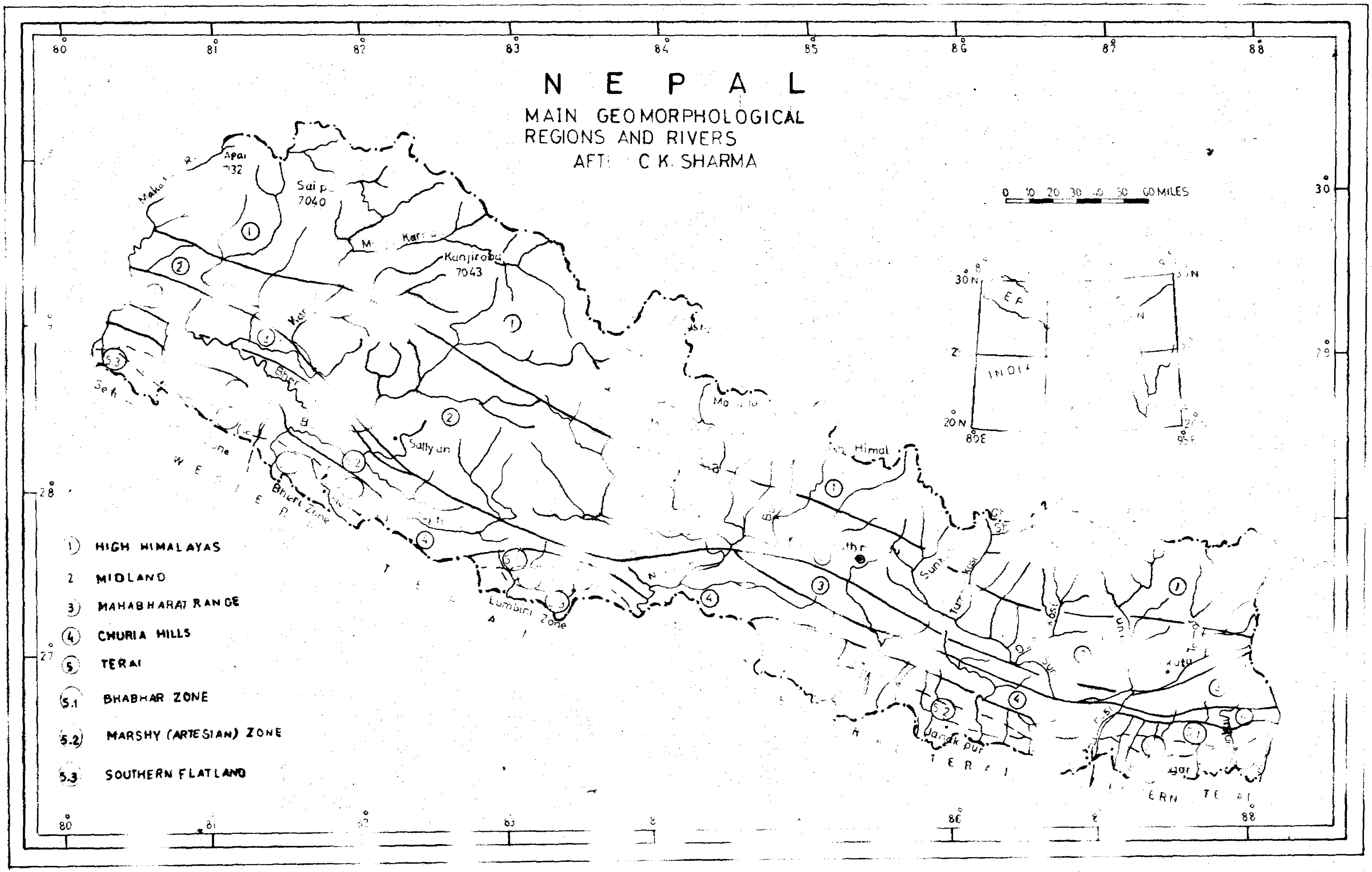
9. Saravanapavananthan N. — Rural Water Supply,Drianage and Sanitation Situation in Nepal. National Community Water Supply and Sanitation Project. Project Nepal 0029. 1974

10. Sharma C.K. — A Glimpse of the Ground Water Resources of Nepal. Ground Water Investigation Project HMG of Nepal. Lajimpat, Kathmandu 1970.

/....

R E F E R E N C E S

11.	Sharma C. K.	Ground Water Resources of Nepal. Wonder Printing Press. Naradevi, Kathmandu 1975
12.	Stern G. and Anderson K.	Nepal Agriculture Credit Project Reconnaisance Mission, International Development Association, 1975.
13.	UNICEF, Kathmandu	Annual Report, 1973-74
14.	"	Plan of Operation for the Development of Services Benefiting Children in Rural Nepal 1975-1980. Second Draft. August 1975.
15.	"	Rural Drinking Water and Sanitation Project Executed by Village Ex-Servicemen or Other Villagers. "Noted" Project-Nepal. September, 15, 1975
16.	US Geological Survey and the Department of Irrigation and Hydrology, Ministry of Food and Agriculture, HMG Nepal, under the auspices of USAID.	Ground Water Resources Investigations in Lumbini Zone, Western Terai, Nepal, July, 1973.
17.	World Health Organisation.	Report on Rural Water Supply Nepal. Regional Office of South-East Asia. EH/SEARO/74,8. July 26, 1974


N E P A L
MAIN GEOMORPHOLOGICAL
REGIONS AND RIVERS
C.K. SHARMA
0 10 20 30 40 50 60 MILES
Saipal 7040
Kanjiroba 7043
Sallyan
Lumbini Zone
Janakpur
TERAI
INDIA
1) HIGH HIMALAYAS
2 MIDLAND
3) MAHABHARAT RANGE
4) CHURIA HILLS
5) TERAI
5.1 BHABHAR ZONE
5.2) MARSHY (ARTESIAN) ZONE
5.3 SOUTHERN FLATLAND