

GROUNDWATER DEPLETION AND ITS IMPACT ON ENVIRONMENT IN KATHMANDU VALLEY

(A Technical Report)

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GROUNDWATER DEPLETION AND ITS IMPACT ON ENVIRONMENT

INTRODUCTION:

Water is Nepal's largest known natural resources. The major sources of water are rainfall, glaciers, rivers, and groundwater. Over times, the country's requirements for water for drinking and personal hygiene, agriculture, religious activities, industrial production, hydropower generation, and recreational activities such as navigating, rafting, swimming, and fishing have increased. Yet, the rivers are also the main repositories for the nation's untreated sewage, solid waste, and industrial effluent.

Concerning about water includes both quantity and quality of the resources and relates to human health standards. Normally, a person requires 2.5 liters of water per day for their basic physiological processes. In addition, water is also required for domestic hygiene such as washing, bathing, cleaning, and so on. An adequate supply of drinking water alone does not fulfill human health needs, as its quality refers to the suitability of the water to sustain living organism and other uses such as drinking, bathing, washing, irrigation, and industry. Anthropogenic activities are considered as major factors for bringing our qualitative and quantitative water quality changes.

Groundwater provides 50% of the present Kathmandu water supply and abstraction from both shallow and deep aquifers.

There is intense pressure on the water resources being used in Nepal due to the limited amount available with respect of demand of the peoples. Population growth, urbanization, migration of the people etc factors that puts pressure on the existing water supply in urban areas. Other activities that need water are industries, irrigation, motor workshops, and so on (**Source:** State of the Environment, Nepal, 2001, MOPE, ICIMOD, SACEP, NORAD, UNEP, Page No. 121-122).

The Kathmandu valley has a population of about 1.1 million, which is growing at 4% annually. About 50% of the urban water supply is derived from groundwater and about 20 million cubic meters is extracted annually. The Kathmandu valley occupies an intermixed basin containing up to 550 m of Pliocene-Quaternary fluvio-lacustrine sediments. An upper unconfined aquifer of Late Quaternary sand up to 20 m thick overlies an aquitard of black clay with peat and lignite bands. The aquitard is especially well developed on the western side of the valley, where it is up to 200 m thick. Beneath the aquitard is a sequence of Pliocene sand and gravel beds, intercalated with clay, peat and lignite. These sand and gravel beds collectively comprise a deeper, confined aquifer, which provides an important water supply to the central urban area of Kathmandu. Recharge to the upper aquifer is from direct infiltration of monsoonal rain and from streamflow on the north and east of the basin. The basin has a surficial outlet through the

gorge (throat) of the Bagmati River, in the southwest (**Source:** Mani Gopal Jha, Mohan Singh Khadka, Minesh Prasad Shresth, Sushila Regmi, John Bauld and Gerry Jacobson, 1997(AGSO+GWRDB), The Assessment of Groundwater pollution in the Kathmandu Valley , Nepal, page 5)

Surface Water:

There is a huge demand for surface water because of rapidly increasing population. The annual drinking water supply is inadequate to meet the growing demand. Similarly, the use of water for agriculture is increasing. Following table shade light on the scenario of the surface water available of Nepal.

Table 1: Surface water availability and its use in Nepal

Description	1994	1995	1996	1997	1998
Total annual renewable surface water (km ³ /yr)	224	224	224	224	224
Per Capita renewable surface water ('000m ³ /yr)	11.20	11.00	10.60	10.50	10.30
Total annual withdrawal (km ³ /yr)	12.95	13.97	15.10	16.00	16.70
Per Capita withdrawal ('000 m ³ /yr)	0.65	0.69	0.71	0.75	0.76
Sectoral withdrawal as % of total water withdrawal					
Domestic	3.97	3.83	3.68	3.50	3.43
Industry	0.34	0.31	0.30	0.28	0.27
Agriculture	95.68	95.86	96.02	96.22	96.30
Source: State of the Environment, Nepal, 2001, MoPE, ICIMOD, SACEP, NORAD, UNEP, Page No. 122					

The pressure on drinking water supply is very heavy, particularly in the Kathmandu Valley. Almost all-major rivers have been tapped at source for drinking water supplies; and the supply is only about 115 million l/day (mld) during the rainy season, 79% of the estimated daily demand of 145 mld (NPC 1998).

Ground Water:

The country ground water is being used for domestic, industrial, and irrigation purpose. It is estimated that the Terai region has a potential of about 12 billion m³ of groundwater, with an estimate annual recharge of 5.8 to 9.6 billion m³ (the maximum that may be extracted annually without any adverse effect). Current groundwater withdrawal is about 0.52 billion m³ per year.

The groundwater of Kathmandu valley is under immense pressure as it is being heavily used for drinking as well as for other activities that require water, resulting in a decline of its water level. The study of Metcalf and Eddy (2000) depicts an alarming situation concerning a drop in pumping water level from 9 m to as 68 m in the valley over a few years. However, because there is no regular monitoring program, groundwater depletion rate is uncertain in the Kathmandu valley. The total sustainable withdrawal of groundwater from the valley's aquifers is approximately 26.3 mld (Stanley 1994), but the total groundwater currently extracted is about 58.6 mld (Metcalf 2000). The study

indicates that the groundwater in the valley is overexploited. Since studies are not carried out in a regular basis, it is difficult to determine the real degree of overexploitation.

Following table indicates the scenario of the Groundwater availability and its condition in Kathmandu valley.

Table 2. Dry season deep aquifer depletion at selected location of Kathmandu Valley

Location	Previous water level(m)			1999 Water level(m)		Decline	
	Base year	SWL	PWL	SWL	PWL	SWL	PWL
Bansbari	1997	48.08	67.60	80.63	136.14	32.55	68.54
Baluwatar	1996	FW	21.00	22.4	30.00	22.41	9.00
Pharping	1996	FW	25.00	13.00	44.00	13.00	19.00
PWL= pumping water level SWL= static water level FW= flowing well							
Source: State of the Environment, Nepal, 2001, MOPE, ICIMOD, SACEP, NORAD, UNEP, Page No. 123							

Groundwater usage:

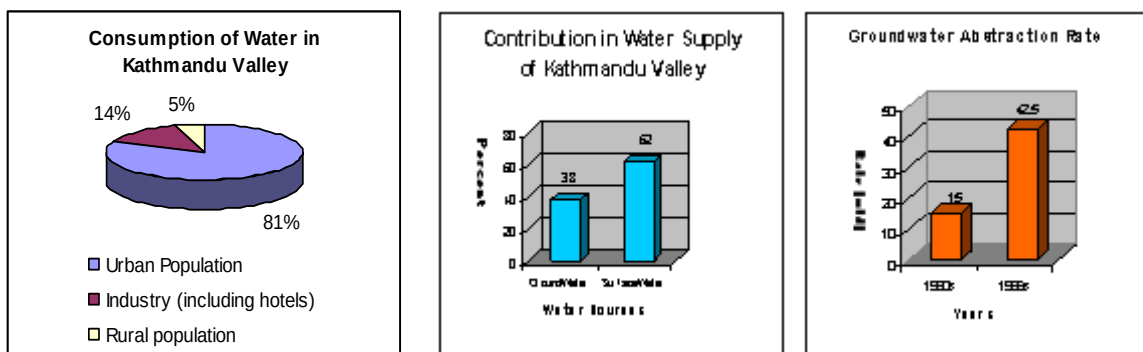
The total groundwater abstraction in the valley was estimated to be about 50,000 m³/d in 1992 (CES, 1992). Of this, about 37,000 m³/d was derived from wells belonging to the Nepal Water Supply Corporation, which has 22 production wells in operation. Another 13,00 m³/d was derived from private wells: there were 334 private wells in operation, of which 188 were shallow tubewells. i.e. in the shallow aquifer, and 146 were deep tubewells. The natural recharge of groundwater in the valley has been variously estimated at about 30,000 to 40,000 m³/d (Binnie & Partners, 1989), about 15,000 m³/d (JICA, 1990), and about 13,000 m³/d (Gautam & Rao, 1991). The marked seasonality of the rainfall and river flow must also be reflected in the groundwater recharge.

According to Gautam & Rao (1991), the total groundwater resources are insufficient to fulfil the water demand in the valley. The well fields of the Nepal Water Supply Corporation in the deep aquifer have shown a draw down of the potentiometric surface of 15-20 m since the construction of the wells in 1984/85, indicating substantial overexploitation (Source: The Assessment of Groundwater Pollution in the Kathmandu Valley, Nepal by Mani Gopal Jha, Mohan Singh Khadka, Minesh Prasad Shrestha, Sushila Regmi, John Bauld and Gerry Jacobson Page 14).

Because the current water system is not reliable from a quality or quantity standpoint. Many wealthier users have developed their own water systems. Pumping supply from water mains or their own wells and strong water in rooftop tanks or underground cisterns. It has been estimated that the groundwater withdrawals by private users may be between 10 and 30 million liter per day. Indication are that these withdrawals are depleting the groundwater resources (**Source:** Metcalf & Eddy, Urban Water Supply Reforms in the Kathmandu Valley, Ex. Summery and Final Report, ADB TA Number 2998-NEP, 18th Feb, 2002, p 1-1).

Water Supply and Demand:

About 146 million liters of water are used each day in the Kathmandu Valley; of which 81 % is consumed by the urban population, 14% by industries **(including hotels)** and the remaining 5% is utilized in rural areas. Surface water including water from tankers, supplies about 62% of the total water used, while groundwater including dhungedhara, inar and shallow tubewells supply 38% of the total water used. Of the total water consumed, NESC's contribution is about 70%. The current groundwater abstraction rate of 42.5 million liters per day is nearly double the critical abstraction rate of 15 million liters/day according to JICA (1990)(**Source:** Environmental planning and Management of the Kathmandu Valley, HMG, MOPE, Kathmandu, Nepal, 1999, P 38).



Following table shows the estimated water demand for domestic use in the Kathmandu valley water

Table 3: Estimated Water Demand for Domestic use in the Kathmandu Valley (mld)

Descriptions	1994	2001	2006	2011
Population(million)				
➤ Urban	1.210	1.578	1.801	2.227
➤ Rural	0.335	0.417	0.473	0.572
Total	1.545	1.995	2.274	2.799
Demand for Drinking Water (ml/day)				
a) Theoretical demand				
➤ Urban ¹	181.5	233.7	297.2	367.5
➤ Rural ²	15.0	25.4	35.9	54.3
Sub-Total	196.5	259.1	333.1	421.8
b) Observed demand medium level 1				
➤ Urban ³	121.0	195.7	243.1	331.8
➤ Rural ²	15.0	25.4	35.9	54.3
Sub-total	136.0	221.1	279.0	386.1
c) Non-domestic demand, Industry, hotels and others ⁴	20.0	26.0	32.5	41.5

1 =150 lcd in 1994 and 2001, and 165 lcd in 2006 and 2011

2 =Rural demand is estimated to be 45 lcd in 1994, 61lcd in 2001, 76 lcd in 2006 and 95 lcd in 2011

3 =Estimated to be100 lcd in 1994, 124lcd in 2001, 135 lcd in 2006 and 149 lcd in 2011

4 =Annual growth of 5 %

Source: Environmental planning and Management of the Kathmandu Valley, HMGN, MOPE, Kathmandu, Nepal, 1999, P 38

Water Scenario:

Even after the completion of the Melamchi Project the water supply situation by 2011 will remain more or less similar to1981, i.e. running at an approximate 30% deficit.

In addition, water demand is expected to increase significantly from various commercial, industrial establishments, hotels and restaurants and the demand from the urban population is also expected to increase.

As the current water supply cannot sustain the urban population's increasing demand for water, this could be the most important factor limiting growth in the Kathmandu Valley. The water deficit could have a significant, adverse effect on public health and sanitation (**Source:** Environmental planning and Management of the Kathmandu Valley, HMGN, MOPE, Kathmandu, Nepal, 1999, P 39).

Following tables shows the deficit in water supply for Domestic use in Urban Areas:

Table 4The deficit in water supply for Domestic use in Urban Areas

	1981	1991	1994	2001	2006	2011
Percent of						
• Theoretical demand	33.6	49.2	70.9	74.1	74.2	39.1
• Observed demand	17.0	23.9	56.4	69.1	68.4	32.5

Source: Environmental planning and Management of the Kathmandu Valley, HMGN, MOPE, Kathmandu, Nepal, 1999, P 39

Urban Water:

Nepal, the urban population is growing and both the percentage of population being served by drinking water connections and the total connections have increased. However, the remarkable point is that the consumption per capita or per connection has decreased. With the increase in population, the total water demand per year has also increased. Nevertheless, the per capita consumption of piped water has decreased because of scarcity of water. This has put pressure on groundwater extraction, especially in the Kathmandu Valley. Another striking feature of the drinking water supply in the urban towns of Nepal is unaccounted for water of leakage, which accounts for 40% of the total supply. Water supply seems to be one of most crucial problems in the country.

Following table shows the scenario of the water supply and coverage in urban areas of Nepal.

Table 5: water supply and coverage in urban areas of Nepal

Particulars	Before 1992		End of 1998	
	Kathmandu Valley towns	Towns outside the valley	Kathmandu Valley towns	Towns outside the valley
Population (^000)	780	640	1097	878
Population served(%)	68	56	87	57
Total produced(mld)	87	55	107	63
Total surface water produced(mld)	61	26	78	36
Total groundwater produced(mld)	26	29	29	27
Water sold (mld)	52	33	64	38
Unaccounted water (%)	40	40	40	40
Per capita consumption(lcd)	98	92	67	76
Consumption per connection(lcd)	674	927	636	721
Total connections	77468	35588	100916	52379
lcd= liter consumption/day; mld= million liter/day				
Source: State of the Environment, Nepal, 2001, MOPE, ICIMOD, SACEP, NORAD, UNEP, Page No. 130				

GROUNDWATER ZONE OF KATHMANDU VALLEY:

Groundwater occurs in the crevices and pores of the sediments. Based on the hydrological formation of various characteristics including river deposits and others, the Kathmandu Valley is divided into three groundwater zones or districts: a) northern zone, b), central zone and c) southern groundwater zones (JICA 1990).

Northern Groundwater Zone:

The northern groundwater zone covers Bansbari, Dhobi khola, Gokarna, Manohar, Bhaktapur and some principal water supply wells of NWSC are situated in this area. In this zone, the upper deposits are composed of unconsolidated highly permeable materials, which are about 60 m thick and form the main aquifer in the valley. This yields large amounts of water (up to 40 l/s in tests). These coarse sediments are, however, interbedded with fine impermeable sediment at many places. This northern groundwater zone has a comparatively good recharging capacity.

Central Groundwater Zone:

The central groundwater zone includes the core city area and most part of Kathmandu and Lalitpur Municipalities. Impermeable stiff black clay, sometimes up to 200 m thick, is found here along with lignite deposits. Beneath this layer, there are unconsolidated coarse sediment deposits of low permeability. Marsh methane gas is found throughout the groundwater stored in this area. Existence of soluble methane gas indicates stagnant aquifer condition. The recharging capacity is low due to stiff impermeable layer.

According to dating analysis, age of gas well water is about 28,000 years. The confined groundwater is probably non-chargeable stagnant or "fossil"

Southern Groundwater Zone:

The southern groundwater zone is located in the geological line between Kirtipur. Godavari and the southern hills. Thick impermeable clay formation and low permeable base gravel is widespread here. The aquifer is not well developed.

GROUNDWATER RECHARGE AND ABSTRACTION:

Groundwater recharge is generally poor in the overall valley scenario. Only the northern aquifers are well located for recharge, which is higher in the monsoon season. Also, steep grades cause the precipitation water to flow quickly as runoff. The two primary constraints to groundwater recharge are: a) widespread distribution of lacustrine layers interbedded with impermeable stiff black clay which prevents easy access to recharged water, and b) excessive accumulation of decaying organic matter in the central part of the valley, which causes poor quality of ground water.

The recharge rate, calculated on the basis of a simulation model is 27,000 m³/day (JICA 1990). Gautam and Rao (1991) estimated the recharge rate to be around 12,630 m³/day while JICA (1993) reported the critical recharge rate as 15,629 m³/day. This suggests that the recharge rate is around 15 million-liter per day.

The current groundwater abstraction rate, about 42 million liters per day, is over two times higher than the critical abstraction rate of 15 MLD, as suggested y JICA (1990). The abstraction rate has declined over the years. CES (1993) reported an abstraction rate of 50-55 MLD, of which NWSC extracted 36.5 MLD. Stanley International (1994) reported about 52 million liters per day ground water abstraction, of which 8.4% was from shallow wells and 91.6% from deep wells (Table below).

Table 6 : Groundwater abstraction for various use ('000 l/day)

	SHALLOW	DEEP	TOTAL
Private (Industry/hotels/embassies)	3,802	5,119	8,921
HMG/N Institutions	286	2,945	3,231
NWSC Wells	-	39,242	39,242
Others	286	583	869
Total	4,374	47,889	52,263

Source: Stanley International (1994). Annex 10: Appendix A.

- data summaries. This does not include shallow tube wells and "Inar" in the urban areas, currently about 48-50% of the household have shallow wells.

The abstraction rate was highest in 1989-90, after the commissioning of all wells constructed under IDA projects. The rate subsequently decreased as a result of declining water level. The average abstraction rate from NWSC wells has declined from 32 MLD in 1989 to 24 MLD in 1993.

Private use of groundwater has increased significantly since 1989. IN 1992 the number of deep wells in operation were 23, out of a total of 334 wells. This included only private wells from industrial use and wells which was in continuous operation for at least one hour and it not cover the shallow tube wells fitted with hand pumps. Out of 334 deep wells, 188 wells were shallow (<245m) and 146 wells were deep (>245M). In the last few years' groundwater extraction from shallow depths up to 15 m, mainly for purposes other than drinking (although people also drink it in places) has increased tremendously.

The use of groundwater in the valley is continuously increasing. Though Nepal Water Supply Corporation (NWSC) is still the largest user, the abstraction for private users is increasing rapidly. Most of the private wells are located in the central district of the valley and are drawing basically fossil water, the quality of which is not good. (**Source:** Regulating Growth: Kathmandu Valley HMG & IUCN May 1995 Page. 47, 48 & 49)

Recharge of Groundwater:

According to the sedimentary development, the area suitable for recharging aquifers is located mainly in the northern part of the Kathmandu Valley and along the rivers or paleochannels. In the southern part recharge is restricted to the area around Chovar and the Bagmati Channel, and probably along gravel fans near the hillside. Detailed investigations of the recharge and related data are missing.

Though the annual precipitation of Kathmandu valley is quite high, the ground condition in general is not effective for recharging aquifers from precipitation. Wide spread silty lacustrine deposits control groundwater recharge in the valley, interbedded with the impermeable clay, which prevents easy access of percolating rainwater to the aquifers. Most of the annual precipitation falls during monsoon from June to September, but runs off quickly as surface flow and is not sustained during the dry season. Streams of the Kathmandu Valley receive some water from the shallow aquifer after the monsoon season. (**Source:** Hydrogeological Conditions and Potential Barrier Sediments in the Kathmandu Valley, Final Report, Prepared by, B.D. Kharel, N.R. Shrestha, M.S. Khadka, V.K. Singh, B. Piya, R. Bhandari, M.P. Shrestha, M.G. Jha & D. Mustermann, February 1998, page 28)

GROUNDWATER QUALITY OF KATHMANDU VALLEY:

The groundwater quality in the Kathmandu Valley is also contaminated due to polluted surface water, leachate, and sewage. None of the water from groundwater sources, such as dug-well, deep tubewells, stone spouts, ponds, and piped water in the valley is guaranteed free from faecal contamination. The studies of ENPHO (2000), CEMAT (1999), and Jha et al. (1997) indicate that the concentration of ammonia-N even in deep

well is above WHO standards. Similarly, nitrate-N concentration is also higher in shallow and dug wells than WHO standard.

Table 7: Bacteriological water quality from different sources, Kathmandu Valley

Faecal coliform/100 ml	Value as % of sample units of 15							WHO guideline value
	Dug well	Shallow well	Deep well	Spring	Stone spout	Pond	Piped water	
0	0	60	80	40	20	0	60	0
1-100	40	30	15	30	40	0	20	
101-1000	30	5	5	30	40	0	20	
>1000	30	5	0	0	0	100	0	
Source: State of the Environment, Nepal, 2001, MOPE, ICIMOD, SACEP, NORAD, UNEP, Page No. 132								

The most significant pollution of the shallow aquifer is beneath the old cites of Patan, Bhaktpur and the source is presumed to be taking sewage pipes and septic tanks. There is evidence that pollutant concentrations are greater during, and immediately following the monsoon. This seasonal impact is particularly evident in the dugwells. The widespread faecal pollution of the shallow aquifer presents a serious health risk for Kathmandu people. There is also indirect evidence of pollution by industrial effluent.

Samples from four out of 20 tubewells in the deeper confined aquifer contained faecal indicator bacteria. In most cases, however, this can be attributed to post-headwork's entry of contaminant microbes rather than to contamination of the deep aquifer itself. The deeper aquifer has natural groundwater quality problems, with high concentration of ammonia, methane, manganese and iron which are derived from the intercalated peat and lignite deposits (**Source:** Jha, Mani Gopal et al.1997, Assessment of Groundwater pollution in the Kathmandu Valley, Nepal, page 5).

Groundwater Quality - Shallow Aquifer:

The shallow unconfined aquifer is used widely by Kathmandu Valley citizens for domestic water supply. Of the 12 dugwells and 43 shallow tubewells which were sampled in this aquifer. About 60 percent contained faecal indicator bacterial and this was generally associated with elevated concentrations of ammonia, nitrate and phosphate.

Evidence of faecal contamination:

Faecal contamination, as determined by the presence of faecal (themotolerant) coliforms (FC) was evident in the shallow aquifer, overall in 58% of wells sample. The incidence of contamination (% FC-positive samples) was higher in dugwells than in shallow tube wells.

A total of 25 of the dugwells and shallow wells surveyed in the Kathmandu Valley contained >10FC/100 ml. The most polluted wells include dugwells in Bhaktapur and Patan, and dugwells and shallow wells in the old city of Kathmandu.

Table 8 Kathmandu Valley groundwater: relative levels of faecal contamination

Well type	Number of wells	Mean number faecal coliforms/100 ml	
		Monsoon	Dry season
Dugwells	12	4404	132
Shallow tubewells	43	88	136
Deep tubewells	20	(18)	(<1)

Nutrients:

Dugwells show the highest nitrate-N concentrations compared with shallow and deep tubewells. In the dugwells both mean and median values are about 9-10 mg/L nitrate-N. Nitrate concentrations present in groundwater from dugwells and shallow tubewells. During and immediately following the monsoon, about half of all dugwells, and some shallow tubewells, contained nitrate-N concentrations above the WHO (1993) drinking water guideline value of 11.3 mg/l nitrate-N (equivalent to 50mg/l nitrate). The ingestion of nitrate above the guideline values is considered to be potentially deleterious to health. Although the epidemiological data for adults is suggestive rather than (P19)

TAPPING GROUNDWATER:

One solution to water supply problems in some areas is heavier reliance on groundwater, which makes up about 95% of the world's supply of fresh water. The quality of groundwater is usually excellent because the porous rock of an aquifer filters the water and removes suspended particles and bacteria. In the United States, total groundwater withdrawals tripled between 1950 and 1985. Two-thirds of this water is used



Pumping Groundwater



Water Pollution



Cleaning Groundwater

for irrigation, especially in Texas, Arizona, and California. About half of U.S. drinking water (96% in rural areas and 20% in urban areas), 40 % of irrigation water, and 23 % of all fresh water used is withdrawn from underground aquifer.

This increased use of groundwater gives rise to several problems:

1. Aquifer depletion or overdraft when groundwater is withdrawn faster than it is recharged by precipitation.
2. Subsidence or sinking of the ground water as groundwater is withdrawn,
3. Salt water intrusion into freshwater aquifers in coastal area and
4. Groundwater contamination from human activities.

Although U.S. groundwater withdrawals amount to only about 10% of the country's overall groundwater supply, much if this water is drawn from large parts of Southwest and center smaller area elsewhere. The major groundwater overdraft problem is in part of the California-size Ogallala Aquifer extending across the farming belt from northern Nebraska to northwestern Texas. Aquifer depletion is also a serious problem in northern China, Mexico City, and parts of India. For recharging aquifer, deep groundwater can be pumped up and spread out over the ground to recharge shallow aquifers, or it can be injected directly into an aquifer through a well. But this can deplete deep aquifers and contaminate shallow aquifers because deep groundwater often has a high dissolved-mineral content. Another approach is to recharge aquifers with irrigation water, wastewater, and cooling water from industries and power plants. But much of this water is lost by evaporation, and in many cases it is better and cheaper to reuse cooling water in the industries and power plants themselves. The most effective solution is to reduce the amount of groundwater withdrawn by wasting less irrigation water and by abandoning irrigation in arid and semiarid areas.

Groundwater overdrafts can also cause the land overlying aquifer **to sink, or subside**. Groundwater in an unconfined aquifer fills the pores in the soil above and thus helps support it. When groundwater is withdrawn faster than it is replenished, the soil becomes compacted and subsides. Such **subsidence** has been a major problem in parts of the southwest and southern California. In 1981 a sinkhole formed in Winter Park, Florida, swallowing several cars, a house, two houses, two businesses, and part of the municipal swimming pool. Widespread subsidence in the San Joaquin Valley of California has damaged homes, factories, pipeline, highways, and railroad beds. Some cities are sinking at a disastrous rate because of a combination of groundwater overdrafting, petroleum mining, rising sea levels, and the weight of tall buildings. Scientists project that within 100 years Houston, New Orleans, and Long Beach, California will have sunk too much that annual flooding will cause billions of dollars in damage.

Case Study: Depletion of the Ogallala Aquifer

The vast Ogallala aquifer was formed more than 2 million years ago from melting glaciers. The Ogallala's extensive groundwater resources were virtually unknown until the early 1900s and were not tapped for irrigation water until around 1950. Today water withdrawn from this aquifer is used to irrigate one-fifth of all U.S. cropland in an area too dry for rainfall farming. To support \$32 billion of agriculture production a year, mostly wheat, sorghum, cotton, corn, and 40% of the country's grain-fed beef.

Although the aquifer contains a large amount of water, it has an extremely low natural recharge rate because it underlies a region with relatively low average annual precipitation. Today the amount of water being withdrawn is so enormous that overall the **aquifer is being depleted eight times faster than its natural recharge rate**. Even higher depletion rates, sometimes 100 times the recharge rate, are taking place in parts of the aquifer that lie in the Texas, New Mexico, Oklahoma, and Colorado. The entire billion-dollar agricultural economy of the Texas High Plains is built upon an annual overdraft of groundwater from the Ogallala by an amount nearly equal to the annual flow of the Colorado River.

Water resources experts project that at the present rate of depletion much of this aquifer could be dry by 2020, and much sooner in areas where it is only a few meters deep. Long before this happens, however, the high costs of obtaining water from rapidly declining water tables will force many farmers to switch from **irrigated farming to dryland farming** (planting crops such as winter wheat and cotton that require no irrigation) and to give up the cultivation of profitable but water-thirsty crops such as corn. The amount of irrigated land already is declining in five of the seven states using this aquifer because of the high and rising cost of pumping water from depths as great as 1,825 meters (6,000 feet). If all farmers in the Ogallala regions began using water conservation measures, depletion of the aquifer would be delayed but not prevented in the long run. However, the tragedy of the commons shows us that most farmers are likely to continue withdrawing as much water as possible from this commonly shared resource to increase short-term profits.

In case of Kathmandu Valley having high rate of urban sector growth covering most of the groundwater recharging zones by asphalt roads and multistoried shopping complexes and hotels buildings in one hand along with the excess unregulated overdraft of groundwater by these hotels for their day to day purpose will definitely threaten the depletion of groundwater aquifer resulting contamination of the remaining and collapsing of several weak bands of the earth's crust (Source: G.Tyler Miller, JR, Living In The Environment, page 226).

Excessive removal of groundwater near coastal areas can lead to saltwater intrusion. Such intrusion threatens to contaminate the drinking water of many towns and cities along the Atlantic and Gulf coasts. It is especially severe in a number of cities in Florida and southeastern Georgia, both below sea level. Saltwater intrusion is also a serious problem in the coastal areas of Israel, Syria, and resulting contamination of groundwater is difficult if not impossible to reverse.

Another growing problem in many MDCs (Mega Development Countries) such as the United States is groundwater contamination from agricultural and industrial activities, septic tanks, underground injection wells, and other sources. Because groundwater flow in aquifers is slow and not turbulent, contaminants that reach this water are diluted very little. In addition, organic waste contaminants are not broken down as readily as in rapidly flowing surface waters exposed to the atmosphere because groundwater lacks decomposing bacteria and dissolved oxygen. As a result, it can take hundreds to thousands of years for contaminated groundwater to cleanse itself. Because of its location

deep underground, pumping polluted groundwater to the surface, cleaning it up, and returning it to the aquifer is an extremely difficult and expensive process (Source: G.Tyler Miller, JR, *Living In The Environment*, page 224 - 227).

Impact and Consequences of Overdrawing Groundwater:

"Adverse effect in this context can include depletion of the groundwater reserves (groundwater level decline), intrusion of water of undesirable quality, impacts to existing water rights, higher extraction costs, subsidence, depletion of streamflow, and environmental impacts. Historically, additional extraction from a groundwater basin above the safe yield value has been called overdraft. Overdraft is defined in Bulletin 118-80 as "the condition of a groundwater basin where the amount of water withdrawn exceeds the amount of water replenishing the basin over a period of time."

To augment supplies of high-quality fresh water humans have increasingly turned to groundwater, and advances in drilling and pumping technology have made it convenient and economical to do so. In groundwater taping a large but not unlimited natural reservoir. Its sustainability ultimately depends on balancing withdrawals with rates of recharge.

Falling Water Tables and Depletion:

Rates of groundwater recharge aside, however the simple indication that groundwater withdrawals are exceeding recharge is a falling water table, a situation that is common throughout the world. A prime example is the Great Plains region of Texas, Oklahoma, New Mexico, Colorado, Kansas, and Nebraska. In the past 40 years, the water table has dropping rapidly and has dropped about 30 m (100ft) and is lowering at 2m per year. Irrigated farming has already come to a halt in some sections, and it is predicted that over the next 10 years another 3.5 million acres (1.4 million ha) in this region will be abandoned or converted to dryland farming (ranching and production of forage crops) because of water depletion.

Although running out of water is the obvious eventual conclusion of overdrawing groundwater, falling water table have other consequences before the water is entirely depleted.

Diminishing Surface Water:

Surface waters are also affected by falling water tables. In various wetlands, for instance, the water table is essentially at or slightly above the ground surface. Dropping water tables results in such a wetlands drying up, with the ecological results described earlier. Further, as water tables drop springs and seeps dry up, diminishing streams and rivers even to the point of dryness. Thus, excessive groundwater removal leads to the same effects as diversion of surface water.

Land Subsidence:

Over the ages, groundwater has leached cavities in the Earth. Where these spaces are filled with water, the water helps support the overlying rock and soil, but as the water table drops, this support is lost. Then there may be a gradual settling of the land, a phenomenon known as **land Subsidence**. The rate of sinking may be 6-12 inches (10-15 cm) per year. In the some areas of the San Joaquin Valley in California, land has as much as 27 feet (9m) because of groundwater removal. Land subsidence causes building crack. In the coastal area, subsidence causing flooding where a 4000 square mile (10,000 km²) are in the Houston-Galveston Bay region of Texas is gradually sinking because of groundwater removal, coastal properties are being abandoned as they gradually are inundated by the sea. Land subsidence is also a serious problem in New Orleans, sections of Arizona, Mexico City, and many other places throughout the world.

Another kind of land subsidence, the occurrence of a Sinkhole, may be sudden and dramatic. A sinkhole results when an underground cavern, drained of its supporting groundwater, suddenly collapses. Sinkholes may be 300 feet (91 m) or more across and caverns through ancient beds of underlying limestone. Estimated 4000 sinkholes have occurred in Alabama alone, some of which have "consumed" buildings, livestock, and sections of highways.

Saltwater Intrusion:

Another problem resulting from dropping water tables is **Saltwater intrusion**. In coastal regions, springs of outflowing groundwater may lie under the ocean. As long as a high water table maintains a sufficient head of pressure in the aquifer, there is a flow of fresh water into the ocean. Thus, wells near the ocean yield fresh water. However, a lowering of the water table or a rapid rate of groundwater removal may reduce the pressure in the aquifer permitting salt water to flow back into the aquifer and hence into wells. Saltwater intrusion is problem at many locations along U.S. coasts (**Source:** Environmental Science, Sixth Edition, Bernard J. Nebel, Richard T. Wright. Page No. 279 to 282)

Reasons for Basin Management:

Overdraft in a basin, or intensive local pumping in one part of a basin, can cause problems in addition to those associated with insufficient water quantity. Some of the most common undesirable impacts are land subsidence and seawater intrusion (or migration of poorer quality water).

Land subsidence caused by groundwater withdrawal has occurred in parts of the Central and Santa Clara Valleys and in localized areas of the south coastal plain. An important groundwater management goal in developed areas is the prevention or reduction of land subsidence. Land subsidence can impact infrastructure, roads, buildings, wells, canals, stream channels, flood control structures (such as levees), and low-lying coastal or

floodplain areas. Actions to monitor and manage subsidence may include monitoring changes in groundwater levels, precisely surveying land surface elevations at periodic intervals to detect changes, installing extensometers to measure the change in thickness of sediments between the land surface and fixed points below the surface, recording the amount of groundwater extracted, recharging the aquifer to control subsidence, and determining when extraction must be decreased or stopped. These management actions could be coordinated with groundwater/land subsidence modeling to predict future land subsidence under various water management scenarios.

One area of particular concern is the West Side of the San Joaquin Valley, where infrastructure affected by subsidence includes state highways, county roads, and water conveyance and distribution facilities.

CASE STUDIES:

Land Subsidence in the San Joaquin Valley
San Joaquin Valley land subsidence was observed as early as the 1920s. The rate of subsidence increased significantly in the post-WWII era as groundwater extraction increased. Subsidence was especially noticeable along parts of the west side of the valley, where land that had been used for grazing or dry farming was converted to irrigated agriculture. By 1970, 5,200 square miles in the valley had subsided more than 1 foot. Between 1920 and 1970, a maximum of 28 feet of subsidence was measured at one location southwest of Mendota. In the years since 1970, the rate of subsidence has declined because surface water was imported to the area. An increase in subsidence occurred during the 1976-77 and 1987-92 droughts, when groundwater extraction increased due to reductions in SWP and CVP supplies. Recent increases in subsidence are the result of increased groundwater extractions to compensate for water supply deficiencies caused by Bay-Delta export restrictions, ESA requirements, and CVPIA.
The Department monitors subsidence along the California Aqueduct, maintaining seven compaction recorders and performing periodic precise leveling along the aqueduct. The data indicate, for example, that a 68-mile reach of the aqueduct near Mendota subsided 2 feet between 1970 and 1994. Over the same time period, the aqueduct subsided approximately 2 feet along a 29-mile reach near Lost Hills, and up to 1 foot in a 9-mile reach near the Kern Lake Bed. At the time of the aqueduct's design, the potential for San Joaquin Valley subsidence was recognized, and measures were taken to compensate for some of its impacts. Canal sections in subsidence-prone areas were designed with extra freeboard, and structures crossing the canal (such as bridges) were designed to allow them to be raised later. Even so, continued subsidence along the aqueduct alignment creates the need for canal lining repairs and reduces the canal's capacity in places.

Seawater intrusion was recognized as a water management problem in California's coastal areas as early as the 1950s, affecting both urban and agricultural water agencies. Overextraction from basins near the coast induces seawater intrusion into the aquifer where the extraction occurred and leads to the expansion of areas of degraded water

quality, as pumpers relocate wells to take advantage of better quality water in deeper aquifers or in aquifers farther inland. Typically, seawater intrusion in larger basins occurs in areas where surface water supplies are limited, relative to the extent of water demands. In this case, a new supply of surface water must be provided to the area as part of controlling seawater intrusion, if existing land use patterns (either urban or irrigated agriculture) are to continue. Examples of areas which have experienced seawater intrusion problems include some of the managed basins in the highly urbanized South Coast Region, small basins serving individual communities in the Central Coast Region, and the Salinas Valley (a highly productive agricultural area). Imported supplies from the SWP have helped local agencies manage seawater intrusion in the South Coast Region; local agencies are also increasingly turning to recycled water supplies to help manage intrusion.

Seawater Intrusion in Orange County
Orange County Water District was formed in 1933 to protect and manage the groundwater basin that underlies the northwest half of the county. Groundwater supplies about 75 percent of OCWD's total water demand. As the county developed, increased groundwater extractions resulted in a gradual lowering of the water table. By 1956, years of heavy pumping to sustain the region's agricultural economy had lowered the water table below sea level, and saltwater from the ocean had encroached as far as 5 miles inland. The area of seawater intrusion is primarily along 4 miles of coast between Newport Beach and Huntington Beach known as the Talbert Gap.
To prevent further seawater intrusion, OCWD operates a hydraulic barrier. A series of 23 multi-point injection wells 4 miles inland delivers fresh water into the underground aquifer to form a water mound, blocking further passage of seawater. Water supply for the Talbert Barrier is produced at OCWD's Water Factory 21. The supply is a blend of recycled water and groundwater pumped from a deep aquifer zone that is not subject to seawater intrusion. The first blended recycled water from the plant was injected into the barrier in October 1976.
Water Factory 21 recycles about 10 mgd and, with the deep well water used for blending, produces about 15 mgd. OCWD has applied for and has received a permit to modify the treatment process to allow for injection of 100 percent recycled water, eliminating the use of deep well water for blending. The plant's current treatment includes chemical clarification, recarbonation, multi-media filtration, granular activated carbon, reverse osmosis, chlorination, and blending. The blended injection water has a total dissolved solid content of 500 mg/L or lower, and meets DHS primary and secondary drinking water standards.

(Source: *Bulletin 160-98: California Water Plan*, California Department of Water Resources, January 1999).

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Over the last 15-20 years, static water levels have declined by 13 to 33 meters and pumping water levels have declined by 5 to 69 meters in deep tube wells in the heavily pumped areas of the Northern Groundwater District. In the Central and Southern Groundwater districts the static water levels are depleted by greater than 21 and greater than 13 meters respectively and pumping water levels have declined by 9 to 19 meters respectively. Heavy pumpage from deep Aquifer wells in the Basbari, Dhobi Khola, and Manohara well fields of the Northern Groundwater District have caused alarming groundwater depletion based on the decline of static water level (Source: Metcalf & Eddy, Urban Water Supply Reforms in the Kathmandu Valley, Ex. Summery and Final Report, ADB TA Number 2998-NEP, 18th Feb, 2002, p III-4).

Groundwater Use:

The 1999 total annual groundwater use from shallow and deep tube wells and dug wells is estimated to be 46.86 MLD. The 1999 wet season (monsoon) groundwater use is estimated as 13.13 MLD. The 1999 dry season (non monsoon) groundwater use is estimated as 33.73 MLD.

The major uses of groundwater from deep tubewells are for public water supply, hotels, industry and government. Public water supply uses over 62 percent, or 29.17 MLD, of this water.

Hotels and industries withdraw 25 percent of the deep tube well production in the valley, or about 11.59 MLD. These entries are not charged for the use of this precious resources that s owned by HMGN. This represents a potential sources of revenue that could be used for programs to improve water management in the valley, such as artificial groundwater recharge, better seepage practices, and water pollution control (**Source:** Metcalf & Eddy, Urban Water Supply Reforms in the Kathmandu Valley, Ex. Summery and Final Report, ADB TA Number 2998-NEP, 18th Feb, 2002, p III-8).

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