Assessment of Groundwater Recharge Using GIS

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Abstract

Pressure on drinking water is increasing tremendously due to the increase in population in Kathmandu valley. Groundwater is serving as one of main source of water supply in the valley. Due to the scarcity of surface water and high demand for drinking water, excess extraction of groundwater than it replenishes may cause negative effect to Kathmandu valley like subduction. Thus, proper quantification of groundwater recharge must be done to define sustainable extraction of the groundwater. This study is conducted with the aim to demonstrate the simple water balance model within the GIS environment in order to quantify the spatial distribution of groundwater recharge. The simple water balance model Thornthwaite and Marther (1955) was used to quantify the water balance components in the upper bagmati watershed. The study shows that the groundwater recharge is high at the northern part specifically where there is high water holding capacity.

Background

The demand of water for domestic use has increased due to the high population growth along with the increasing number of industrial, tourism and institutional establishments which have put tremendous pressure on the limited source of water of Kathmandu. In order to fulfill these demands groundwater could be the alternate source. In spite of the limitedness in amount, groundwater is being used as alternative source for fulfilling the water demand. Groundwater occurs in the cervices and pores of sediments and occurrence are seen in the form of springs and seepages. The groundwater resource in Terai and the Inner Terai Valleys is estimated to be 12 billion m^3 (Kansakar 2001). Systematic evaluation of Nepal's groundwater resources began in the late 1960s under the auspices of a USAID (LRMP report, 1986). Based on the hydrological formation of various characteristics including river deposits and others, the Kathmandu Valley is divided into three groundwater zones:

a) the northern zone

b) the central zone and

c) the southern zone (JICA 1990).

According to the Snowy Mountains Engineering Corporation (SMEC, 1992), the upper limit of groundwater extraction in Kathmandu should be about 40.1 MLD. In spite, in 2002, NWSC's Optimizing Water Use in Kathmandu Valley Project (OWUKVP) found that the amount of groundwater extracted by NWSC and private wells for domestic use was about 47 MLD (Table 1). In addition, it is estimated that extraction for other domestic and private use is 13.2 MLD, yielding a total extraction of about 60 MLD a figure very much higher than the upper limit of extraction calculated by SMEC in 1992 (Dixit & Upadhaya, 2005).

Table 1: Groundwater extraction in Kathmandu Valley

System	Groundwater extraction (MLD)			
	Deep tube wells	Shallow tube wells	Dug wells	Total
MWSC	23.79	2.06	3.31	29.17
Hotels	5.50	0.90	0.12	6.53
Private	2.47	1.30	0.71	4.48
Domestic	0.07	0.32	0.19	0.58
Govt./Inst.	5.22	0.41	0.03	5.67
Embassy	0.43	0.00	0.00	0.43
Total	37.49	5.00	4.37	46.86

Source: OWUKVP, 2004

The increasing population in the Kathmandu valley is increasing high demand for drinking water. The surface water available for drinking is not sufficient to fulfill the demand. Thus, groundwater is being one of the alternative sources. However, the over extraction of the groundwater has also started producing problems which is seen as decrement in the water level at the well. So in order to go for sustainable yield of water, proper analysis of the groundwater recharge potential is necessary This study attempted to analyze the potential ground water recharge zone for extraction.

Objectives

The main objective of this case study is to demonstrate water balance model in GIS environment to:

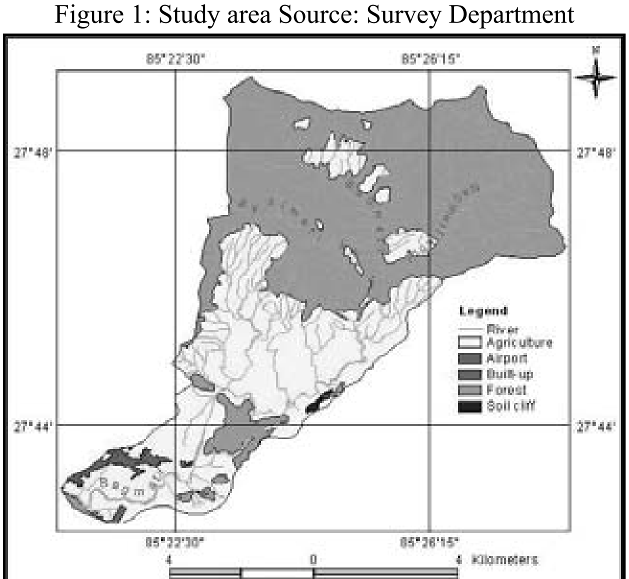
- quantify groundwater recharge potential
- delineate groundwater recharge zone

Study Area

The Bagmati river and its major tributaries Nagmati Khola and Syalmati Khola originate from the Northern fringe of Kathmandu valley (figure 1). The hydrological boundary of the Bagmati river considering Gaurighat as outlet is selected for this case study. The total area of the study watershed is 65.43 km^2. The study area extends from Latitude 27°42’11”N to 27°49’2”N and Longitude 85°21’6”E to 85°29’13”E. The study area includes some portion of Shivapuri National Park.

The study area lies in the Mid Mountain Region and the elevation within the study area ranges from 1,320 masl to 2,710 masl. Mean annual precipitation in the study area ranges from 1500mm to 2000mm (DHM).

Figure 1: Study area Source: Survey Department



Methods

The simple water balance model (Thornthwaite and Marther, 1950 was applied in the study. The water balance is modeled taking into account the spatial distribution of rainfall and evapotranspiration, and soil texture.

Each and every component of water balance model (*Figure 2*) was computed in GIS environment using Integrated Land and Water Information System (ILWIS) 3.3.

In this model, it was assumed that a portion of rainfall will leave the area as surface runoff.

i. SR=c1*rain

Where, SR is surface runoff, C1 is runoff coefficient & rain is the total rainfall occurred in the study area in the concerned month.

Remaining part is called effective rainfall. From the total amount of effective rainfall, portion of it is returned to atmosphere as evapotranspiration. The remaining part is available for infiltration into the soil as surface recharge.

ii. SRECH = (rain - SR) - ET

where SRECH is surface recharge and ET is evapotranspiration

When the soil is below the water holding capacity (WHC) and surface recharge is positive i.e. effective rainfall is more than evapotranspiration, then surface recharge is used to replenish the soil moisture.

iii. $SM_{(i)} = SM_{(i-1)} + SRECH_{(i)}$

Where, $SM_{(i)}$ is soil moisture of the month i and $SM_{(i-1)}$ is soil moisture of previous month (i-1)

As soon as the soil moisture reaches WHC, the remaining part will percolate to the groundwater called as groundwater recharge. Thus soil moisture remained after loosing portion of water into groundwater recharge from total soil moisture is the remaining soil moisture.

iv. GRECH = SRECH - (WHC - SM)

where GRECH is ground water recharge

When surface recharge is negative i.e. the effective rainfall is less than the evapotranspiration, water will be withdrawn from soil moisture, thus resulting in the exponential soil moisture depletion. The soil moisture depletion curve is described by the following formula:

v. $SM = WHC * Exp^{(-APWL/WHC)}$

Accumulated potential water loss (APWL) is a variable which describes the dryness of the soil. In the months with surface recharge less than zero, APWL is calculated as

vi. $$APWL_{(i)} = APWL_{(i-1)} - SRECH_{(i)}$$

In the months with a surplus of water i.e. SRECH>0, APWL=0. If previous month (i-1) with surplus of water is followed by the month (i) with water deficit, APWL is calculated by using the formula:

vii. $$APWL_{(i-1)} = -WHC*\ln(RSM_{(i-1)}/WHC)$$

where RSM is remaining soil moisture from previous month.

Underground surface contains groundwater store called as detention. This detention causes delay in groundwater runoff. Some percentage of water holding capacity of the soil is taken as detention coefficient. When groundwater recharge is greater than zero, water is added to the detention from the previous month.

Not all the water in the groundwater store becomes part of groundwater flow but only a certain fixed percentage goes as runoff in same month.

viii. $$GRO_{(i)} = C2*(DET_{(i-1)} + GRECH_{(i)})$$

where GRO is ground water flow DET is detention andC2 is detention coefficient Rest is detained till next month. Thus the new detention for the month will be

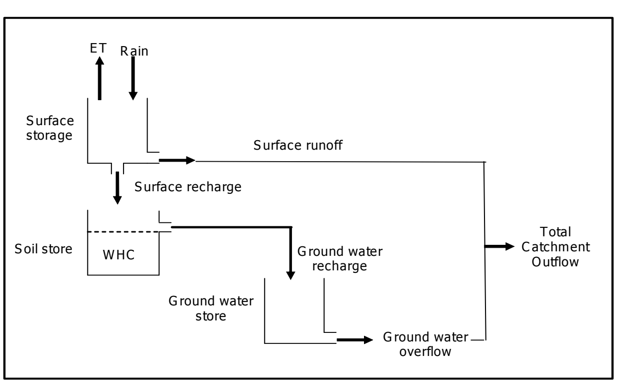
ix. $$DET_{(i)} = (1-C2)*(DET_{(i-1)} + GRECH_{(i)})$$

In this study 20% is taken as detention coefficient.

The direct runoff (surface runoff) together with groundwater flow forms total catchment outflow.

As after the rainy season, soil moisture will be at it's full capacity. Hence, September was selected as starting month to begin the calculation.

Figure 2:
Graphical representation of the water balance model
(Adopted from Meijerink et al 1994).



Materials

Drainage map, contour map, land use map and land system map of the Kathmandu Valley were collected from ICIMOD (Shrestha & Pradhan 2000).

The rainfall data recorded at the rain gauge stations which lies within and around the study area were collected from Department of Hydrology and Meteorology (DHM). The stations were Sundarijal, sundarijal Power House, Tribhuvan International Airport, Changunarayan, Budhanilkantha and Sankhu. Similarly, long term evaporation data of the Khumaltar station. Average monthly discharge from the Upper Bagmati Watershed at the outlet point (Gaurighat) was also collected from DHM.

Limitations

This study was conducted as case study to fulfill the partial requirement for M. Sc. in Environmental Science within limited time and resources. Hence, the estimation of runoff and detention coefficient which need long calibration process could not be carried out. These coefficient were estimated by trial method for number of times till the value of discharge after computation match with that of the observed data at the outlet

Results

Total inflow volume of water received as rainfall by the system is 154.2 million m^3. Similarly total outflow (includes depletion from evapotranspiration and discharge at the river) volume was 166.93 million m3. Thus, the percentage error was 8.25%. The error could be due to assumed runoff coefficient, detention coefficient and excluding the water use for irrigation at Gokarna due to unavailability of data.

From the study it is seen that maximum recharge is in the month of July.

Table 2: Estimated and measured river discharge

Month	Measured average monthly discharge (m3/sec)	Estimated monthly discharge (m3/sec)
January	0.439	0.009
February	0.318	0.008
March	0.356	0.007
April	0.420	0.010
May	0.734	0.009
June	1.611	2.998
July	8.666	8.371
August	13.375	12.325
September	7.509	6.674
October	2.949	1.087
November	1.080	0.555
December	0.570	0.035

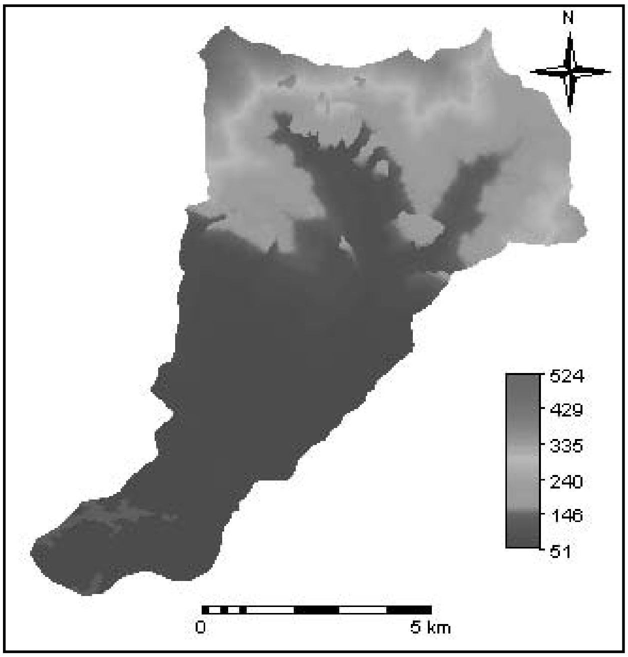


Figure 3: Total annual rainfall (mm)

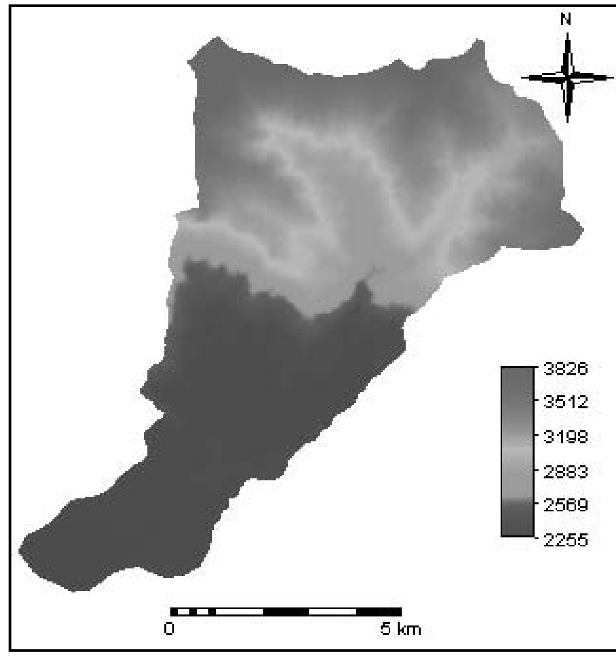


Figure 4: Total annual groundwater recharge (mm)

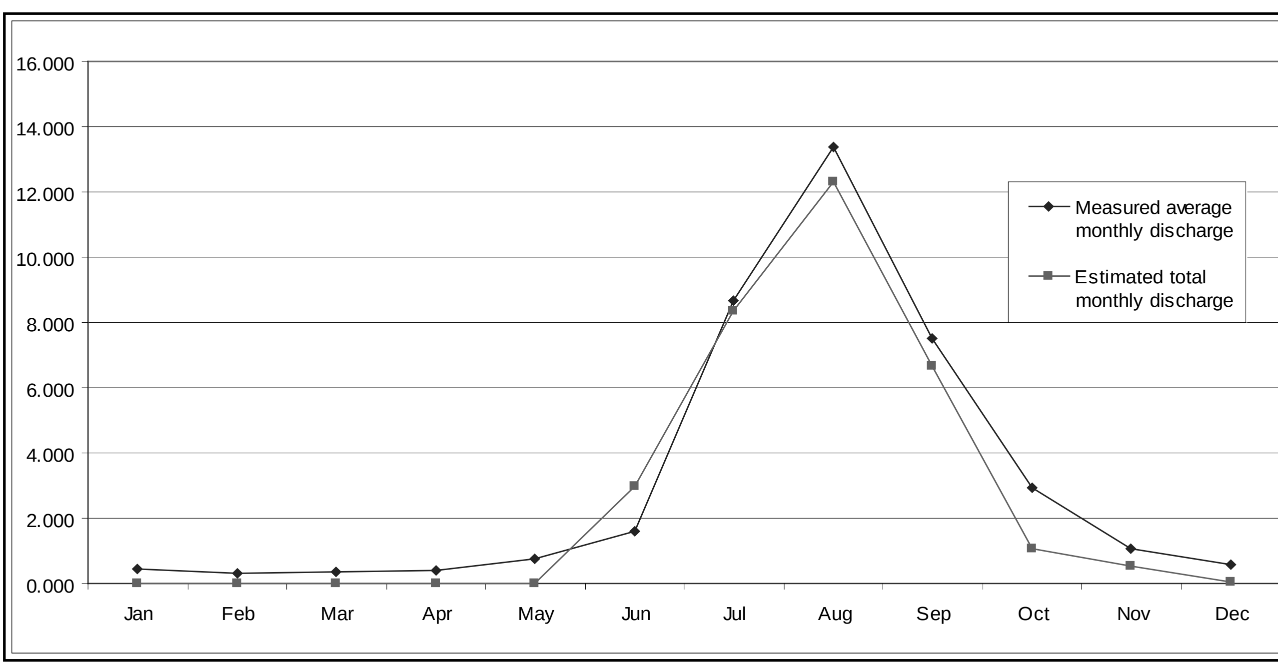


Figure 5: Graphical representation of measured and estimated discharge

Conclusions

Since last decade, population of Kathmandu valley is increasing day by day. Some of the reasons are the job opportunities, facilities, security, political issues etc. Thus the required resources for day to day life are being scarce to fulfill the needs of this increasing population. Among these resources water resources is also one. Surface water is not enough to fulfill their demand. Thus groundwater is one of the alternate sources.

This case study is used to access the groundwater potential zone by using available data in GIS environment which makes the task easier and reliable too. From the study it is seen that the major groundwater potential zone is the Sundarijal VDC area. At the southern part of the study area i.e. urban area, groundwater recharge is less in comparative to northern part. This is because of the soil texture at that area with low water holding capacity than in the northern part. The next reason is the increasing urbanization which increases surface runoff rather than surface recharge. The maximum groundwater recharge occurs in the month of July.

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