Shallow Groundwater Level Variation in the Kathmandu Valley: A GIS-based Study

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Abstract—**In the Kathmandu Valley (Valley), groundwater provides a critical source of water for domestic, commercial, and agricultural purposes. Haphazard urbanization and uncontrolled population growth lead to excessive use of groundwater resulting in the decline of the water table in the Valley. Since the groundwater level varies from place to place depending on its geology, land use and topography, it is important to understand its spatial variation. Also, one of the major sources of recharge of this underlying groundwater is rainfall, so it is critically important to understand the seasonal fluctuation of groundwater level and its relationship with the rainfall. For this study, groundwater data on monthly groundwater depth of spatially-distributed 32 groundwater sites were chosen by developing a grid map using GIS for the period July 2017 to June 2019. All the data were collected by the citizen scientists with the help of an Android application called Open Data Kit (ODK) Collect. The rainfall data of 12 stations of the Valley was procured of the period of 5 years from 2011-2015 was obtained from the Department of Hydrology and Meteorology (DHM). Seasonal groundwater level variation, groundwater fluctuation and its relationship with rainfall were prepared by using Inverse Distance weighted (IDW) interpolation in GIS. The result showed that groundwater rises in the month of August i.e. monsoon season while other seasons show a declining trend. Moreover, in the northern and eastern parts of the Valley, the groundwater level was shallow while the central part was deep. Furthermore, the groundwater level fluctuates highly in the western and southeast parts of the Valley with respect to rainfall while it remains constant in central, eastern and northern parts throughout the year.**

Keywords—the Kathmandu Valley citizen scientist groundwater fluctuation rainfall

I. INTRODUCTION

Groundwater is a critical water supply source for domestic, commercial, and agricultural purposes in the Kathmandu Valley (Valley). Groundwater is more likely to be free from pollution and requires no special treatment. So, if managed wisely and protected from undue exploitation and contamination, it can be considered as an easily available, cost-effective, more sustainable and better alternative of irregular piped water supplies in the Valley [1;8]

Although, uncontrolled population growth, unsustainable utilization of groundwater resources and significant land-use changes have led to lowering of groundwater levels, degradation of water quality, sinkhole formation, and land subsidence [13;16] According to ICIMOD (2007), about 79% of the water demand in the Valley (60-70% in the dry season) is fulfilled by groundwater which immensely increases the pressure on groundwater resources, resulting in a decline of the water table [8]. To reduce the growing imbalance between water demand and supply, recently, the number of household wells has been increased by 50% in the Valley, which will further stress the available groundwater sources [12;19].

Groundwater table varies from place to place thus it can be inferred that if the depth to the water level from ground level is shallow, then the groundwater condition is good but if the depth is deep then the groundwater level is poor [7,14]. Groundwater level fluctuates seasonally since the seasonal weather variation leads to change in recharge and discharge of groundwater. Although some of the wells show the direct and rapid response whereas some wells show gradual response which indicates that groundwater fluctuations depend on the geology and topography

[3;13]. A small aquifer with low storability will obtain high variations, and larger aquifers with high storability obtains, in general, less variations in groundwater level fluctuations [11].

Since the only way of recharging the underlying groundwater in the Valley is rainfall of which 80% occurs in monsoon, it is critically important to understand the seasonal fluctuations of groundwater level and its relationship with the rainfall and other associated factors: land-use, geology and topography [13].

II. Material and Method

A. Study Area

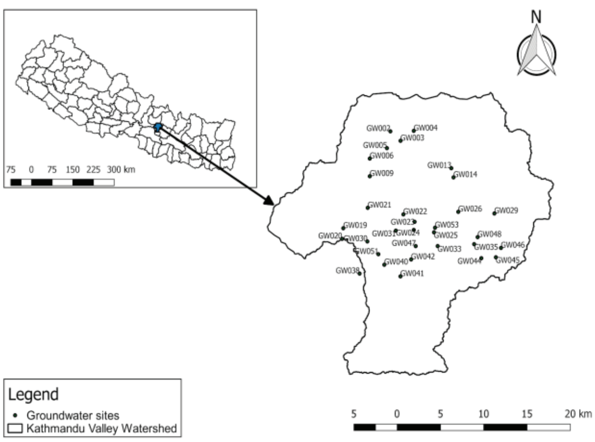

Fig. 1. Map of the Kathmandu valley Watershed with groundwater location sitesUnits

The study area, Kathmandu Valley, is located in Province number 3 of Nepal which lies between 27°32′13″ - 27°49′10″North latitude and 85°11′31″ - 85°31′38″ East longitude. The Valley comprises of 3 districts; Kathmandu, Bhaktapur and Lalitpur. The Valley small intermontane basin, roughly 25 km diameter and approximate geographical area of 587 km2. The land use of the Valley is classified into 33% natural, 41% agriculture, and 26% built [4]. The Valley lies between 1300 to 1400 m above sea level and is surrounded by hills ranging from 2000 to 2750m above sea level in elevation [10]. The weather of the Valley is classified into four seasons: pre-monsoon (Mar-May), monsoon (Jun-Sep), post-monsoon (Oct-Nov) and winter (Dec-Feb). The average annual precipitation is 1700 mm out of which 80% falls in the monsoon season and the annual average temperature is 18 °C based on 21 years (1988–2008) of temperature records from Kathmandu Airport Station [5].

According to the JICA (1990) , the Kathmandu Valley has been divided into three groundwater district based on the physical and chemical properties of groundwater and geological condition [19]. The Northern District is the main recharge zone with high transmissivity composed of unconsolidated highly permeable materials of micaceous sand and gravel. The Central District has shallow aquifers with underlain by thick impermeable clay layers and permeable coarse sediments respectively which have low transmissivity. The Southern District has a thick impermeable clay layer and the aquifers are not developed.

B. Sample Size

Using GIS, a 10*10 grid map was developed in which watershed map of valley was overlaid where only 73 grids were intersected. The desired number of monitoring wells was based on one groundwater site per grid. Since the valley is surrounded by dense forests, the probability of finding groundwater sites in those grids lying in the forest was very low. So, the target range of the groundwater sites for monitoring was around 50-55. But due to the inconsistent data and heavy extraction and pumping in some of the sites, these were not considered for the data analysis. So, the monitoring groundwater sites were reduced to 32.

C. Data Collection Method

Groundwater level data were collected from 32 groundwater sites located within the Kathmandu Valley for a period of 2 years from July 2017 to June 2019 mobilizing citizen scientists. Citizen Scientists (CS) took monthly measurements of groundwater depth in every 15^{th} of each month (+/- 2days) of their area using a 30 meters measuring tape. All measurements were recorded in an Android Application called Open Data Kit (ODK) Collect. Following procedures were followed by citizen scientists for groundwater measurement in a customized ODK form:

a) Date, time and GPS location were recorded.

b) The measuring tape was lowered until the end of measuring tape touched the groundwater level.

c) The photograph of measuring tape and reference point was recorded when the measuring tape just touch the groundwater level (figure 2a) .

d) The photograph of measuring tape and reference point was recorded when tape was pulled up so that the next whole meter of the tape was visible (figure 2b).

e) The depth to groundwater level from reference point was entered in meters.

f) The collected data were transferred into the database via wifi or cellular network.

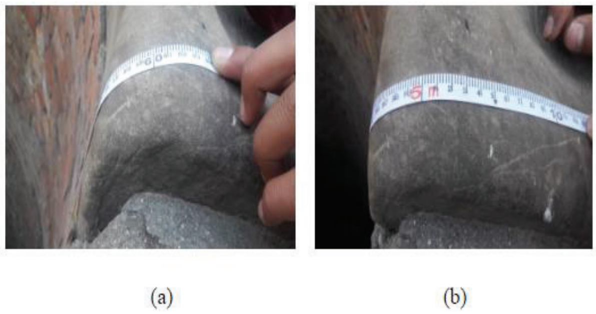

Fig. 2 (a)Image of measuring tape and reference point when the tape just touch the groundwater level and (b) Image of measuring tape and reference point when the tape was pulled up to show next whole meter of the tape.

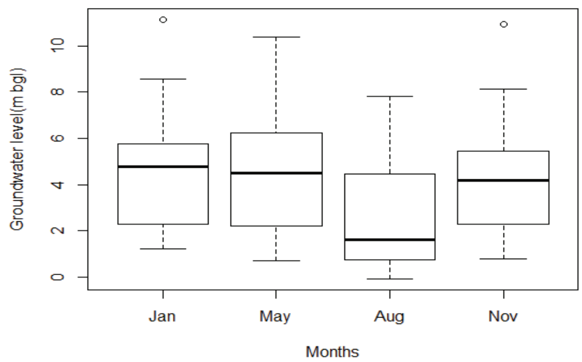

Fig. 3 Mean groundwater level variation (m bgl) of representative months of 4 seasons-winter: January, pre-monsoon: May, monsoon: August, and post-monsoon: November (*bgl= below ground level)

D. Data Analysis

The data collected from the different groundwater sites were quality controlled by comparing photos and measurement value and depth from the reference point to the ground surface was reduced. The groundwater level data was assorted monthly and mean monthly data was interpreted graphically using Microsoft office Excel 2013 and RStudio. Then, the representative month of 4 different seasons; January (winter), May (pre-monsoon), August (monsoon), and November (post-monsoon) were interpolated to know the spatial variation seasonal groundwater level. Range of mean monthly data for the overall year was calculated and interpolated to identify the groundwater level fluctuation. For the analysis of the rainfall, the data was procured from 12 rainfall station of Valley obtained from Department of Hydrology and Metrology, Nepal (DHM) for a period of 5 years (2011-2015). The mean annual rainfall of station were interpolated to know the spatial variation in the valley.

III. RESULT AND DISCUSSION

A. Seasonal groundwater level variation

In our study, we observed the groundwater level from the ground surface for all four seasons, as mentioned in the methods section. From Figure 3, in August, the groundwater level was found to be shallow compared to the other months. In August, the water table naturally rises as the underneath water fills in the space between the sediment which eventually increases the groundwater level. During the pre-monsoon, winter and post-monsoon seasons, groundwater level declines i.e. the level start to decline from pre-monsoon to post-monsoon and reaches the lowest in May. Since, pre-monsoon, winter and post-monsoon seasons has more dry days which significantly impact on the water retention on the groundwater due to evaporation, transpiration, etc. resulting in the decline of groundwater level.

From the figure 4c, for the month of August the mean groundwater level was between 2-4 m bgl and ranged from -0.089 to 7.77 m bgl. The groundwater level in the central part was found to be more than 4-6 m bgl whereas other parts was below 3 m bgl. Some of the sites in the northern and eastern part the groundwater has meet the ground surface which might be due to the presence of porous medium and high infiltration capacity which apparently flow to groundwater. In the study of Sishodia (2016), the groundwater level was high in post-monsoon than pre-monsoon[17]. However, in our study, a similar trend in the groundwater level was observed i.e.4-5 m bgl in both season and ranging from 0.72 to 10.39 m bgl and 0.98 to 10.94 m bgl in November and May respectively (figure 4b and 4d). In January, May and November, the western, central and southeast part of the Valley observed decline in groundwater level i.e. above 5 m bgl while in the northern, eastern and southern it was below 4 m bgl.

From Figure 4, we found the groundwater level to be shallow (>3 m bgl) throughout the year in the northern part of the Valley. In western and some eastern parts, the groundwater level was found to be deeper (<5 m bgl). Besides, in the central part, we observed a deep and constant groundwater level (>6 m bgl). Being specific, the reason for shallow groundwater level in the northern part of the Valley might be because of the high recharge potential in that area. The available water can be further used during the intense dry period in the Valley [18]. Due to concentrated population and increased abstraction in the central part of the Valley, the overall groundwater level is high (seen in figure 4) corresponding to increasing demand throughout the year. Similar findings were generated by Foster (1999) i.e. high population and increased abstraction increases the groundwater level from ground surface [6].

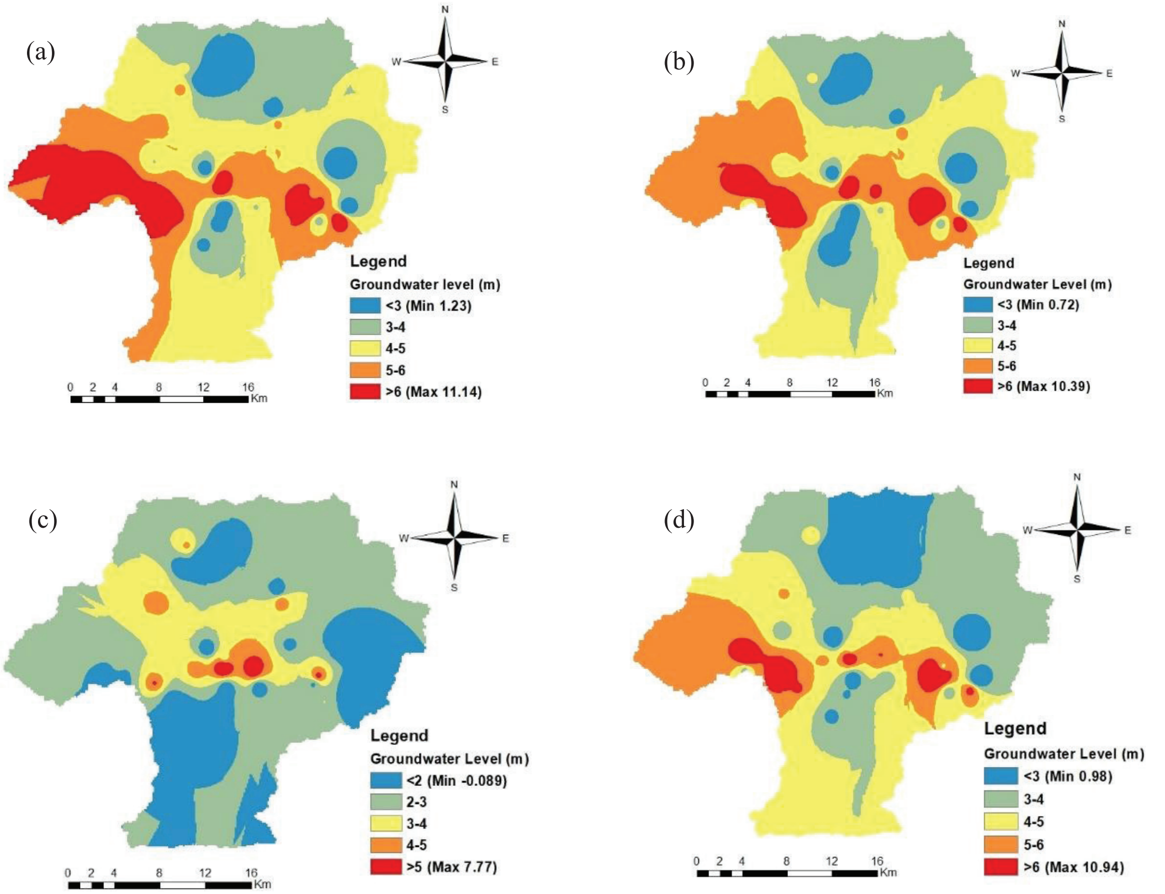

Fig. 4 Map showing average groundwater level of representative months of 4 seasons- (a)Winter: January, (b)Premonsoon: May, (c)Monsoon: August, and (d)Post monsoon: November

B. Effect of rainfall in groundwater level

The mean rainfall and fluctuation of groundwater level of the Valley is shown in Figure 5. Overall year mean groundwater level fluctuation in the Valley ranges from 0.53 to 9.32 m bgl. From Figure 5a, the western and eastern part of the valley found to highly fluctuate above 4 m bgl while in the central and northern parts show less fluctuation below 3 m bgl. The groundwater fluctuation depends on different factors; duration and intensity of precipitation and storability of aquifer are some of them [11;20].

Since the groundwater is more sensitive to change with the precipitation with respect to soil type and presence of aquifer the groundwater level fluctuation was different in part of the Valley [15]. The northern part of the valley has highest annual rainfall (>1800mm) thus groundwater level remain very shallow depth throughout the year in that area and show less fluctuation. On the other hand, western and Southeast part receive comparatively less annual rainfall (<1400mm) but on response of rainfall show rise in the water level in the month of August (figure 4c) while decline in other months which result in high water level fluctuation (<5 m bgl) which might be the result of impermeable layer and quick response by the lower storability aquifer [11]. In the central part of the Valley, shows similar water level throughout the year above 5 m bgl and lower fluctuation range below 2 m bgl on response of moderate amount of rainfall (1500 mm). As central region is highly urbanized with highly built land use which indicates high amount of runoff due to the large intensity of rainfall suggest groundwater level is not only depend on rainfall factor but also depend on human activities and structural factor of that area [2;14].

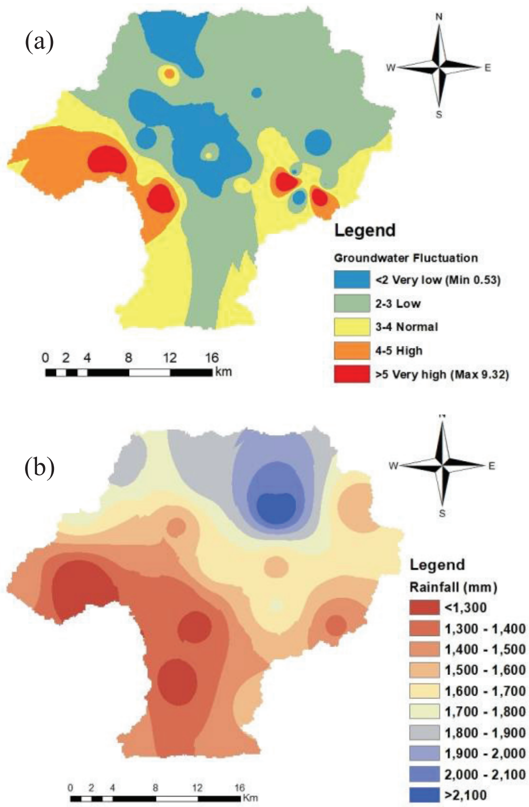

Fig.5 (a) Map showing Seasonal Groundwater Level Fluctuation and (b) Map showing mean annual rainfall for the period of 5 years (2011-2015).

IV. CONCLUSION

The groundwater level variation and fluctuation in the groundwater level, and effect of the rainfall on groundwater in the Kathmandu Valley were analyzed through the data collected by the citizen scientists using GIS. From our study, we can analyze that monsoon was the most dominant factor affecting the groundwater level of the Valley with August having shallow groundwater depth. We found that the northern and eastern parts of the valley remained shallow and central part remained deep throughout the year, while western, southeast parts showed a high level of groundwater level fluctuation across seasons which might be due to the response of rainfall. Thus, these parts were prone to drought in the dry season therefore, alternative source of water like rainwater harvesting could be the best option.

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