Effect of Monsoon on Groundwater Depth in a Mega City

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Abstract

Rainfall infiltration-recharge is one of the most essential component of groundwater recharge. Therefore, better understanding of the physical process of rainfall-recharge through the vadose zone is of fundamental importance for the management of water quantity and quality of groundwater systems. However, quantifying groundwater recharge still remains a challenging task. A GIS-based analysis has been carried out to compare year wise and intermediate changes in seasonal water-level fluctuation in response to pre-monsoon and post-monsoon rainfall obtained from Pilot balloon observatory data as well as NOAA APT data. Furthermore, overall decline rate has been calculated and compared with the previous studies along with the map of zones with declining trend of watertable. The results show monsoon contribution as an important factor but not the only factor. The decline rate is also found to be steepening with time and suggests further deterioration of situation in future.

Introduction

Climatic variability is the key factor in determining the groundwater response but the link between the two is more complex than that with the surface-water systems. Ground water occurs in a stable system, and responds slowly with a time lag to climate variability yet the characteristics of aquifer react differently to the surface stresses [1].

Climate change will affect groundwater recharge rates [2]. There has been very little research on the impact of climate change on groundwater [3]. Precipitation, the basic component of hydrologic cycle is what dictates, for most part, the groundwater level variations as it not only directly replenishes the levels but also is responsible for surface flow of water bodies such as rivers, canals and streams. However, the later part depends not only on the precipitation within the aquifer region but also on precipitations that might have contributed to the flow of the water bodies before entering into that region.

Fluctuation of water table is controlled by recharge and discharge [4]. Seasonal rainfall is the only source of ground-water recharge in a semi-arid hard-rock terrain where streams and channels are mostly dry, whereas discharge takes place through evaporation and withdrawal. Rainfall in northern India and Pakistan is governed by the southwest monsoon [5], which downpours from the middle of June till the end of September. Temporal delay, variability and change in spatial rainfall pattern is of great concern in tropical arid and semi-arid zones, since in those regions natural vegetation and agricultural ecosystems are highly sensitive to small variations of rainfall [4]. Weak monsoon in successive years affects agricultural activities and aquifer-recharge.

Physical basis for a relation

Infiltration is the process on which an aquifer mainly depends for its water supply whereas percolation is when rainwater moves underground through tiny spaces between soil particles

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and rocks. So the amount of precipitation within a region as well as surrounding region may contribute directly or indirectly as sub-surface or surface flow. Depending on the type of soil and the depth of the aquifer, some areas allow water to percolate water underground faster than others, resulting in different recharge rates [6].

Water reaching the aquifer pushes the older water and this process continues to ensure addition to the groundwater reservoir. This flow mechanism is called the piston flow [7]. With the increase in depth to groundwater, the degree of correspondence between rainfall and recharge processes decreases. After a certain depth, only the relationship among relatively large rainfall events and crests in the recharge processes may be observed [8].

The relationship between a single rainfall event and its effect on groundwater recharge may be easily observed in shallow groundwater areas whereas for deeper regions the response is usually slow and gives a significant indication after sufficient time period. So, natural replenishing of deep aquifers is a slow process because of the slow movement of water through unsaturated zone and aquifer. Therefore rate of recharge is also an important consideration which suggests whether years or centuries will be required for an aquifer to refill.

Previous Studies

Before analyzing the data in hand, a brief review of some of the works that have addressed relationships between precipitation, temperature and other factors that influence groundwater levels is given. Relationships between rainfall and infiltration-recharge have been studied using groundwater regime data [8][9] [10]**.** Several approaches have been used to study the relationship between precipitation and groundwater levels.

Leggette (1942) used the correlation between precipitation and water table height and Fetter (1976) noted that averages provided a better fit and concluded that the correlation shows the quick or slow response of the water table to changes in recharge [11]. Capone and Slater (1990) found close correspondence between peaks and valleys in precipitation and water table heights. Stanley, Floyd and Hsu (1988) showed that statistical relationships between monthly precipitation and shallow groundwater can be used to find strong temporal relationship between rainfall and ground water [11].

Even visual comparison shows major decrease in aquifer-recharge and variation in its spatial patterns because of large changes in the rainfall distribution [4]. Moreover in context to local monsoon found differences in fluctuations in the pre- and post-monsoon periods indicating different controlling factors for the two seasons (monsoon and non-monsoon) [4].

The infiltration to recharge can be predicted directly from rainfall measures through a statistical correlation and introduced a concept of effective rainfall events to analyze the rainfall-recharge relationship [8].

Butterworth et al (1999) used long term rainfall records to assess the effects of difference in rainfall on groundwater. Their outcome suggested that a shallow aquifer normally responds to differences in precipitation with large fluctuations in groundwater levels [12].

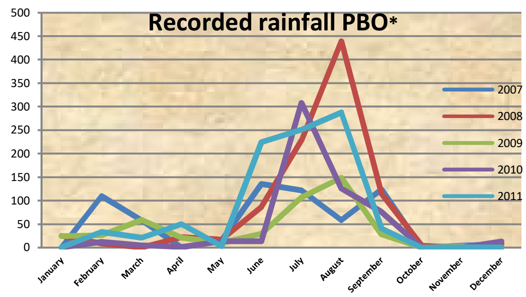
It is usually assumed that recharge to groundwater is negligible under arid conditions. However, studies indicated that significant recharge may occur in arid and semiarid regions, even where annual potential evapo-transpiration exceeds precipitation [8].

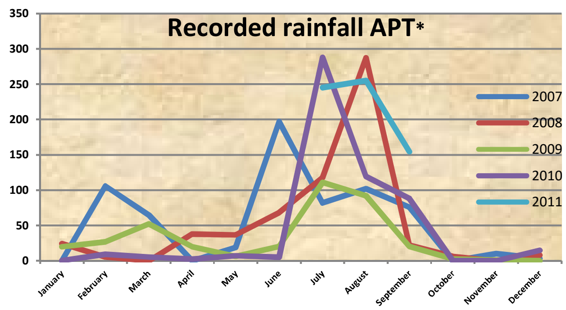
Rainfall Trends in Lahore

Lahore is a semi-arid climate region so here the rainfall during the monsoon seasons becomes much more important than tropical or subtropical regions.

During the last five years monsoon rainfalls have fluctuated a lot. The normal monsoon rainfall in Lahore is 470.1mm. The monsoons start from the last week of June and remain till the end of September. The monsoon of 2009 was far below level because Pakistan was facing effects of El-Nino.

Lahore receives rain from December till February in winter season. In 2009, below normal rainfalls were received in Lahore and normal rains in 2007 and 2011.





Procedures and Methods

To study the effect of precipitation on the groundwater depth in the region of Lahore, precipitation values were obtained from Meteorology Department as shown in figure2. The WASA observation data for tubewells of Lahore was used to form raster using the optimum parameters and methods of interpolations [13]. For the years ranging from 2007 to 2011, watertable surfaces were generated for the months of April, July and October. To generate surfaces of differences in depths with spatial context, the successive raster were subtracted using the raster calculator of the spatial analyst extension in ArcGIS and thus difference raster were created e.g.

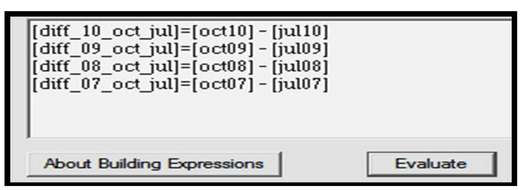


Figure2: The code for difference raster of July to October

Similarly, difference surfaces were created for other months. The month-wise raster were all reclassified with a defined interval size of five and using the same color scheme for each interval so that they can be compared or overlaid to assess the shifting/changes in the regions. The difference raster were also reclassified with their own color scheme and defined interval size of three. Finally, an overall change raster to calculate the mean change for the year 2007 through 2011 was created and the mean was assessed with the previous studies.

Results and Discussions

As a result of the adopted procedures, the following outputs were obtained;

Correlation Tables and graphs

The correlation between the difference in depths and the corresponding rainfall values gives indication of the type of relation between the two variables. Positive values of difference raster show that depth has increased during the time period. e.g. if difference raster of October to July has a positive mean then on average water table has gone lower in that region during the period of July to October. So, positivity of the mean shows increase in depth during this time. As rain is expected to raise the groundwater level by physical processes discussed earlier, therefore it decreases the depth values. A large rainfall value is expected to result in lower means of the raster showing that rainfall gives watertable a tendency to rise or to slow down its rate of decline. Therefore, negative correlations (one increase, other decreases) should result.

The correlations of the pre and post monsoon changes with the two types of rainfall values (ATP and PBO) are shown.

Table1: Negative correlations between rainfall and decline-rate

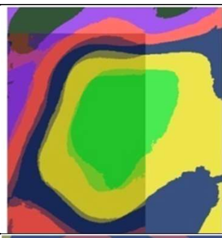
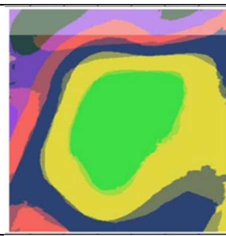
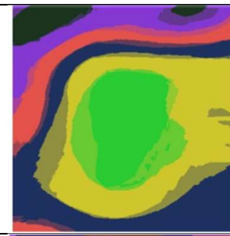
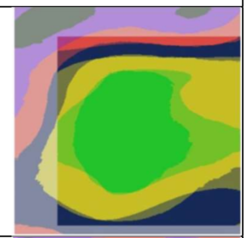
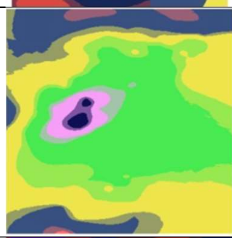
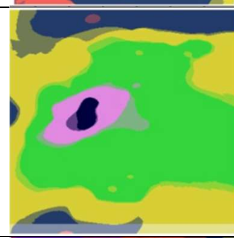
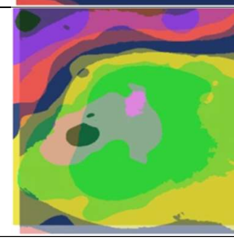
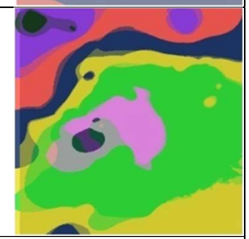
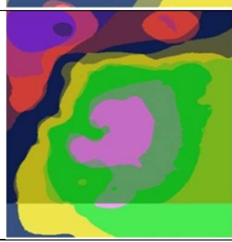
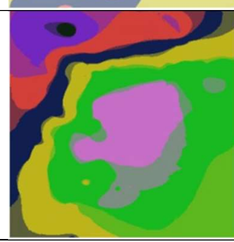
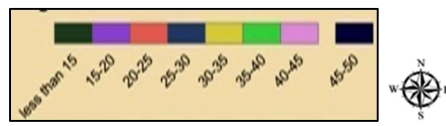
CORRELATIONS				
	Average Rain (PBO)		**Average Rain (APT)**	
	Pre-Monsoon	*Post-monsoon*	*Pre-Monsoon*	*Post-monsoon*
Raster Mean	**-0.892**	**-0.707**	**-0.919**	**-0.775**
Points Mean	**-0.850**	**-0.721**	**-0.863**	**-0.756**

As expected, the pre-monsoon and post-monsoon correlation for both types of rainfall values is negative. The values of ATP (NOAA) show a higher correlation with the mean decline of in both pre and post monsoon as the rainfall values corresponding to the transmission system are representative of the overall area whereas PBO values are more constricted to nearby areas. Also the fluctuations that occurred during the monsoon between 2007 and 2011 (shown in figure 3) contributed to the slightly less response of the post monsoon correlations. Moreover, the river Ravi flow/flooding contributed in the year 2010 [13]. Yet there is adequate indication that rainfall recharge is a key factor in groundwater recharge of Lahore and to slow down the constantly declining trend of depth values.

Table2 is formed by using the reclassified raster of each observation month and then overlaying them two at a time with the earlier raster set to partially transparent theme and slightly darker in brightness to see through the amount and direction of the shifts of the respective ranges or regions in successive months. This output can be used in time series analysis as well in the precipitation/monsoon effect study and using the monsoon data and rainfall times several important points can be obtained.

Heavy rainfall during monsoon period is the only precipitation that raises groundwater levels and the meager rainfall during pre-monsoon period contributes to only slightly slowing down the declining trend. The heavy monsoon flooding during 2010 and 2011 replenished the mean decreasing water table and caused the difference raster' mean to be negative. It is also observed that at some points the aquifer behaves as slow response aquifer and at times it behaves as a quick response aquifer. E.g. the April 2007 July rain values showed their effects on the mean change in levels.

Table2: Pre and Post Monsoon Groundwater level shifts

YEAR	Pre-Monsoon (Apr-Jul)	Post-Monsoon (Jul-Oct)	year	Pre-Monsoon (Apr-Jul)	Post-Monsoon (Jul-Oct)
2007			2008		
2009			2010		
2011			Legend		

Initially in 2007and 2008 there is no purplish depression portion representing the range from 35-40m depth and only green depression is present. The green region in 2007 did not shift much in direction and location. However, in 2008 it gradually grew up in size and spread in East-West direction more than the North-South direction. In year 2009 the water table condition was at worst point. This can very well be correlated with the El-Nina condition that persisted in Lahore in 2009 during which monsoon rains were much below usual. There was a greater depression zone/region of above 45m depth that existed during 2009 till the post monsoon observation month of October 2010. The flood of 2010 greatly affected the rapidly decreasing watertable of Lahore and gave it some height. During 2009 and 2010 the green region had grown to a much larger extent and spread to encompass a larger area of Lahore. Moreover, the East-West spread is again more than the North-South spread. The eastern portions of the rasters are declining more rapidly; this trend can be attributed to the presence of river Ravi on the western side. Although the above 45m portion has disappeared after 2010 monsoon but the region of 40-45m depth is constantly spreading in the center. Moreover the pre-monsoon rainfall that are less than monsoons contribute as in this season the extraction is comparatively less than during hot summer season.

Total Decline

The overall trend of the groundwater in Lahore is of decline and comparing the results with the previous studies, it is evident that the decline rate per year is increasing with time as shown in figure

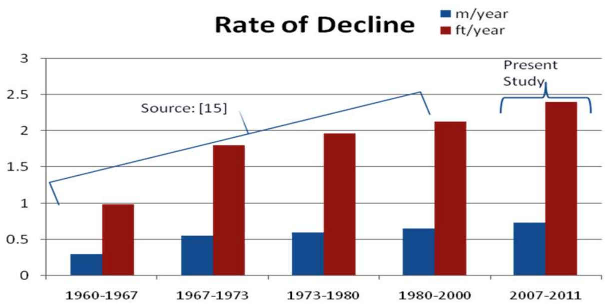


Figure3: Trend of Decline-Rate (historic and present)

The geographic distribution of the trend of decline during 2007-2011 is shown in the map of Lahore below. The areas near Shahdra (upper left) have shown an increase in levels. The populated city regions have experienced a decline with a central depression contour around Shadman area.

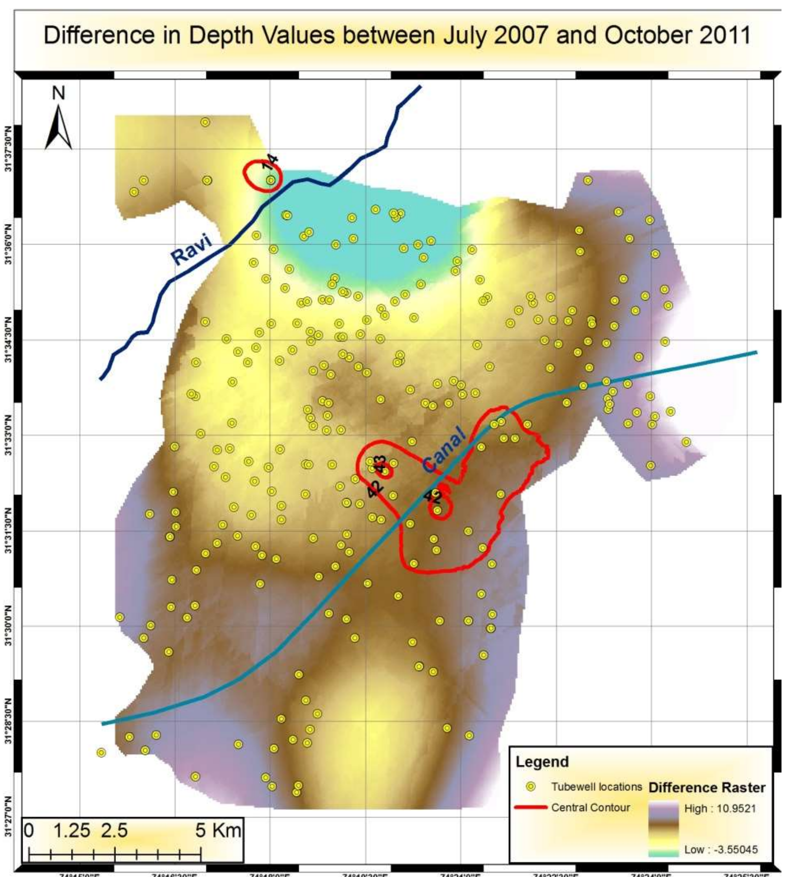


Figure: Geographic distribution of decline with the central depression.

The mean difference over the period of 2007-2011 calculated from above geographic area is 0.73 meters per year. So the decline has accelerated even though there was flooding during the study period.

Conclusions

From the correlations and fluctuations it can be concluded that monsoon rainfall is important for groundwater recharge of Lahore. Also the trend suggests that the depression area will

spread even more with time unless heavy monsoon or in general rainfall replenishes the lost water. The depression in the center will cause the gradient to steepen even more and hence, large Basal flow may also cause surrounding regions to lose their groundwater. Furthermore, it can also be concluded that other recharge sources such as river Ravi will have to play a big role in recharge of the Aquifer. With the current extraction rate, above average monsoon rains alone will not be able to stop the decline in groundwater levels.
Analysis of this type performed on a much longer time-span can reveal even more important dependence of groundwater on monsoon rainfall in Lahore. Moreover, interpolation errors and different data extents of the observation values might also have played their role. So, continuous observation values for a longer period of time are important in further elaborating the trend.

References

- Aflatooni, M. and Mardaneh., 2011. "Time-series analysis of ground water table fluctuations due to temperature and rainfall change in Shiraz plain". International Journal of Water resources and Environmental Engineering 3(9): 176-188.
- Kundzewicz, Z.W et al, 2007. "Freshwater resources and their management. Climate Change: Impacts, Adaptation and Vulnerability". Contribution of Working Group II to the Fourth Assessment Report of the IPCC , Cambridge University Press, Cambridge, UK, 173-210.
- Alley,W.M., 2001. "Ground water and climate". Ground Water. 39: 161.
- Bhuiyan, C., Flugel W.A and Singh R.P., 2009. "Erratic monsoon, Growing water demand, and declining water table". Journal of Spatial Hydrology 9(1).
- Mulky K. and Bwnerji G. R., 1959. Journal of meteorology the mean upper-wind circulation around monsoon depressions in India, Regional Meteorological Center, Nagpur.
- Kommadath A., 2000. "Estimation of natural ground water recharge". In proceedings of LAKE.
- Sharma K.D. and Kumar S., "Hydrogeological Research in India in Managing Water Resources". National Institute of Hydrology, Roorkee, 247667 extracted from Groundwater dynamics in hard rock aquifers.
- Wu, J. and Zhang R. 1994. "Recharge to groundwater'. In Proceedings of Fourteenth Annual American Geophysical Union: Hydrology Days, Proceedings 1994 WWRC-94-09.
- Wang P. et al., 2011. "Relationships between precipitation, soil water and groundwater at Chongling catchment with the typical vegetation cover in the Taihang mountainous region, China". Environ Earth Sci 62:787–796
- Stanley A.C., Floyd A.H and Hsu C.F., 1988. "Relations between precipitation and shallow groundwater in Illinois". American Meteorological Society 1:1239-1250.
- Fetter, C.W., 1994. *"Applied Hydrogeology, 3rd Edition".* Macmillan College Publishing Company: New York.
- Butterworth J.A., Schulze R.E., Simmonds L.P, Moriarty P. and Mugabe F., 1999. "Long-term groundwater level fluctuations due to variation in rainfall" Hydrology and Earth System Sciences, 3(3):353-361.
- Khalid M., Asim D. R., Salman T., Shamsa K., Roshaan A., Haider A, Tayyab T., 2013. "Groundwater Levels Susceptibility to Degradation in Lahore Metropolitan". Science International, 25:123-126.
- Rajabhat S., Low Cost NOAA Satellite Receiving System for Rainfall Prediction Chonmapat Torasa Industrial Electrical Technology Department, Thailand.

- Mashhadi, S. N. and Muhammad, A., 2000. *"*Recharge the Depleting Aquifer of Lahore Metropolis, Proceedings of Regional Groundwater Management Seminar*"* Oct. 9 - 11, Islamabad, Pakistan Water Partnership (PWP), 209 – 220