GROUNDWATER LEVELS SUSCEPTIBILITY TO DEGRADATION IN LAHORE METROPOLITAN.

Khalid Mahmood*, Asim Daud Rana* , Salman Tariq*, Shamsa Kanwal, Roshan Ali*, Anees Haidar Ali*** and Tayyab Tahseen***.**

*Department of Space Science, University of the Punjab, Lahore, Pakistan.

**Institute of GIS, School of Civil and Environmental Engineering, National University of Sciences & Technology, Islamabad, Pakistan.

***Institute of Geology, University of the Punjab, Lahore, Pakistan.

Corresponding Author: Khalid.m270@yahoo.com

ABSTRACT: *Lahore is the second largest city of Pakistan and capital of Punjab province. It has a long history of groundwater over abstraction with continuously decreasing rate of aquifer recharge which results in water table level recession substantially. Water supply demand has been increased as a result of rapid increase in population, urbanization and industrialization. On the other hand, land development has reduced the recharge as a significant portion of the land has become impermeable. River Ravi which was considered a dominant source of recharge to groundwater remains almost dry except in the monsoon season. Groundwater conditions are likely to worsen in near future if the situation remains persistent. The basic step towards remedial measures for the issue is to quantify this rate of degradation and to identify possible causes as well. In this study Geographic Information System (GIS) has been used as it provides Interpolation, classification and Contour delineating tools for this kind of quantitative measurements. A depression zone in the groundwater levels below 38m has been identified which goes on expanding after 2004 persistently with an average rate of about 24.5 Km^2 per year. The expansion trend in the depression zone has also identified consequences of recent developments in the study area and increased flow of Ravi in 2010.*

Keywords: Groundwater, Water demand, Recharge, Ravi, City growth, Depletion, GIS, Lahore

INTRODUCTION

Water is absolutely essential to life and is used for numerous purposes including drinking, bathing, washing and so many others. Earth is a watery place [1] but only 2.5 % of Earth's total water is fresh [2, 3]. For human use, only one-third of this meager amount of fresh water is available [4] and more than half of it is already being consumed [5]. Approximately 99 % of all liquid fresh water is in underground aquifers [6] and at least a quarter of the world's population draws its water from these groundwater supplies [7]. The total water withdrawn for human use has almost tripled in the last 50 years from 1382 km^3/year in 1950 to 3973 km^3/year in 2000 and the worldwide projections predict that the human water consumption will further increase to 5235 km^3/year by 2025 [8]. This blessing is now facing geographical issue and almost every region of the world is under water crisis. Groundwater has surpassed surface water in its importance in many regions of the world [9]. Since the water demands are almost entirely met by groundwater [10], therefore the study of groundwater depletion and increasing water demands are very important.

The mega city of the Lahore is also facing the problem in that is water level is lowering down mainly due to excessive pumpage compared to recharge [6, 11-15]. Lashari et al. [16] estimated that about 60-70% population of Pakistan depends directly or indirectly on groundwater for its livelihood. Groundwater supplies about 80% of the domestic water usage [13, 17] and more than 50 % of the drinking water supplies. Many studies reported a number of problems arising due to overexploitation and degradation of groundwater [13, 18-25]. This paper seeks to highlight causes of decline in water table in Lahore and to quantify this decline in terms of depression zone expansion.

STUDY AREA

Lahore metropolitan is the second largest city of Pakistan, and the provincial capital of the Punjab. It covers a total area of 1014 km² and lies between 31°15′-31°45′ N and 74°01′-74°39′ E. It is entirely groundwater dependent city [26]. Lahore's population is almost 10,000,000 [11] and now it is about to become one of 'mega cities'-cities with more than 10 million inhabitants.

The major sources of groundwater recharge for Lahore are rainfall and river Ravi [11, 6, 14]. Lahore is a sub-tropical, semi-arid region with average rainfall of the order of 575mm per year but can vary from 300-1200mm which accounts for more than 40% contribution to groundwater recharge in a year. Most of the remaining recharge supply depends upon the water flow in the Ravi River.

FACTORS REDUCING GROUNDWATER LEVEL

Population Growth

The number of tubewells and, hence, the groundwater abstraction has been increasing with the increase in population. The groundwater level, has gone down to more than 40m, which used to exist at about 4.5m below surface.

Peripheral growth

Figure-1: History of Water flow in Ravi

Reduction in number of irrigation fields due to progressive urbanization and industrialization has reduced the rate of recharge to aquifer, as a significant part of the land has become impermeable.

River Ravi

It is a big setback that River Ravi enters in Pakistan from neighboring country India. The surface flows to the Ravi River started facing reductions immediately after independence in 1947 ending to nearly zero flows after the construction of Thein Dam in 2000 upstream of Madhopur head works in India [11, 27, 6, 13]. The river remains dry

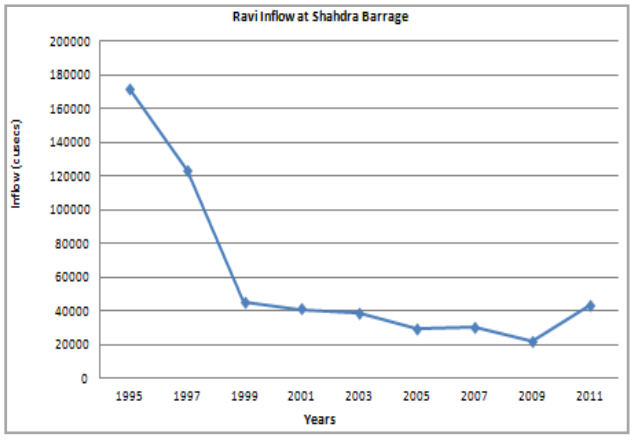

Figure-2: History of Water flow in Ravi

except during the monsoon season. It results in lowering of groundwater levels in river adjoining areas of Lahore city [6]. Graph in Figure-1 shows that River Ravi inflow has went on reducing with the passage of time.

Along with the increase in population, the construction of Thein Dam also has contributed well in this decline as shown in Table-1.

Table-1: Average annual rate of groundwater decline [10, 28]

Period	1960 to 1967	1967 to 1973	1973 to 1980	1980 to 2000	2000 to 2011
Rate of Decline (m/year)	0.30	0.55	0.60	0.65	**0.792**

QUANTIFICATION OF THE DEPRESSION ZONE

For this study expansion of groundwater depression zone has been considered as a measure of water table recession. This depression zone is calculated using Geographical Information System (GIS), which is popular for planning and management because of its ability to easily link different disciplines like resource management and natural hazards etc. Static water level (SWL) values were available from Water and Sanitation Agency (WASA). The coordinate information for 476 tubewells was gathered by field survey of each tubewell site specifically for the study using Garmin GPSmap 76CSx with an accuracy of 3 m shown in Figure-2. number of techniques have been applied over the dataset to get best interpolation surfaces for the analysis. Accuracy results of various popular techniques for the given dataset are shown in the Table-2 which suggests kriging as the best method for the interpolation.

Table-2: Comparison of Various Interpolation techniques for Lahore's Groundwater

Method	**RMSE**	**Correlation**	**Rank**
IDW	3.492	0.890536	3
Spline	3.399	0.897549	2
Kriging	**3.37**	**0.898589**	**1**

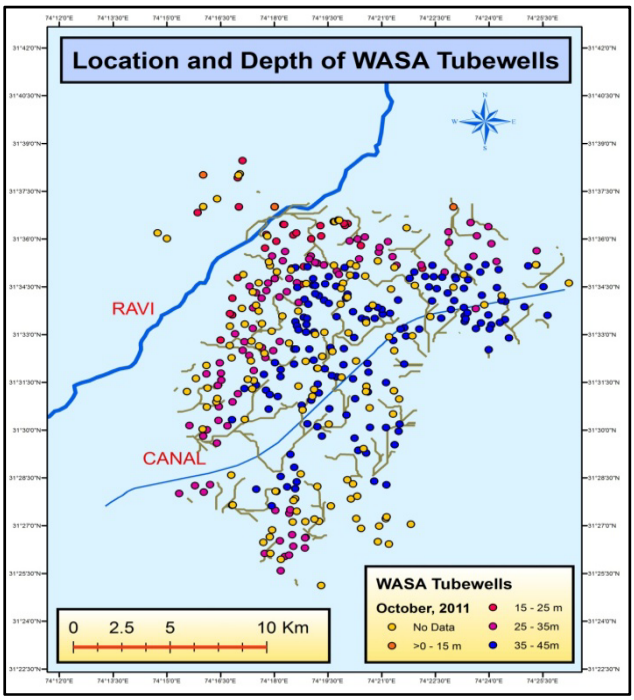

Figure-2: Location of Tubewells installed by WASA in the Study Area

A Depth surfaces for the month of October from 2007 to 2011 have been created using kriging as the interpolation method in ArcGIS-10 environment. This study is aimed to quantify recent trends in groundwater decline in the city. Therefore the standard depth to measure change is taken from measurements in the year 2004. In October 2004 the maximum depth of groundwater was found to be 37.86 m at Shadman market. In other words in 2004 there was no region having groundwater depth more than 38 m. As the ground water depletion continuous, more and more areas of the city get depth values over 38m. To calculate the area of water table depression zone below this depth limit of 38m contour analysis has been performed. Contours of 38m depth value have been drawn to all five datasets followed by their digitization to polygons as shown in figure- 3. Visual Basic code to find area of polygon was then implied to each of the polygon to find its area. Results of this area calculation have been shown in the Table-3.

Table-3: Temporal Growth of Water table Depression Zone

Year	Depression zone (km^2)	Annual Change (km^2)
October 2007	52.10	
October 2008	69.85	17.75
October 2009	133.86	64.01
October 2010	142.25	8.39
October 2011	150.26	8.01

Contour map shows an eastward shifting of the aquifer depression, showing high abstraction and low recharge rates in these areas. This shifting in the depression zone is a result of recent developments in eastern parts of the city where a large cultivated land has been transformed into concrete structures of populated areas.

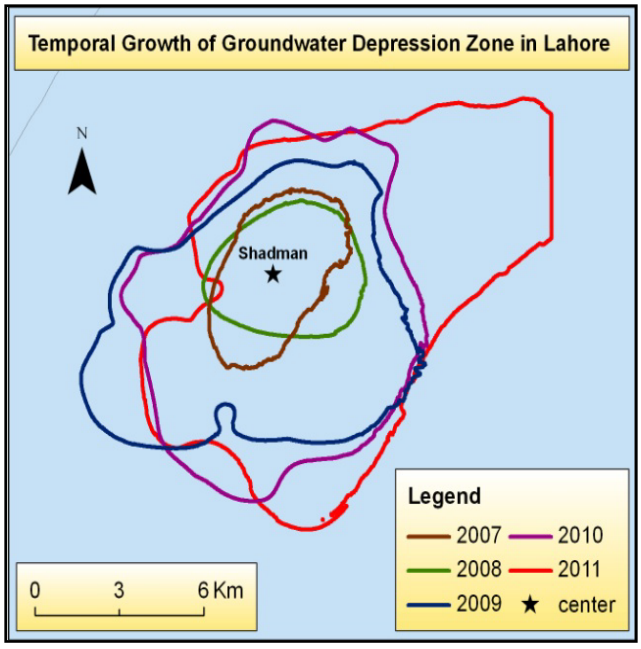

Figure-3:Expansion of Depression Zone from 2007 to 2011

CONCLUSIONS AND RECOMMENDATIONS

Results have shown an increase in the groundwater depth in the city because of high water extraction rates as compare to the recharge. Water demands are increasing due to population growth and recharge is decreasing due to decline in the water flow of the Ravi and increase in the impermeable area in the city. The area in the city with groundwater below depth of 38m is increasing continuously at an average rate of 24.5 Km^2 per year. As a result of heavy monsoon in 2010, the flow of Ravi was improved due to flooding in many areas of the Pakistan and neighboring country. After this monsoon, expansion of the depression zone has considerably reduced to 8 Km^2 during the year, which indicating the role of Ravi flow in the recharge of the Lahore's aquifer. The expansion of depletion zone to the eastern parts of the city highlights contributing role of permeable land to aquifer recharge of the city. All these conclusions suggest the need to understand the dynamics and factors which are responsible for the worse groundwater declines in Lahore. Following steps may be taken to overcome the issue

- Installation of new tubewells should be stopped within limits of Lahore city as heavy pumping of groundwater is the sole cause of lowering water table. In addition to excessive pumping, close spacing of tubewells is also responsible for accelerating groundwater depletion.
- If installation of new tubewells cannot be stopped then large spacing among them may also be helpful to arrest the groundwater draw downs.
- There is need of making public aware about the dwindling status of groundwater so that un-wise usage of water can be reduced.
- Making small ponds of water reservoir in or near River Ravi to store water during heavy rainfalls can serve as another option and may contribute well to save aquifer from exhausting.

REFERENCES

1. The Hydrologic Cycle, *USGS pamphlet* (1984).
2. Limouzin M. & Maidment D., water scarcity is an indicator of poverty in the world, A term project in *University of Texas at Austin* (2009, Spring).
3. PCRWR, Water Quality Monitoring Report Fifth monitoring report (2005-6), **ISBN 978-969-8469-18-4,** Pakistan Council of Research in Water Resources (2007). Available at*:* *www.pcrwr.gov.pk*
4. Pakistan: Appraisal of the Lahore Water Supply, Sewerage and Drainage Project-Phase II, South Asia Projects Department-Water Supply Division, Report No.**996a-PAK** (1976).
5. Compendium on Environment Statistics of Pakistan – 2004, *Federal Bureau of Statistics Government of Pakistan* (2004).
6. Gabriel, H. F. And Khan, S., Climate Responsive Urban Groundwater Management Options in a Stressed Aquifer System, Kovacs Colloqium "Hydrocomplexity: New Tools for Solving Wicked Water Problems". Edited by Shahbaz Khan, Hubert H. G. Savenjie, Siegfried Demuth & Pierre Hubert. *UNESCO, Paris, France. IAHS Publication* **338**: 166-168 (2010).
7. ESA, Water in a Changing World*, Journal of Issues in Ecology, Ecological Society of America*, **Vol-9** (2001).
8. King, J. & Clarke, R., The Water Atlas A Unique Visual Analysis of the World's Most Critical Resource, *spring*, **ISBN: 978-1-56584-907-5** (2004).
9. Vilholth, K.G. And Giordano, M., Groundwater Use in a Global Perspective – Can It Be Managed? *International Water Management Institute, 127 Sunil Mawatha, Pelawatte, Battaramulla, Sri Lanka* (2007).
10. Mashhadi, S. N. H. and Muhammad, A., Recharge the Depleting Aquifer of Lahore Metropolis, *Proceedings of Regional Groundwater Management Seminar, Islamabad, Pakistan Water Partnership (PWP)*, **Oct. 9 – 11,** 209-220 (2000).
11. Akram, T. and Gabriel, H. F., Urban Water Cycle Management of Lahore, Pakistan, ESDev - 2007 *Second International Conference on Environmentally Sustainable Development, organized by COMSATS Institute of Information Technology, Abbottabad,* Pakistan, **26-28 August,** (2007).
12. Gabriel, H. F. and Khan, S., Policy Options for Sustainable Urban Water Cycle Management in Lahore, Pakistan, *ERSEC Workshop on Sustainable Water Management - Problems and Solutions under Water Scarcity, Beijing, China***, 6 - 8 November 2006** (2006).
13. Gabriel, F. H., An appraisal of climate responsive urban groundwater management options in stressed aquifer system, *International Centre of Water for Food Security, School of Environmental Sciences, Faculty of Science, Charles Sturt University* (2010).

14. NESPAK, Groundwater Resources Evaluation and Study of Aquifer under Lahore. *Final Report, National Engineering Services Pakistan (Pvt) (NESPAK) Limited and Binnie& Partners Consulting Engineers, London, UK* (1991).
15. NESPAK, Groundwater Resources Evaluation and Study of Aquifer under Lahore. *Supplementary Report, National Engineering Services Pakistan (Pvt.) (NESPAK) Limited and Binnie & Partners Consulting Engineers, London, UK* (1993).
16. Lashari, B., McKay, J. and Villholth, K. Institutional and legal groundwater management framework: Lessons learnt from South Australia for Pakistan. *International Journal of Environmental and Development*, **4** (1) (2007).
17. Villholth, K. G., Groundwater assessment and management: implications and opportunities of globalization. *Hydrogeology Journal* **14**: 330-339 (2006).
18. FAO Groundwater Management, the Search For Practical Approaches. *Water Reports FAO (Food and Agricultural Organization)* **25** (2003).
19. Llamas, R. and Custodio, E., Intensive Use of Groundwater: Challenges and Opportunities, *Rotterdam, Netherlands*, **vol xii** (2003).
20. Moench, M. and Dixit, A., Adaptive Capacity and Livelihood Resilience, Adaptive Strategies for Responding to Floods and Droughts in South Asia. *ISET (Institute for Social and Environmental Transition), Nepal and Boulder, Colorado, U.S.A* (2004).
21. Moench, M. H. and Burke, J. J., Groundwater and Society: Resources, Tensions and Opportunities. *United Nations Publications*, Sales No. E.99.ll.A.1 (2000).
22. Moench, M., Burke, J. and Moench, Y., Rethinking the Approaches to Groundwater and Food Security. *Water Reports FAO (Food and Agricultural Organization)*, **24** (2003).
23. Morris, B. L., Lawrence, A. R. L., Chilton, P. J. C., Adams, B., Calow, R. C. and Klinck, B. A., Groundwater and its Susceptibility to Degradation: A Global Assessment of the Problem and Options for Management. *Early Warning and Assessment Report Series, RS. 03-3. United Nations Environment Program (UNEP), Nairobi, Kenya* (2003).
24. Richardson, S., Evans, R., Middlemis, H., Ross, J., Howe, P., Hiller, J. and Dyson, P., Guiding Principles for Sustainable Groundwater Management. *IAH Background Paper, MDBC (Murray- Darling Basin Commission), REM (Resource & Environmental Management Pty Ltd.), Australia* (2004).
25. Shah, T., Molden, D., Sakthivadivel, R. and Seckler, D., The Global Groundwater Situation: Overview of Opportunities and Challenges. Colombo, Sri Lanka: *International Water Management Institute (IWMI)* (2000).
26. Ahmad, N., et al, Hydrological Modeling Of the Lahore-Aquifer, Using Isotopic, Chemical and Numerical Techniques, *Back Issues in Journal of Science Vision,* **7,** 16 (2002).
27. Basharat, M. and Rizvi, S. A., "Groundwater Extraction and Waste Water Disposal Regulation-Is Lahore Aquifer At Stake With As Usual Approach", *Pakistan Engg. Congress; World Water Day-April 2011:* 112-134 (2011).
28. Water and Sanitation Agency (WASA), Lahore.