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Spatio-temporal analysis of groundwater regime within Rawalpindi Municipal Jurisdiction, Pakistan

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ABSTRACT

The study investigates the spatial and temporal variation of groundwater table within municipal precincts of Rawalpindi metropolitan city. The research was based on current and historic withdrawals as a primary source of drinking water supply. A geodatabase of 278 tube wells with three distinct timelines of recorded subsurface water levels was developed. Vertical sections were extracted from the interpolated surfaces and reconciled to a common x, y reference to isolate spatial and temporal trend of water table. Over exploitation of groundwater is leading to progressive depletion of the groundwater resource. The decline in groundwater level was observed to be steep in areas farthest from the potential recharge zones, a phenomenon that is also coincident with the density of the installed wells. Gradual cessation of pumpage within the metropolitan area and artificial means of replenishing the groundwater aquifer are recommended.

Keywords: Rawalpindi; Groundwater; Recharge; Drawdown; Spatio-temporal; GIS

1. Introduction

Rawalpindi is the fourth largest city of Pakistan having approximate population of 4.5 million, which is burgeoning at a rate of 4.29% per annum [1]. Geographically, Rawalpindi falls in the Salt range, Potohar plateau and is surrounded by the undulating hilly terrain. The highest regions are found in the northwestern and southeastern areas—1,043 and 660 m high above sea level, respectively. Regular hills, ravines and nullahs (water streams) running out from the hills break the continuity of the terrain. Lai Nullah is the permanent physical feature of the city, which enters from the southwest into densely populated areas. It meanders through developed areas of the city and finally joins Soan River in the south. Sometimes, it overflows during the rainy season causing considerable damages in the city. The study area is situated between latitudes 33°32´55´´ and 33°39´55´´N and longitudes 73°1´5´´ and 73°9´45´´E and is bounded by Kurang River from northeast to southeast, while

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northwestern boundary is bounded by Khayaban-e-Sir Syed. The Soan River covers the southern boundary, while the Lahore-Peshawar Railway line marks the southwestern boundary (Fig. 1). Red points in the map show tube well location in the area.

Drinking water is of utmost importance for human health. To provide safe drinking water and sanitation services to rapid growing population of the city, Water and Sanitation Agency (WASA) was established in April 1998 under Government of the Punjab Act. Currently, WASA served population is 1.5 million and its covered area is 35 km^2 [2]. Surface and ground water are the major water sources managed by the WASA with approximate yield of 18 and 22 MGD (million gallon/day), respectively [3]. The surface water is being taken from Rawal and Khanpur reservoirs and groundwater from tube wells installed in Soan River Basin. Groundwater is a main source of water for the residents Rawalpindi, which is being extracted by a network of more than 254 tube wells. However, as the aquifer of area is limited and inconsistent so groundwater is not sustainable source of water [1]. Water table is sharply depleting because of excessive withdrawal. The water table decreases from approximately 600 m (at the foot of the Margala Hills above mean sea level) to less than 450 m (near the Soan River) [4]. Water table in the study area was 22.8 m in 1995 and it dropped by 1.40 m annually from the year 1988 to 1995 [5]. In 2007, the average depth of the water table in the area was 58 m, and if the trend continues toward over pumping and urbanization, this decline in water table would accelerate in the forthcoming years [6].

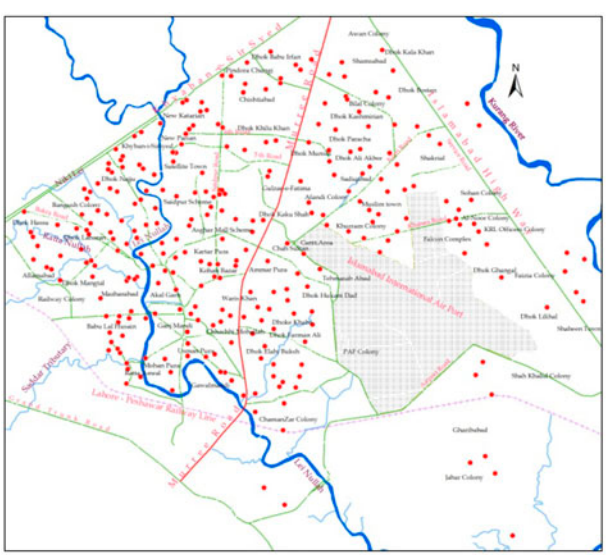


Fig. 1. Location and distribution of water supply tube wells in the study area.

The quality of the groundwater in the study area is not good; mostly, it is biologically contaminated [7]. The main reason of this contamination is the recharge mechanism of Nullah Lai and Korang River which carries the wastewater of 0.545 million m^3/day of twin cities of Islamabad and Rawalpindi. Also, the extraction cost is higher than that of other methods of water supply. Therefore, there is an urgent need of understanding spatial and temporal trends and variations in groundwater-level change and associated possible reasons.

At national level, Pakistan has now essentially exhausted its available water resources and is on the verge of becoming a water deficit country. The per capita water availability has dropped from 5,600 to 1,000 m^3 (Pakistan Council of Research in Water Resources). The aftermath of unscientific exploitation of groundwater is that we are moving toward water stress condition. Even now, some parts of the country are facing acute water crisis. Despite being an important part of the nation's growth, water resource analysis has been fragmentary. An integrated study covering the aspect of groundwater balance is very crucial, particularly in metropolitan cities of Pakistan. The present work is an attempt toward this direction. The study focuses on spatio-temporal analysis of water table and to oversee safe drawdown zones for additional tube well installations utilizing submersible pumps technology.

On this issue, a number of studies have been carried out worldwide. Napoli and Laton employed Geographical Information System (GIS) in their study to analyze long-term changes in groundwater storage in Lucerne Valley Groundwater Basin and found out that spatial tools are very helpful for the assessment of groundwater storage over time [8]. Droogers and Miranzadeh carried out spatio-temporal analysis of groundwater and concluded that GIS tools were supportive for delimitating declined water table zones [9]. McMillian, A. [10] found out water table elevations by contouring and TINs. Mondal, D. [11] carried out spatio-temporal analysis of groundwater using GIS to find out groundwater depletion zones. Shalini, T.K. et al. analyzed ground water levels and rainfall trend using GIS in Jharkand, India. They used time series regression and interpolation methods and found out rise and fall in water table during post and pre-monsoon seasons respectively [12]. Bhuiyan, C. et al. [13] studied effect of different factors like rainfall, evapotranspiration, water extraction on temporal variation in ground water recharge. They found out that there was a significant decrease in aquifer recharge due to variation in rainfall and over-exploitation of water. Chen et al. [14] studied relationships between land use, land cover and groundwater table. He concluded that urbanization and industrialization were reasons of declining water table and deterioration of groundwater quality.

However, in the study area, the Hydrogeology Directorate WAPDA has carried out such investigations in Potwar Plateau and in the Haro River Basin,

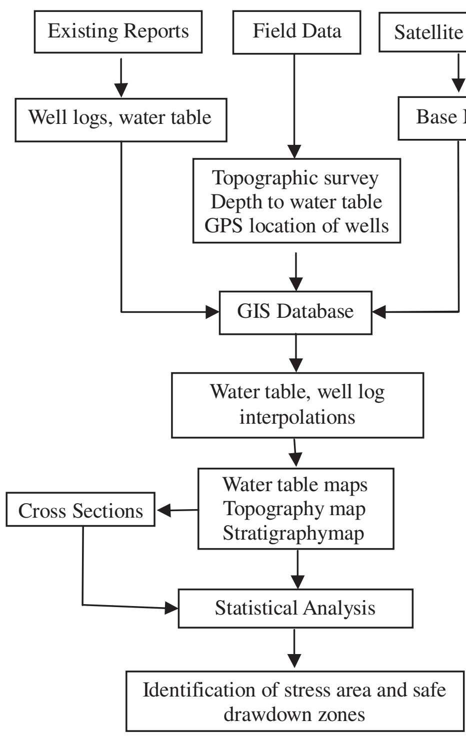


Fig. 2. Methodology flow diagram.

but no analysis has been carried out in the Soan River Basin [1]. Therefore, it is necessary to undertake a study on groundwater situation in Soan Basin to ensure sustainable water supply to the residents. For this purpose, analysis of trends in water table fluctuations is helpful in focusing efforts in right directions to address fast water table depletion. The main objectives of the study are to:

(a) Develop a geodatabase of water supply tube wells of Rawalpindi city showing historic water table levels, depths of wells and extraction information.
(b) Draw and map historic water table contours.
(c) Analyze temporal trends of water table fluctuations in Rawalpindi.
(d) Analyze and compare water table depth and level changes with stratigraphy.
(e) Identify groundwater stress areas and possible reasons (extraction, stratigraphy, landuse, surface water, etc.).

2. Methodology

To accomplish this study, following methodology was adopted (Fig. 2).

2.1. Development of GIS database

QuickBird panchromatic satellite imagery was used to digitized base map layers including settlement

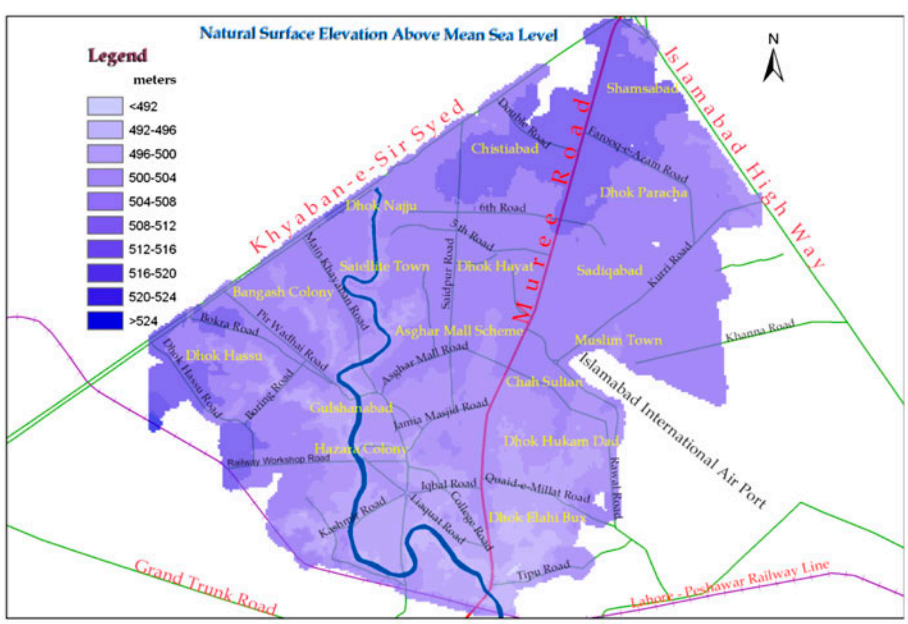


Fig. 3. Natural surface elevation above mean sea level (m).

blocks, landuse parcels, road network, Nullas and railway line. Total station survey was conducted to collect natural surface elevation data. Almost 20,000 points were surveyed for surface elevation data and the data set was fed into GIS Database. These data points were interpolated in ArcMap® using kriging tool. The resulting natural surface elevation map shows a gradient of 23 m from Faizabad up to Marair Chowk in Southward direction (Fig. 3).

GPS survey was conducted to take geographic coordinates of 254 water supply tube wells. These coordinates were updated into the GIS Database, and a water supply tube wells location map was prepared (Fig. 1). The water table data of the years 1998, 2003,

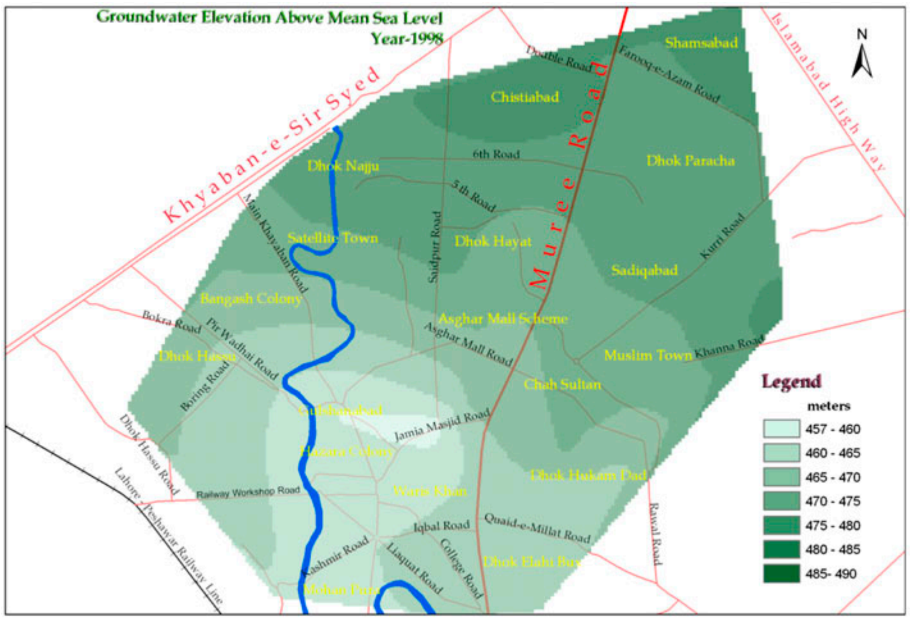


Fig. 4. Groundwater table above mean sea level, 1998 (m).

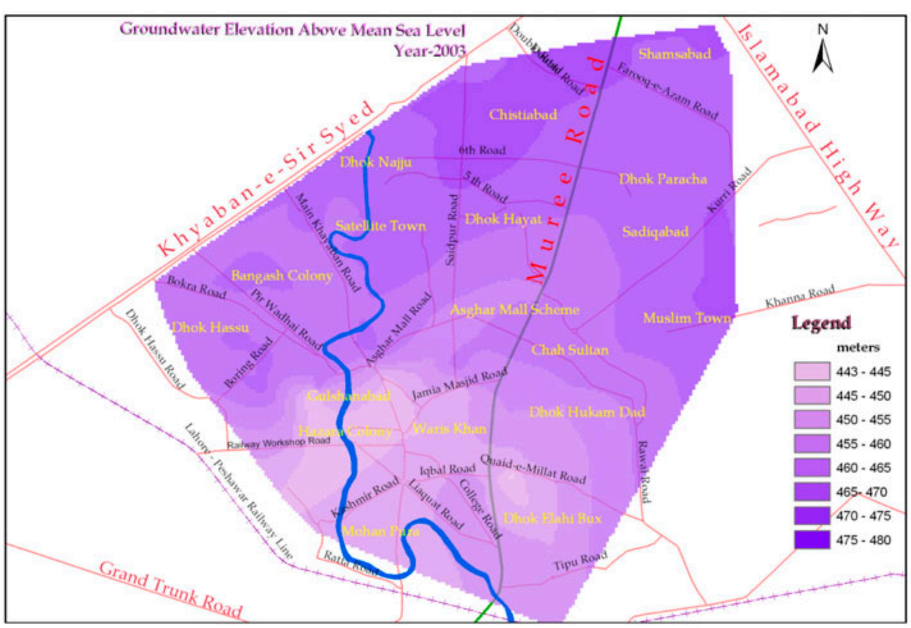


Fig. 5. Groundwater table above mean sea level, 2003 (m).

and 2007 were collected from previous reports that were available in WASA library, and these values were added as attributes of tube wells shape-file into GIS Database. This historic water table data set of the years 1998, 2003 and 2007 were interpolated by using Kriging technique to generate raster surfaces in ArcMap®. These raster surfaces were subtracted from the natural surface elevation raster to obtain the groundwater elevation above mean sea level maps (Figs. 4–6). A polyline shape-file was created and nine horizontal parallel lines were drawn in the study area to take vertical cross-sections of water table. These lines were selected in such a way that they passed through maximum number of well locations and were closely spaced where water table contours were rapidly changing (Fig. 7). Using ArcMap 3D Analyst, these cross-section lines were converted into 3D features by taking surface data of natural elevation,

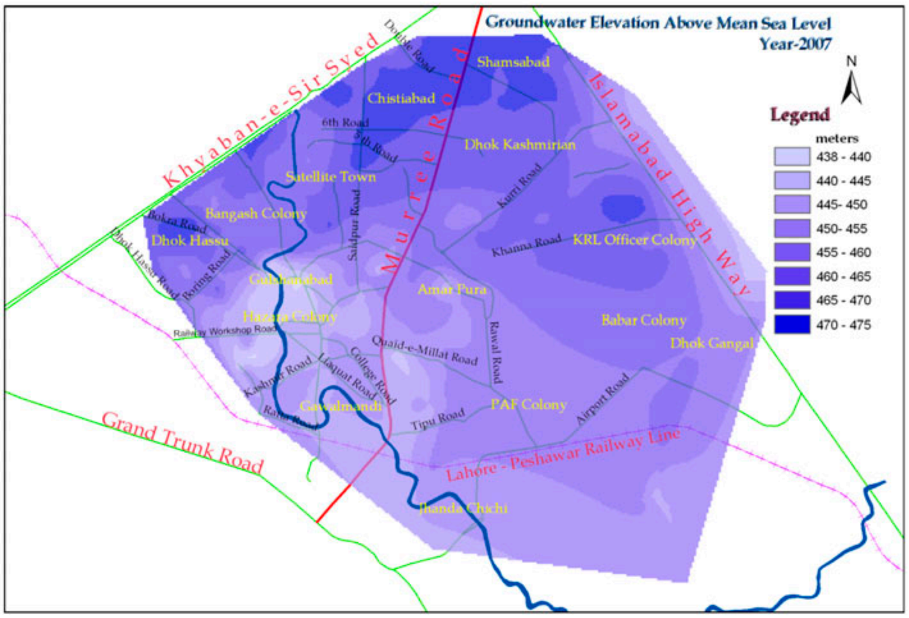


Fig. 6. Groundwater table above mean sea level, 2007 (m).

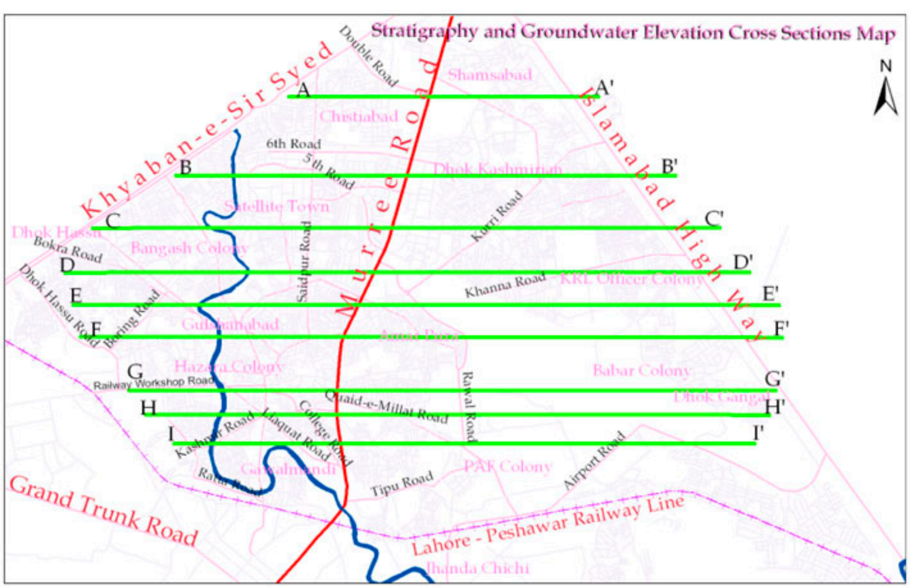


Fig. 7. Water table cross-sections reference lines.

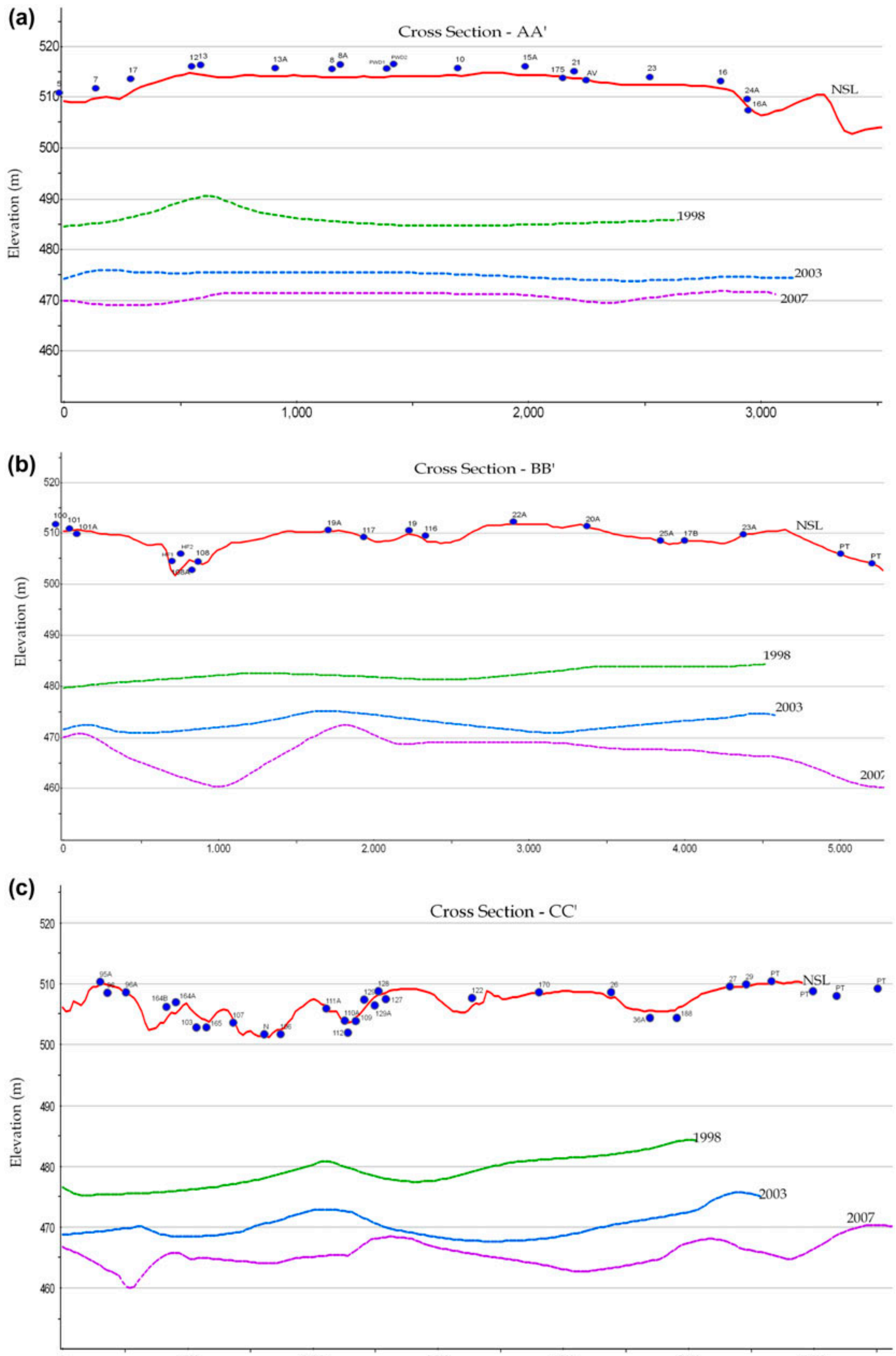


Fig. 8. (a) Cross-section AA´, (b) cross-section BB´, (c) cross-section CC´, (d) cross-section DD´, (e) cross-section EE´, (f) cross-section FF´, (g) cross-section GG´, (h) cross-section HH´, (i) cross-section II´.

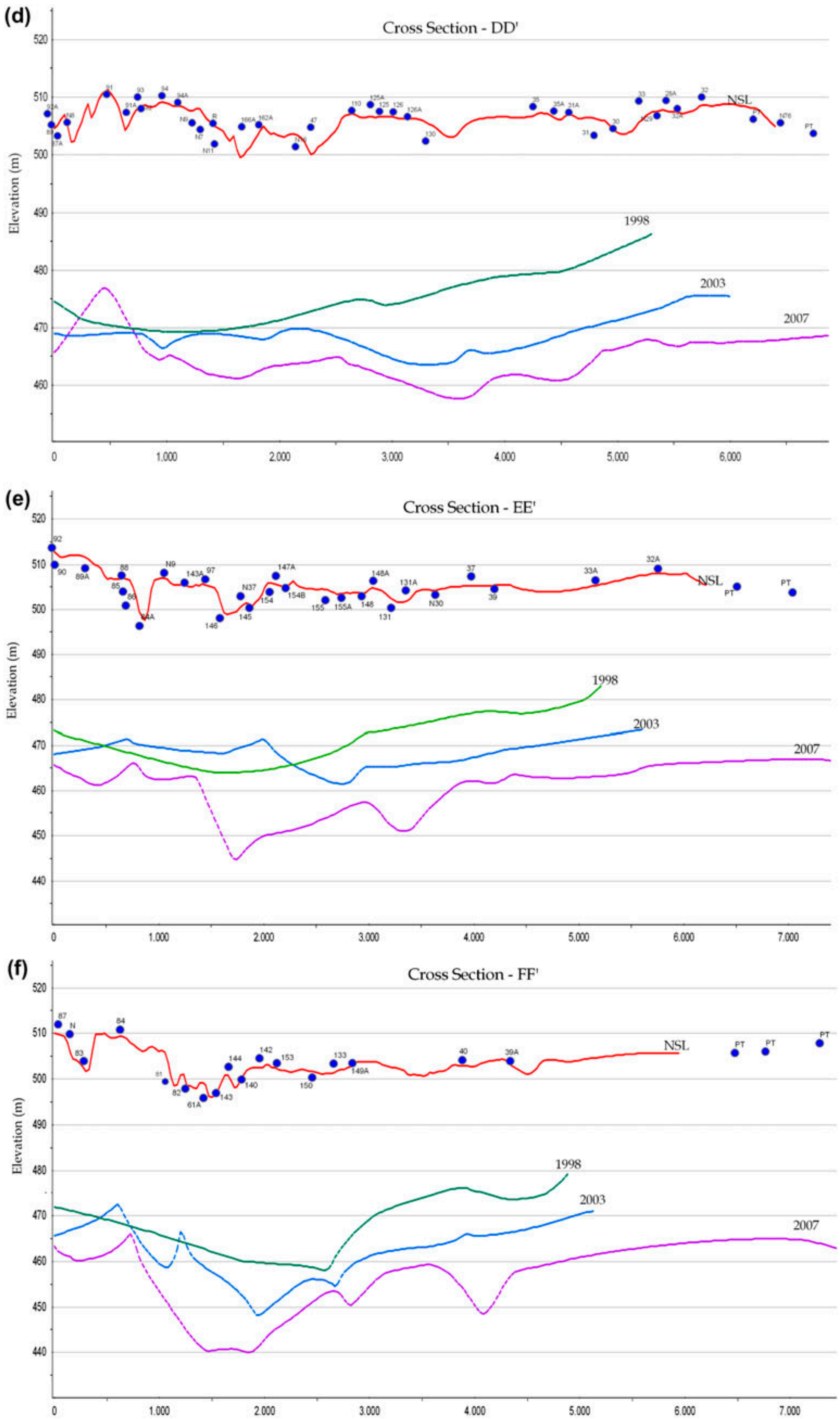
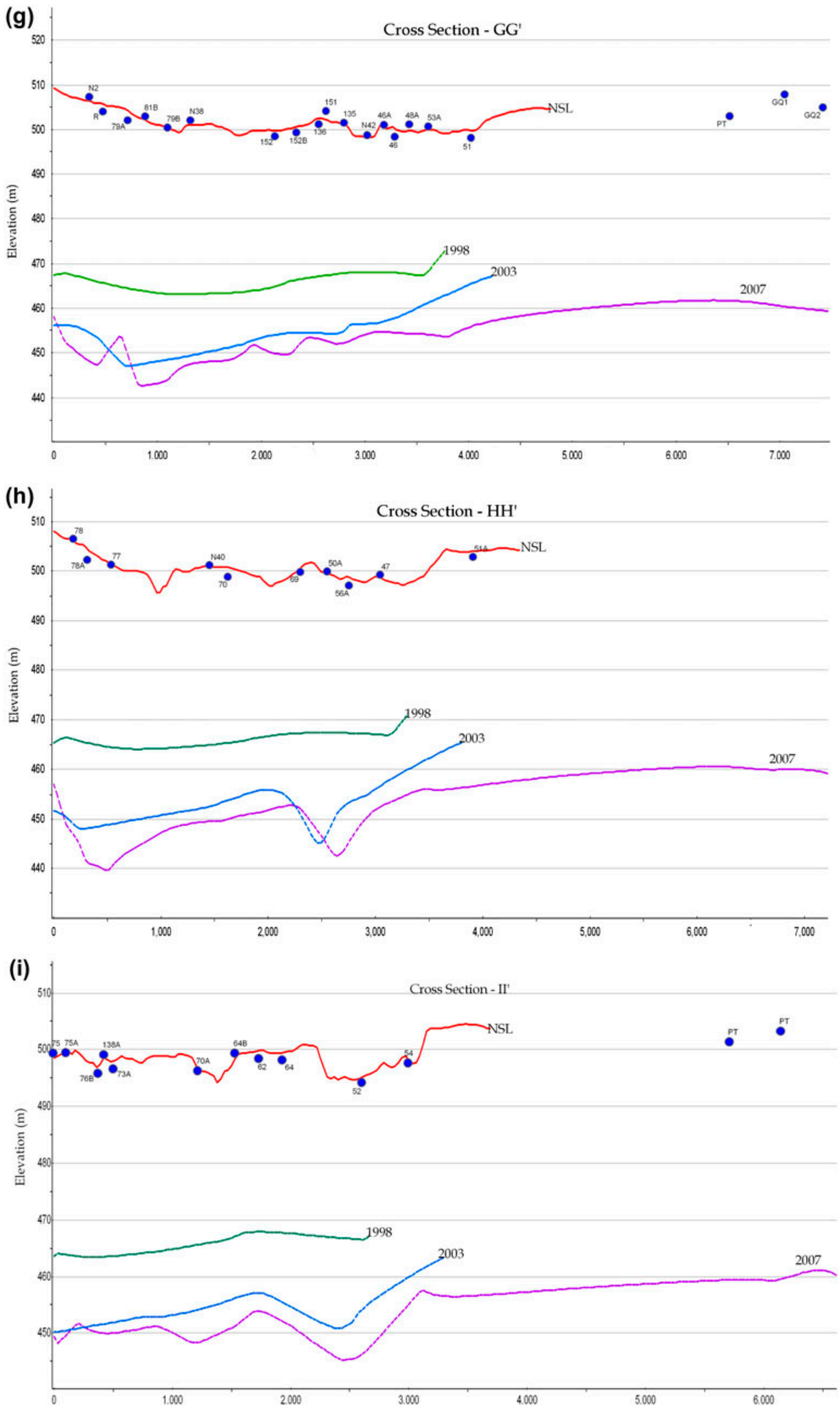


Fig. 8. (*Continued*)



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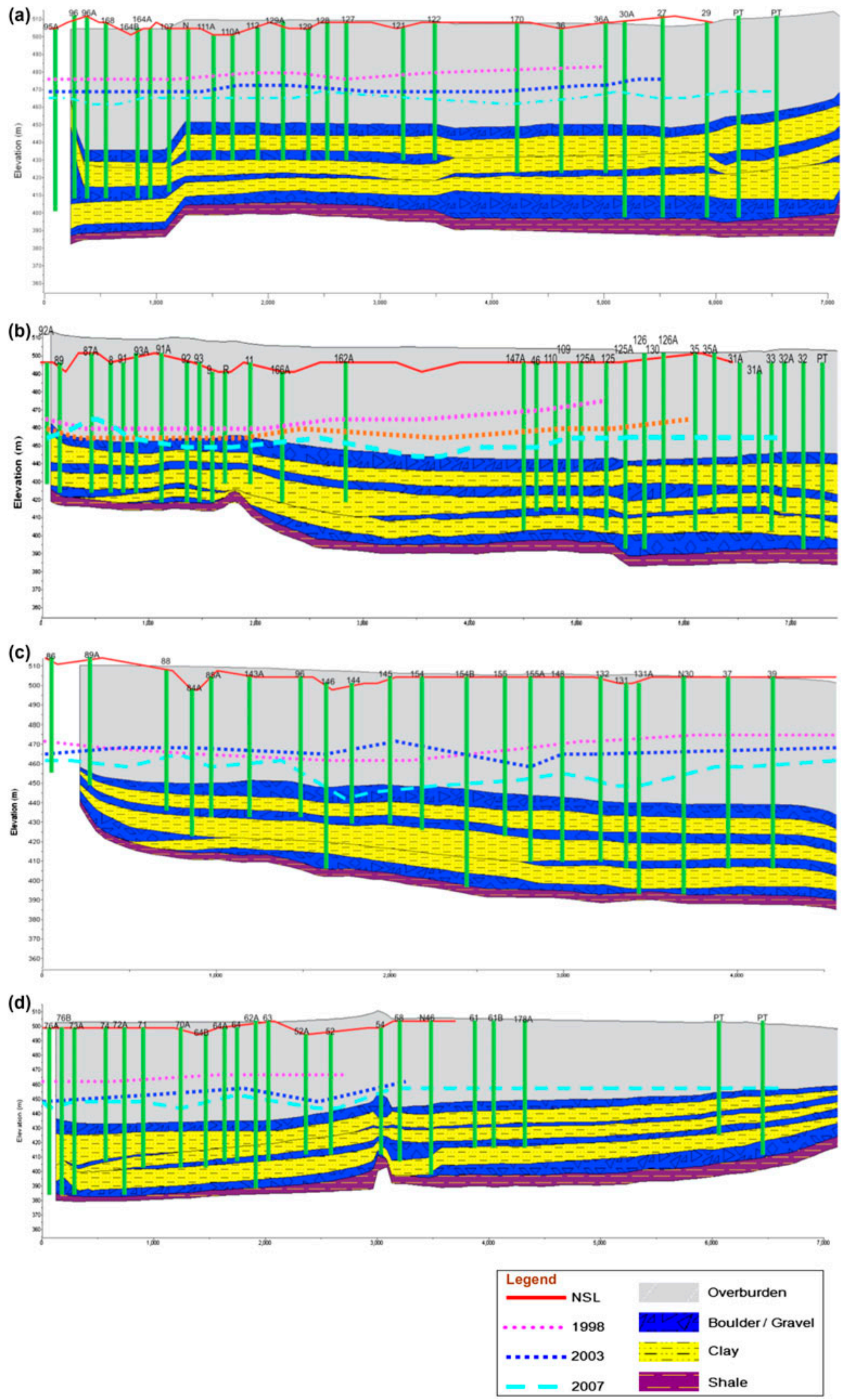

Fig. 9. (a) Stratigraphy and groundwater elevation along cross-section CC´, (b) stratigraphy and groundwater elevation along cross-section DD´, (c) stratigraphy and groundwater elevation along cross-section EE´, (d) stratigraphy and groundwater elevation along cross-section II´.

water table (1998, 2003, and 2007) as a height source. Vertical sections were extracted from the interpolated surfaces and reconciled to a common x, y reference to isolate spatial and temporal trend of water table. Water well points were marked on each cross-section of natural surface elevation. Well log data of 43 well-distributed points in the study area were managed and interpolated in RockWare and water table contours were overlaid on four vertical cross-sections of stratigraphy.

3. Results

The collected data sets were processed according to given methodology and thematic maps and vertical profiles were prepared. Raster surfaces (Figs. 3–6) were produced by interpolating point elevation data and historic water table data.

Based on the concentration of wells in the study area, a map of reference lines was prepared (Fig. 7). From these references, 3D profiles were generated using interpolated elevation surfaces of natural surface and groundwater for years 1998, 2003, and 2007. Hence, Nine unique vertical profiles were prepared, plotted and reconciled to a common x,y reference to isolate spatial and temporal trend of water table (Fig. 8(a–i)).

These cross-sections were also overlaid with stratigraphy (Fig. 9(a–d)) and a thick clay layer sandwiched between first and second aquifer layer was observed. This thick clay layer could be one of the possible reasons of low recharge and fast depletion rate of water table in eastern locations along the Muree road. The stratigraphy profiles also indicate that depletion rate of water table is fast where wells are close to each other and deeply drilled in the aquifer.

4. Discussion

In 1998, only 39 wells were in operation in the study area. With 41 additional drilling of wells in the next five years, the number of operational wells increased to 80 in 2003, whereas in 2007, 278 wells were seen in the area, that is, 198 additional wells were installed in 4 years. A significant drop in the groundwater elevation was observed due to added wells. In 1998, the highest value of groundwater elevation observed in the study area was 490 m and the lowest value was 457 m. The contours were smooth and were fairly spaced. In 2003, with addition of 41 new wells, the uppermost groundwater elevation declined to 480 m and lowermost groundwater elevation to 443 m. Thus water table dropped from 10 to 14 m from 1998 to 2003 and in 2007 it further depleted to 5 m. Overall, the water table dropped almost 15 m at the rate of 1.5 m/year. Apart from increase in number of wells, increase in discharge and over pumping of wells are the major causes of depletion of water table.

Nine unique temporal vertical profiles of groundwater elevation were selected based on the density of wells in the study area (Figs. 7 and 8). These profiles were plotted in a common x, y plane. Profile AA´ is across the Muree road, near Shamsabad and Chistiabad and the average water levels were 25, 35, and 40 m in 1998, 2003, and 2007, respectively. It is obvious that the water level is gradually decreasing at a rate of 1.7 m/year due to significant increase in water discharge. Along cross-section BB´, near Holy Family Hospital, a group of four wells are putting a big pressure on the aquifer and water level has gone down to 50 m as measured in 2007. However, in first five years (1998–2003), the rate of water depletion level across the cross-section is higher with comparison to last four years (2003–2007). The rise in water level in 2007 along cross-section DD´ in Bangash colony near Bokra road may be recharged from Lei Nullah. Lei Nullah carries sewage water and industrial effluent; therefore this is a source of groundwater contamination. The water level in Gulshanabad, Hazara Colony and in the settlements along Dhok Hassu Road is very alarming. As observed from cross-section EE´ FF´ and GG´, the level went down maximum to 70 m in 2007. One of the reasons might be over pumping (more than 20 h daily in summer) and overlapping cone of depression, since the wells are closely installed. It has been observed from groundwater elevation maps and cross-sections that overall water level condition is good in eastern side of the Muree Road as compared to the western areas. This is because of less number of wells in the eastern side and these are fairly spaced from each other. Moreover, land cover of the area indicates that soil is not entirely sealed off and there are open spaces for rainfall infiltration. However, the western areas like Gulshanabad, Hazara Colony and Dhok Hassu are completely sealed off due to urbanization. The depletion trend is comparatively faster in settlements such as Shamsabad, Dhok Kashmirian, KRL Officer Colony and Dhok Gangal along eastern side of the Muree Road.

In the study area, over exploitation of groundwater is leading to progressive depletion of the groundwater resource. According to an estimate, 4–17% of annual rainfall replenishes groundwater in semi arid regions. The annual rainfall in the study area is often scanty and recurring drought frequently prevails. Consequently, the continuous decline in groundwater level is seen year after year. Groundwater aquifer needs to be refilled regularly in order to get some ground sustainability. It could also be attained through artificial means that is, by filling the aquifer with treated wastewater [15]. Moreover, better water management practices should be followed for sustainable groundwater in urban areas [16].

The present research was conducted as part of a larger project under funding from the Asian Development Bank to improve environment and sanitation within the Rawalpindi city. The groundwater spatio-temporal appropriation was further used to oversee safe drawdown zones for additional tube well installations utilizing submersible pumps technology.

5. Conclusion and recommendations

The conclusion and recommendations are based on the interpolated results of groundwater elevation data sets of the years 1998, 2003 and 2007. These were further supported by profiles of groundwater elevation and stratigraphy, well pumping hours and discharge of each well in gallons per minute, as well as local area conditions in the study area. The main conclusions are as follows:

- A trend of continuous drop in groundwater level is observed. On average, the aquifer is depleting at the rate of 1.7 m/year. A maximum of 20 m drop in water level is noticed in Gulshanabad Mohallah of the study area.
- It is observed that drop in water level is more where wells are densely distributed.
- The aquifer consists of varying proportions of gravel, boulder and sand deposits with layers of clay/silt. The physical properties of the aquifer are favorable for the development of groundwater with moderate values of transmissibility and specific yield.

Major recommendations are as follows:

- It is recommended to install new wells, even in peri-urban areas;
- Gradual cessation of pumpage within the metropolitan premises ought to be implemented;
- There is a need for groundwater regulatory framework for the sustainability of groundwater and manage the increasing demand of water in the area;
- There is an urgent need for research on groundwater recharge in the area;
- Recharge of groundwater could be increased by increasing rainwater harvesting and replenishing the aquifer with treated wastewater;
- Apart from drinking, reclaimed wastewater can be used instead of groundwater to reduce dependency.

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References

[1] World Bank and Government of Punjab. Status Quo Report Rawalpindi Urban Water Supply and Sewerage Reform Strategy, 2006. Available from: http://www.urbanunit.gov.pk/pubpublic/pubcomp/50.pdf.

[2] Lt. Col. Islam-ul-Haq, W.A. Cheema, Ch.N.Ahmed, Multifaceted ground water quality and recharge mechanism issues in a mega-city (Rawalpindi, Pakistan), and mitigation strategies, securing groundwater quality in urban and industrial environments, in: Proceedings of Sixth International IAHS Groundwater Quality Conference, IAHS, XXX, Gujrat, 2008.

[3] Lt. Col. Islam-ul-Haq and S. Durez; Managing and planning Water Services, Water and Sanitation Agency (WASA). Available from: http://www.wasa.rda.gov.pk/MD_Papers/Managing_and_Planning_Water_Services.pdf.

[4] K.M. Ashraf, M. Hanif, Availability of ground water in selected sectors/areas of Islamabad—Phase I and II: Pakistan water and power development administration ground water investigation report, 1980, 35, p. 30.

[5] A.H. Malik, Lei drainage basin (Islamabad-Rawalpindi): A model of groundwater recharge, in: Proceedings of Regional Workshop on Artificial Groundwater Recharge, Quetta, 1996.

[6] Rawalpindi Environmental Improvement Project (REIP), Groundwater Modeling, Report, 2007.

[7] Rawalpindi Water and Sanitation Authority (RWASA), Water quality Report. Changes in the Water Table: A case study of Elkhorn, WI, 2003.

[8] N. Napoli, W.R. Laton, GIS; A Tool For Determining Long-Term Changes In Ground Water Storage A Case Study, Lucerne Valley Groundwater Basin. Available from: http://www.grac.org/GIS.pdf.

[9] P. Droogers, M. Miranzadeh, Spatial and Temporal Analysis of Groundwater. Available from: http://publications.iwmi.org/pdf/H036065.pdf.

[10] A. McMillian, Salinas Valley Water Table Elevations: A Visualization Using GIS. Bachelors Project: California State University, Monterey Bay, USA, 2003. Available from: http://hydro.csumb.edu/Doug/html/mcmillian_report.pdf.

[11] D. Mondal, Spatio-Temporal Analysis Of Groundwater Resource Using GIS: A Case Study of Murshidabad District, West Bengal, India. Golden Research Thoughts, 1 (2012) 8. Available from: http://www.aygrt.net/PublishArticles/248.aspx.
[12] T.K. Shalini, A.C. Pandey, M.S. Nathawat, Groundwater level and rainfall variability trend analysis using GIS in parts of Jharkhand state (India) for sustainable management of water resources, Int. Res. J. Environ. Sci. 1 (2012) 24–31.
[13] C. Bhuiyan, W.A Flugel, R.P Singh, Erratic monsoon, growing water demand, and declining water table, J. Spatial Hydrol. 9 (2009).
[14] X. Chen, J.F. Yan, Z. Chen, G.P. Luo, W.Q. Xu, A Geospatial analysis approach for assessing the impact of land use on groundwater resources in the SanGong oasis region, Agric., Food Environ. Sci. 2 (2008) 1.
[15] N.E. El Arabi, M.A. Dawoud, Groundwater aquifer recharge with treated wastewater in Egypt: Technical, environmental, economical and regulatory considerations, Desalin. Water Treat. 47 (2012) 266–278.
[16] M.L. Zellner, H.W. Reeves, Examining the contradiction in 'sustainable urban growth': An example of groundwater sustainability, J. Environ. Planning Manage. 55 (2012) 545–562.