Climate responsive urban groundwater management options in a stressed aquifer system

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WICKED WATER PROBLEM

Pakistan is a country of over 160 million people, which is expected to grow to over 220 million by the year 2025. Like any other developing country, in Pakistan more and more people are moving to cities with a hope of finding a better quality of life, and if this urban migration is unchecked the growth in the urban population will outpace the growth in the rural population by the year 2024. The high urban population growth, urbanization and climate change is exerting stress on the natural resources of the country. The water shortages, combined with urban water pollution as a result of discharge of untreated sewage to rivers, is further affecting public health. The leakage from polluted water bodies to underlying aquifers is degrading the urban water quality. The eco-system is being badly affected by the direct disposal of untreated pollutants from industrial, agricultural and urban sources into surface- and groundwater bodies. The untreated pollutants cause heavily polluted water around the towns and cities of Pakistan. An example of such an urban centre is the Lahore metropolis, which is a groundwater-dependent city. After independence of Pakistan in 1947, problems between India and Pakistan arose over the distribution of water as rivers in Punjab Province flow into the Pakistan territory from across India. To solve this water distribution problem, a treaty known as the Indus Water Treaty, brokered by the World Bank, was signed by the two countries in 1960. As per this treaty, Pakistan has exclusive rights for the three western rivers, namely the Indus, Jhelum and Chenab, whereas India retains rights to the three eastern rivers, namely the Ravi, Beas and Sutlej. The new river water distribution seriously affected the urban centres' aquifers, which were previously recharged by these eastern rivers and their associated irrigation canal systems. The biggest setback due to the lost of water use of one of the three eastern rivers is being faced by the Punjab Province capital city of Lahore where the main source of recharge to the underlying aquifer is the River Ravi.

The River Ravi is one of the most polluted rivers in Pakistan, receiving untreated domestic, industrial and agricultural wastewater, not only from Lahore, but also from bordering country in India through the Hudiara Drain. It has a total length of 98.6 km, of which 44.2 km lies in India and the remaining 54.4 km in Pakistan territory (Afzal *et al*., 2000). It enters Pakistan loaded with pollution from India, is diluted with agriculture runoff, and mixed with some industrial pollutants in Pakistan. The drain carries mainly industrial and agricultural waste from both India and Pakistan. The average effluent flow in Hudiara is much higher from India, and hence the total quantity of pollution in Hudiara Drain from India is much more compared to that from Pakistan (Sami, 2001). The effects of climate change are making things worse. No laws and water policy exists to make the urban groundwater sustainable. Keeping in view the wicked water problem being faced by Lahore city, a parsimonious working surface–groundwater interaction groundwater flow model, using the MODFLOW Package, was developed for understanding the hydrogeological dynamics under different aquifer management interventions as part of a climate responsive policy to explore policy options, which takes into account climate change and population growth for sustainable groundwater development.

CONCEPTUAL MODEL OF LAHORE CITY AND ITS SURROUNDING AREA

Figure 1 shows a schematic diagram of the conceptual model of Lahore City and its surrounding area. The following hydro-geological features are represented in the developed groundwater model:

- Lithology of Lahore Aquifer including top and bottom elevations and hydraulic characteristics
- Vertical interactions between the different aquifer layers
- Recharge due to irrigation and rainfall
- Groundwater abstractions (public, industrial, irrigation, others) from different aquifer layers
- Leakage to and from the irrigation supply channels
- Leakage to and from the storm water nallahs (drains)
- Leakage from urban water supply
- Leakage to and from sewage drains
- Surface water–groundwater interactions for the Ravi River
- Regional groundwater flow interactions for different aquifer layers at the boundaries of the model domain.

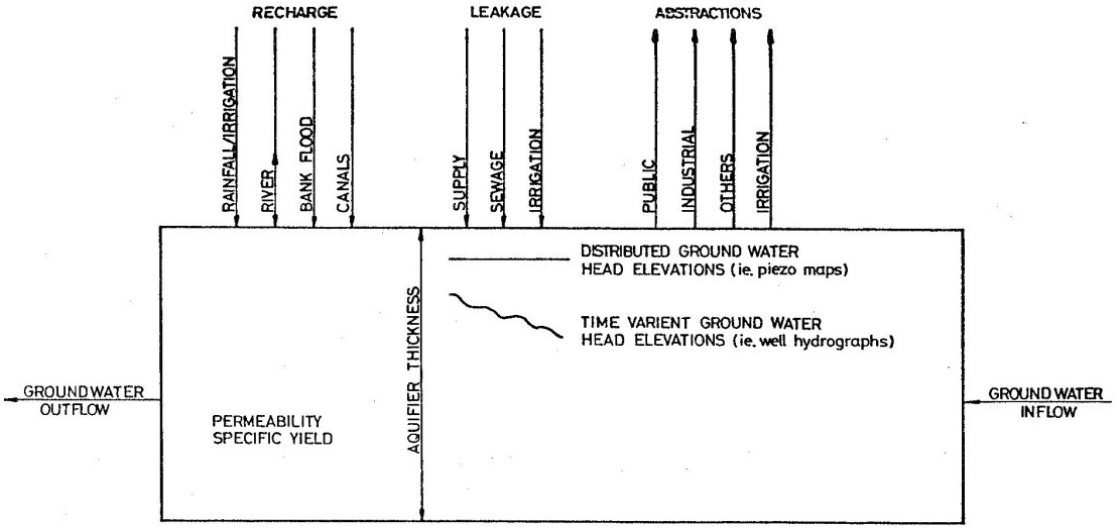

Fig. 1 Schematic diagram of hydrological processes in the study area (after Nespak, 1991, 1993).

For the model development, the MODFLOW (United States Geological Survey (USGS) Modular Three-Dimensional Groundwater Flow Model) (McDonald & Harbaugh, 1988; Harbaugh & McDonald, 1996a,b) package under PMWIN Pro (Chiang & Kinzelbach, 1998; WebTech360, 2003) environment were used.

The developed model was calibrated using the PEST (acronym for Parameter ESTimation) Package. There was a close agreement between the observed and simulated heads and the overall trend of the observed groundwater hydrograph was also followed well by the modelled data. Statistical performance indicators for the regional groundwater model were checked by using Australian Groundwater Modelling Guidelines (Murray-Darling Basin Commission, 2000), as these performance indicators provide lumped measures of calibration that do not indicate the spatial or temporal distribution of the error, therefore, a Scatter Diagram was also produced. The model results were also expressed through water balance of the study area. Plotting of contours for the calibration period revealed that the cone of depression developed in the metropolitan area has started widening with the rate of increase in pumping as the number of high capacity tubewells increased to over 300 in 2004. The Lahore aquifer is not only mining its groundwater storage, but also mining water from the adjoining areas, thus depleting the surrounding areas' aquifers.

KEY LESSONS LEARNT

The groundwater model developed for Lahore and its surrounding areas indicates that the Lahore Aquifer has become unsustainable. Institutional reforms linked with the objectives of sustainable development are urgently required. These institutional reforms should lead to a sustainable water policy, based on the developed framework, through active public participation. A key aspect of this policy should be water auditing, water accounting, water management and ensuring an inter-generational and intra-generational equity. The central theme of the new policy should be sustainable management of natural resources to meet reasonably foreseeable needs of future generations, safe-guarding the life-supporting capacity of air, water, soil, and ecosystem, and avoiding adverse impacts of human activities on natural resources. Adoption of climate responsive policy will result in sustainable integrated water resources management of the Lahore urban groundwater system.

Based on this study, there is a need to develop a groundwater early warning system for Lahore which can forecast groundwater quantity and quality trends at critical situations. Future research also needs to consider microbiological aspects of water quality and related human health impacts.

REFERENCES

Afzal, S., Ahmad, I., Younas, M., Zahid, M. D., Khan, M. H. A., Ijaz, A. & Ali, K. (2000) Study of water quality of Hudiara drain, India-Pakistan. *Environ. Int.* **26**(2000), 87–96.

Chiang, W. & Kinzelbach, W. (1998) *Processing MODFLOW, a Simulation System for Modeling Groundwater Flow and Pollution*. Hamburg, Germany/Zurich, Switzerland.

Harbaugh, A. W. & McDonald, M. G. (1996) User's documentation for MODFLOW-96, an update to the US Geological Survey modular finite-difference ground-water flow model. *USGS Open-File Report 96-485*.

McDonald, M. G. & Harbaugh A. W. (1988) *A Modular Three-Dimensional Finite-Difference Groundwater Flow Model*. US Geological Survey Techniques of Water-Resources Investigations, Book 6, Chap. A1.

Murray-Darling Basin Commission (2000) Groundwater flow modelling guideline. Aquaterra Consulting Pty Ltd, Project no. 125. Final Guideline – 16 January 2001, Perth, Australia.

NESPAK (1991) 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.

NESPAK (1993) 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.

Sami, F. (2001) Water quality monitoring of Hudiara drain, an independent consultancy for data analysis and water quality management plan.