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Sustainable Groundwater Management
Lessons from Practice

Case Profile Collection Number 23

Lucknow City – India
Groundwater Resource Use & Strategic Planning Needs

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This Case Profile comprises a diagnosis of the groundwater resource situation in Lucknow City, the Uttar Pradesh (UP) state capital, which can be regarded in many ways as indicative of the position of most rapidly-expanding cities and large towns on the Gangetic Plain. The assessment includes the development of a more strategic approach to improvement of 'water-supply security' in the face of continued expansion and of the probable impacts of accelerated climate change, including definition of the further investigation required for this purpose. The work constitutes a contribution to both the World Bank-financed UP Water Sector Restructuring Project and the World Bank-India AAA Study on Political Economy of Groundwater Resource Management – and greatly benefited from effective local arrangements by the UP-Irrigation Department (PACT) and the UP-State Water Resources Agency (SWaRA).

EVOLUTION OF URBAN GROUNDWATER USE

Hydrogeological Setting of Lucknow City

- Around 85% of the land-area of Lucknow City is situated on the Central Ganga alluvial plain, and stretches across both banks of the Gomti River (Figure 1) – which is an entirely lowland river naturally dependent on groundwater discharge for its dry-weather flow. The city is underlain by a large thickness of Quaternary alluvial sands (at best of medium-grade) with occasional interbedded silty clay aquitards.

- Three 'more productive levels' (I, II & III) of the thick aquifer system (in effect containing the highest proportion of medium-grade sand) are widely recognized (Figure 2) with intervening aquitards at around 70 and 200 m bgl. The 'third productive level' extends to more than 300 m bgl – and the total proven thickness of the alluvial deposits is more than 600m.

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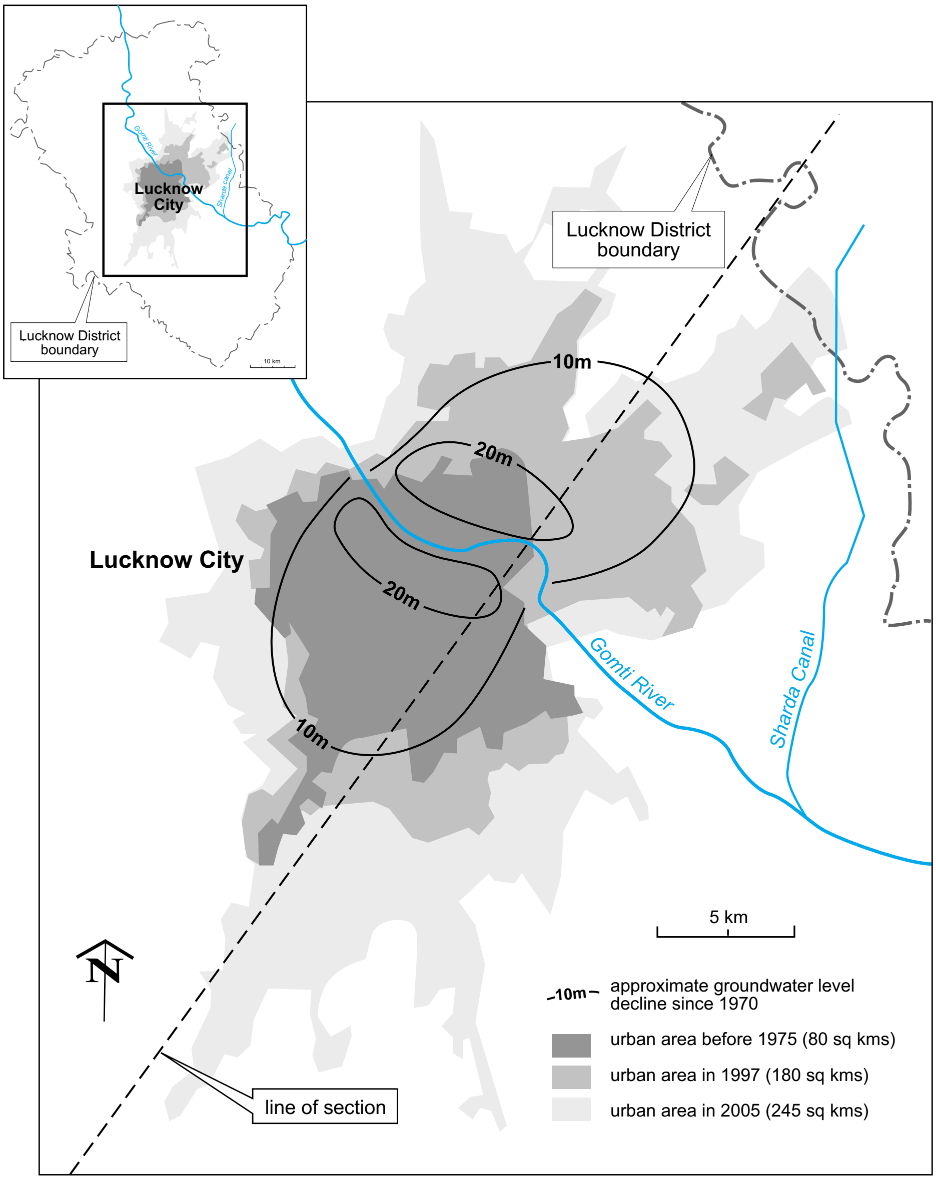
Figure 1: Lucknow District – map showing the rate of urban growth during 1975-2005

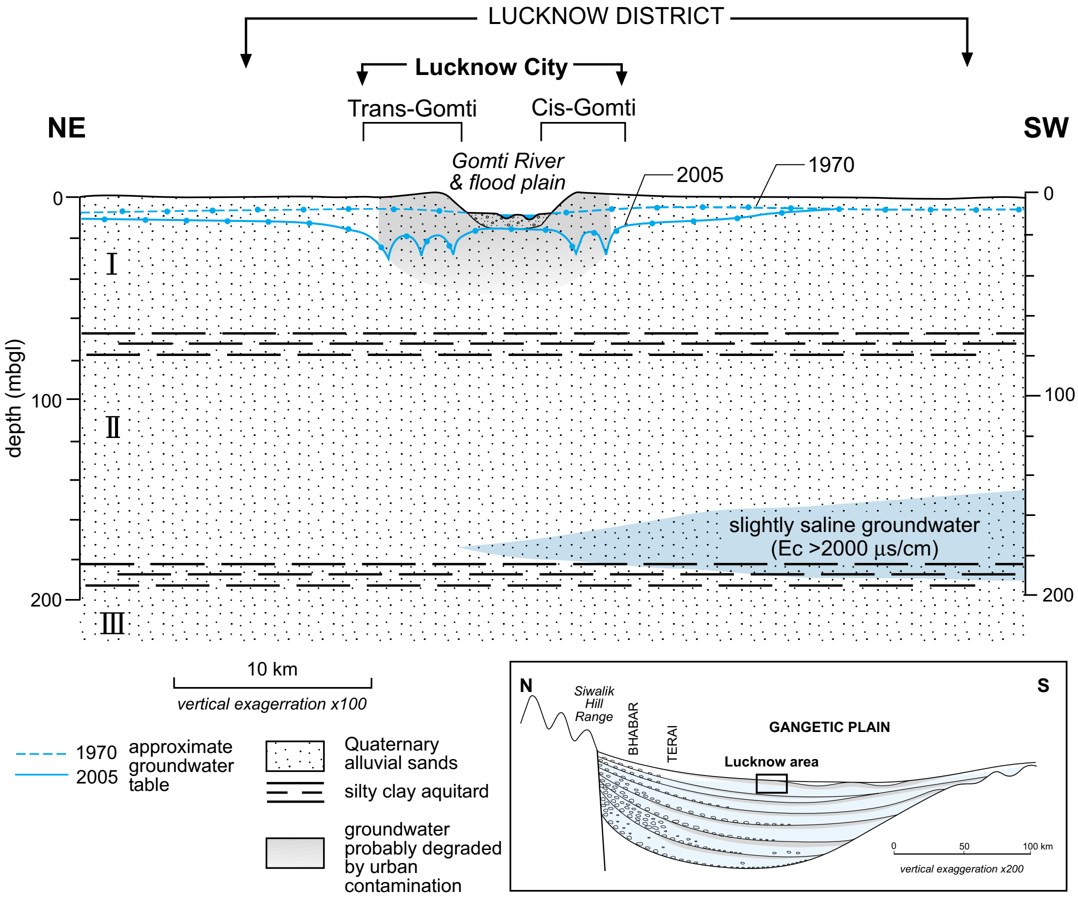


- There are significant but subtle lateral (spatial) variations in the aquifer system – including most notably the consistent occurrence of marginally-saline groundwater in the alluvial sequence over the depth range 140-200 m bgl across all of the 'cis-Gomti' (west bank) area but thinning towards the city centre (Figure 2) – which is probably the relict of former climatic conditions in the 'geologically-recent past' and could be remobilized by indiscriminate water well construction and operation.

- The geologically-older alluvial deposits form a low terrace, above the narrow Gomti flood plain, whose surface reflects palaeo-river features (such as channels and levees) and includes some conspicuous land-surface depressions to the north-east of the city limits.

- The climate is sub-tropical with an average rainfall of 1140 mm/a, the majority of which normally falls during the main monsoon months (June-September) but it should be noted that in some years the monsoon rain (which typically total over 700 mm) can almost fail or be much reduced here – in the last 20 years there have been two with a total monsoon rain of under 500 mm and two with over 1,000 mm.

Figure 2: Simplified hydrogeological cross-section of Lucknow District



History of Water-Supply Provision

- Lucknow is a city with a very long history. Since 1892 the Lucknow Jal Sansthan or Water-Supply Utility (LWSU) had a limited public water-supply network based on an intake and small treatment works on the Gomti River just north of the original city margins. But the population of Lucknow Metropolitan Area (LMA) grew very rapidly from around 0.3-0.4 million in the 1950s to 1.0 million in 1981 and 2.3 million in 2001 (including numerous high-density urban colonies of more than 70 persons/ha) – and is projected to reach 4.0 million by around 2020.

Table 1 : Summary of the historical evolution of LWSU groundwater supply

YEAR	1975	1985	2005	2009
no. of tubewells	45	70	300*	500*
typical tube well depth(m)	120	120	200**	200**
well-screen depth(m)	70 - 120		90-140/100-200***	
aquifer productive level tapped	II	II	II (III)**	II (III)**
typical tube well yields (l/s)	20 - 25		10 - 20	
total municipal groundwater supply (Ml/d)	50	70	190	240

* *approximate total number but at any one time some (around 10%) being reconditioned or replaced*
** *some tube wells drilled to 350m depth so as to tap third aquifer productive level*
*** *difference between cis-Gomti and trans-Gomti areas because of occurrence of saline groundwater*

- The first record of tube well construction for LWSU, by the UP Water-Supply & Sanitation Board (UP-WSSB), was in 1973-75 to augment the river-intake supply in an effort to provide adequate coverage to 5 newly-defined urban water-supply zones – they were of 120 m depth with a static water-level of around 10-12 m bgl and tapped only the 'second productive level' (II) by setting intake screens from below 65 m depth (Table 1). Although groundwater had been exploited prior to this date for centres of concentrated demand, such as the military cantonment and the railway depot.

- The subsequent growth in the numbers of LWSU tube wells, in efforts to meet rapid urban growth and spiraling water-demand, is summarized in Table 1 – by 2005 over 300 tube wells in total had been drilled (with the more recent of 200 m depth and 200 mm diameter completion, and some going deeper to 350 m with their upper sections drilled at 350 mm diameter), although not all were operational at any one time. Throughout this development process the UP-WSSB (when implementing tube well drilling on behalf of LWSU) has always had to select sites close to the new local demand centres within LMC boundaries, and no attempt has been made at a wider study of groundwater development potential throughout Lucknow District and beyond, and of the possible construction of 'protected external well fields' for example.

- Since 2005, with continuing rapid urban expansion and groundwater level decline at around 1.2-1.5 m/a in the more central parts of the city and >0.5 m/a elsewhere, the UP-WSSB and LWSU have been faced with the 'major public works effort' of having to construct and bring into operation 40-60 new tube wells per year and to replace or recondition a further 30-40 per year.

CURRENT STATUS OF URBAN WATER RESOURCES

Position of Lucknow Water-Supply Utility

- Today the LWSU has a total gross available supply of about 490 Ml/d – of which around 240 Ml/d is derived from up to 500 tube wells and 250 Ml/d from surface water, with the Gomti intake having been replaced by an authorised offtake from the Sardhar Irrigation Canal because of reduced base flows and quality deterioration at the river intake.

- The LWSU operational position can be summarized as follows :
  - they are faced with substantial physical leakage losses (estimated around 30% overall), especially from older sections of the distribution network, which reduce their deployable supply to about 345 Ml/d (insufficient especially in the immediate pre-monsoon months when ambient temperatures and water-demands are highest)
  - they are constrained by source and distribution limitations, such that their service is typically 6 hours/day at low pressure with individual use about 100 lpc/day – but in a few areas they can offer 24 hours/day supply at rates up to 250 lpc/day whilst in some outlying colonies the service level is very poor with dependence on water tankers.

- It should be noted, however, that because of the long-term availability of local groundwater resources the municipal water-supply position in the LMA is considerably better than that in most cities of peninsula India for example – and that the current problem is as much one of distribution system constraints (caused by rapid and unplanned growth) as it is one of absolute resource shortage.

Private In-Situ Self-Supply from Groundwater

- Given the limitations of the LWSU service in some areas there has been a rapidly increasing trend of private water well construction, in essence as a 'coping strategy' by those seeking and prepared to pay more for a secure continuous supply. But there is no inventory or systematic assessment of the scale of private residential groundwater use – although It has been estimated that around 1100 tube wells are in operation across Lucknow District by commercial, industrial and institutional water users (although only a few extract more than 10 Ml/d). In addition to the military cantonments and large railway installations, other large demands for groundwater come from the diary industry within the city and for irrigating mango orchards on the alluvial-terrace areas immediately to the south-west.

Costs of Groundwater Production

- The current average production (running) cost of the LWUS supply (without amortization of capital investment) stands at just under Indian rupees (I rps) 5/m^3 – although it reaches I rps 6/m^3 for certain new local supplies coming on stream. Some 95% of the LWUS supply is used via domestic connections which are not metered but subject to a fixed annual connection charge at a subsidized estimated equivalent cost of just over I rps 2/m^3. For full operational cost recovery there is a proposal to sell water to all metered premises at rates ranging upwards from I rps 2/m^3 to I rps 12/m^3 depending on use category and consumption. But the very large number of non-metered domestic properties results in low awareness of the need for water conservation, and much leakage and wastage on premises.

- Typically water wells constructed by commercial and industrial private users are around 150 m deep and have 150 mm diameter completion, with costs of equipped tube wells running at I rps 180,000-220,000 – although no estimates of the costs of their water-supply in I rps/m^3 (with or without capital amortization) are yet available they are likely to be in the range I rps 8-14/m^3.

- It is a characteristic of 'alluvial groundwater cities' (metropolitan areas where local groundwater from alluvial deposits provides a substantial proportion of the municipal water-supply) that there tends to be a smaller differential between the full economic cost of the municipal supply (relatively low overall since obtained without treatment and long-distance transmission from local groundwater) compared to private in-situ tube well water-supply (which is more expensive than in hard-rock aquifers because of the need for more costly well construction).

Groundwater Overexploitation and Its Impacts

- In the 1950s, the pre-monsoon depth to water-table in Lucknow City appears to have been for the most part less than 10 m bgl and even shallower along the Gomti River flood plain (Figure 2). Today it has been widely depressed to below 20 m bgl and has passed 30 m bgl in some areas (such as Gomti Nagar, Indira Nagar, Vikas Nagar) and continues to decline at rates in excess of 1.0 m/a – although in some outlying newly-developed colonies it remains within 15 m of the surface.

- There does not appear to have been a systematic groundwater resource study of Lucknow District (or its metropolitan area) – although an indication of groundwater resource status can be gleaned from the experience of water well development (Table 1), which shows how tube well yields have reduced significantly. The cause of this is more the highly localized concentration and continuous use of tube wells rather than an overall resource deficiency in the aquifer system – which is witnessed by the fact that in some locations not too distant from the city there are waterlogging problems due to shallow and rising water-table.

- Whilst groundwater development for public water-supply by the LWSU has been largely unplanned, UP-WSSB has tried to follow an empirical well-spacing criterion of 300 m separation minimum, but completely uncontrolled development by the commercial and industrial sectors means that many wells are located at 50 m or less apart.

- The consequences of water-table decline go beyond tube well yield reductions to include:
  - the Gomti River changing from 'effluent condition' (gaining flow from natural groundwater discharge) to 'influent condition' (losing flow to groundwater infiltration) – which gives rise to concern about groundwater pollution from polluted river-water and lack of flow for dilution of sewage discharges
  - much greater constraint on the use of surface-mounted centrifugal pumps for tube well pumping and general need for much more expensive pumping equipment

  although there are no reports of significant groundwater-extraction related land subsidence.

Potential Groundwater Quality Concerns

- There has been no systematic survey of groundwater quality and its depth, spatial and temporal variations in the LMA, although from individual one-off analysis it is reported that:
  - all LWSU tube wells tapping the 'second productive level' of the aquifer (and in some cases also the 'third productive level') deliver raw water quality conforming with current Indian drinking water norms
  - many tube wells tapping the 'first productive level' record elevated NO_3 concentrations (over 100 mg/l)

and in other cases dissolved Fe and Mn problems are reported – this suggests a local (and perhaps more general) heavy DOC and N load from wastewater infiltration causing reducing conditions initially and at greater depth progressive natural in-situ oxidation with NO_3 as the residual (although the presence of other synthetic organic contaminants used by the urban population and industry cannot be ruled out).

- However, the current depth of (and still declining) water-table will tend to assist the elimination of pathogenic micro-organisms infiltrating with wastewater, and they should not present a problem except in tube wells which are poorly-sited and/or inadequately-constructed from the sanitary standpoint. The presence of sand in tube well discharge is also widely reported but this simply reflects the difficulty of adequate well design in these thick sequences of sandy alluvial deposits, some of which are of fine-grade.

STRATEGIC APPROACH TO URBAN WATER-SUPPLY SECURITY

Vision of 'Planned Conjunctive Use'

- There are plans in hand to further augment Sardhar Canal flows from the Sardhar River in the Upper Ghaghara Basin (150 km or so distant from Lucknow) in an attempt to guarantee the availability of 500 Ml/d in all seasons at the Lucknow City off take. However, such a scheme has significant vulnerabilities:
  - to surface water flow reductions from the Himalayan mountain chain under various climate-change scenarios
  - at times of drought potential conflicts with the farming community across whose land the canal runs.

- Moreover, the 2025 demand prediction for Lucknow City requires a gross available supply of 810 Ml/d (before leakage losses are deducted), which would imply maintaining or even expanding local groundwater production. Thus it is considered that the only robust way to face the future urban water-supply challenge is to look towards a more integrated and harmonised conjunctive use of surface water and groundwater sources.

- Potential opportunities for expanding and spreading municipal groundwater extraction must exist by investigating the numerous areas (say) within 20 km of Lucknow City which are experiencing soil waterlogging as a result of high and/or rising water-table and constructing well fields in such areas with either :
  - delivery of water to the urban distribution system by pipeline, or
  - augmentation of flows in any conveniently-located canals, during periods of high-demand, for subsequent off take in the vicinity of Lucknow City

  both options would have the secondary benefit of improving land drainage and crop productivity in the corresponding rural areas.

Requirements to Design a Sustainable Groundwater Use Policy

- This diagnosis of groundwater resource status and strategic planning needs now requires critical review and complementary investigation to consolidate a long-term sustainable groundwater use policy. Among the critical elements of follow-up work required are:
  - a systematic but selective evaluation of private water well use, costs and other drivers
  - an assessment of the scale and significance of groundwater pollution, with sampling in a selection of tube wells in various colonies and of different screen-depth
  - a general overview of wastewater handling – including areas with mains sewerage systems, differing types of in-situ sanitation, and in which the pluvial drainage system has widespread domestic waste-water connections
  - a more detailed groundwater resource assessment (in coordination with CGWB-North Region Office), preferably including the elaboration of a numerical aquifer model to explore different conjunctive use scenarios – thus making better use of the data collected from the new network of urban piezometers
  - a review of the current benefits, risks and effectiveness of urban rainwater harvesting for aquifer recharge enhancement, including the mandatory provision in respect of all new housing developments and all government buildings – evaluating whether deep water well or soakaway percolation to target productive aquifer levels is technically and economically feasible.

- In addition, and most importantly, an appraisal of institutional roles in relation to urban groundwater is needed, with consideration of institutional mechanisms to incorporate groundwater issues into urban infrastructure decision-making. It will also be necessary to significantly increase stakeholder awareness of the main groundwater management issues relating to the provision of an efficient and sustainable water-supply for a rapidly expanding city.

Publication Arrangements

The GW•MATE Briefing Notes Series is published by the World Bank, Washington D.C., USA. It is also available in electronic form on the World Bank water resources website (www.worldbank.org/gwmate) and the Global Water Partnership website (www.gwpforum.org).

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