URBAN GROUNDWATER PROTECTION AND MANAGEMENT: LESSONS FROM 2 DEVELOPING CITY CASE STUDIES IN BANGLADESH AND KYRGHYZSTAN

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ABSTRACT: The inexorable expansion of the world's urban population and the realisation that water resources are finite have forced many developing cities in emergent economies to consider how sustainability can be introduced into their plans for infrastructural improvement. Groundwater-dependent cities should feel this need keenest. Yet the pace of urban aquifer management remains slow. Simple but context-sensitive aquifer protection policies would help plan for sustainable urban development, especially if stakeholder involvement increases the chances for the gap between policy enactment and enforcement/compliance to be closed. The experience of two such developing cities in Bangladesh and Kyrghyzstan that are attempting to develop their own groundwater protection plan along sound hydrogeological principles is described.

KEY WORDS: Groundwater, protection, developing countries, urban growth, groundwater quality, hazard assessment, groundwater vulnerability, urban water management

1. Introduction

This paper describes an ongoing three-year collaborative research project[1] which commenced in late 1998 in the two developing cities of Narayanganj, Bangladesh and Bishkek, Kyrghyzstan. The objectives of the project are:

[1] UK Dept for International Development KAR Project R7134, Groundwater Protection and Management for Developing Cities

- to employ available data to conduct aquifer vulnerability and subsurface contaminant load surveys to provide pollution risk assessments in each case study city,
- to use these assessments to engage groundwater stakeholders in the development of policy options for a city groundwater protection plan comprising a concise set of policy guidelines and a groundwater resource planning map,
- to generalise the lessons learnt from the case-studies for wider use by other groundwater-dependent developing cities.

The rationale of the project is to demonstrate whether practical aquifer protection policies can be developed within the limited financial and institutional resources typically available to those tasked with managing and planning the urban water infrastructure of a groundwater-dependent city in an emerging nation. As described in the following section, there is a sustainable development case for such groundwater protection plans and an increasingly pressing need.

2. Background

2.1 ROLE OF URBAN AQUIFERS

It is estimated that half the world's predicted population of 6500 million will live in towns or cities by 2010 [1]. Much of this increase will be concentrated in the developing world, which accounted for 85% of urban population growth between 1980 and 2000. The result is that by the year 2000, about twice as many people were living in cities in developing countries (1900 million) as in the developed world (950 million). A high proportion of these urban dwellers depends day-to-day on groundwater for domestic, industrial and commercial water supply, and nowhere more so than in the developing world. It has been estimated that about one-third of Asia's population (some 1000-1200 million people) and some 150 million Latin Americans are groundwater-reliant [2]. Half of the world's 23 mega-cities as well as hundreds of smaller towns and cities are also groundwater dependent (Table 1).

TABLE 1. Groundwater dependence of the world's mega-cities

City and estimated population in 2000 (millions)					
Mexico City	**25.8**	Rio de Janeiro	13.3	**Cairo**	**11.1**
Sao Paulo	24.0	**Shanghai**	**13.3**	Los Angeles	11.0
Tokyo	20.2	**Buenos Aires**	**13.2**	**Bangkok**	**10.7**
Calcutta	**16.5**	Delhi	13.2	**London**	**10.5**
Greater Bombay	16.0	**Jakarta**	**13.2**	Osaka	10.5
New York	15.8	Karachi	12.0	**Beijing**	**10.4**
Seoul	13.8	**Dhaka**	**11.2**	Moscow	10.4
Teheran	**13.6**	**Manila**	**11.1**		

Groundwater-dependent cities in bold

Uncontrolled groundwater development and indiscriminate waste disposal often accompany urban expansion, resulting in growing water scarcity and deteriorating water quality. This degradation, which occurs within the urban area, on the periurban fringes and downstream, is a contributory cause of spiralling water supply costs. Substitution of degraded urban groundwater by alternative 'out-of-town' supplies is expensive, with unit water costs often 2-3 times greater than current costs [3].

As well as financial and environmental costs, declining urban water quality may also carry health implications, because in areas where public piped water supply and sanitation are over-stretched, poorer people may be obliged to use the shallow subsurface both as source of supply and as receptor for on-site sanitation. In those groundwater settings where such a combination carries a significant health risk, maintenance/improvement of source water quality may be critical to avoid present microbiological hazards and to prevent the introduction of an exotic pathogen into the community which may provoke an unexpected explosive outbreak [4]. It also avoids the need for water treatment within the home, which is expensive, unreliable and places an additional burden on the urban poor.

2.2 GROWING AWARENESS OF NEED FOR AQUIFER MANAGEMENT

The realisation that proactive aquifer management needs to become an integral part of development planning in groundwater-dependent cities arose in the mid-1980s. Studies of urbanisation-induced water balance changes [5,6,7,8,9,10,11] demonstrated how radically aquifer replenishment mechanisms were affected, with many cities establishing a dynamic equilibrium between increased recharge availability and pumped abstraction. Urban hydrologists recognised the importance of the shallow subsurface in runoff/drainage control, for instance its ability to attenuate stormwater runoff peaks ([12, 13]. Development planners came to realise that local aquifer-dependent water supply and on-site sanitation arrangements were not going to be just a short-term transient phase for many low-income districts of expanding developing-world cities [14,15,16,17].

By the mid-1990s urban groundwater had become a topic area in itself, providing the theme for major symposia such as the UN Habitat Conference on Managing Water Resources for Large Cities and Towns (1996, Beijing) and the IAH Congress on Groundwater in the Urban Environment (1997, Nottingham). Urban groundwater management has been embraced and published upon by external support agencies (e.g Foster *et al* [18]) conscious of the link with sustainability issues aired at the 1992 Earth Summit in Rio de Janeiro. With more than 150 countries signed up to Agenda 21, the manifesto which emerged from the Earth Summit, municipal authorities all round the world are become aware of, and responding to, the need to consult with their citizens in developing their own Local Agenda 21 plans for sustainability.

2.3 GROUNDWATER PROTECTION PLANS-THE PARADOX

Against such a background the need for, and the benefits of, urban groundwater protection policies seem self-evident, if urban aquifers are to be treated as sustainable resources rather than as wasting assets, doomed to eventual abandonment. On the face of it there seems every reason to anticipate that groundwater-dependent cities concerned with the future security of their water supplies, as a Local Agenda 21 issue or otherwise, will be putting in place concise aquifer protection policies as a matter of course. Yet this does not seem to be the general case, and certainly not in the developing world, where the real need is keenest. The main reasons for the worrying absence of policy guidance from groundwater engineers and scientists for urban decision-makers seem to be:

– *Inability to see 'the big picture':* Groundwater development is by its very nature incremental, and at least initially, speculative rather than planned. Wells may be drilled by a single utility or by any of hundreds of private users, fragmenting the knowledge base. Problems such as overdraft or water quality deterioration are thus less easy to identify in their early stages. Borehole construction, equipping and bringing into production is relatively light in investment requirements in contrast to large river intake or city hinterland reservoir problems, and so it is the latter which tend to be the subject of a city master water plan. The result is that much groundwater development tends to occur by default rather than by design, and it can be a challenge to separate out key elements of the aquifer setting and groundwater use clearly enough to gain an overview.

– *Sustainability linkage unrecognised*: While groundwater engineers and scientists routinely think in timescales appropriate to groundwater flow, this is much less the case with the general public, for whom reaction/residence times of water in observable features such as rivers are much easier to grasp. It is necessary therefore to actively point out the strong sustainability focus of a resource whose pollution response and replenishment time-scales are typically measured in years→decades→centuries rather than the hours→days→weeks of most city river/reservoir sources. Also that aquifer protection embraces not only security from insidious degradation of water quality but also from erosion of the resource by unregulated overexploitation. Otherwise municipal policymakers will be unaware of the need to include aquifer management in sustainable development initiatives.

– *Lack of data:* If paucity of monitoring information on aquifer development and status is a symptom of the frequent assertion that groundwater is rather taken for granted, then many urban and periurban aquifers are neglected. Even where databases exists, they may not be consciously linked to a management need, and much laboriously collected information is thereby found to be either inapplicable or inappropriate when aquifer assessment is undertaken.

As a result, despite the apparently straightforward techniques required, for the hundreds of groundwater-dependent cities in middle and low-income countries, an aquifer protection policy locally developed to help a particular municipality manage its groundwater resource remains an unusual exercise. It is against this background that the collaborative research project described in this paper was initiated.

3. Pollution risk assessment: stepping towards a groundwater protection plan

3.1 URBAN AQUIFER PROTECTION AND RISK ASSESSMENT-THE LINK

The developing world reality of urban areas rapidly expanding into, and encroaching upon, previously rural and now periurban areas generally precludes the possibility of managing land entirely in the interest of groundwater gathering. So it is a generally-accepted starting point that aquifer protection policies will be required to define protection strategies which, while they constrain land-use, accept trade-offs between competing interests and utilise the natural contaminant attenuation capacity of the strata overlying aquifers [19]. To implement such strategies it is necessary to mesh hydrogeological understanding and requirements into land-use policies and provide simple robust matrices that indicate what activities are possible where, at an acceptable risk to groundwater. Thus a pollution risk assessment forms the logical starting point for the development of a city groundwater protection plan, and was the first stage in both the city case-studies.

3.2 NEED FOR SIMPLE RISK ASSESSMENT TOOLS FOR AQUIFER MANAGEMENT PURPOSES

Neither of the cities studied in this project had previously been the subject of an urban groundwater study, in which the size, scope for future exploitation and development constraints had been formally assessed. In Bishkek, river basin-scale investigations had been undertaken in the 1970s to assess available resource on a broad regional scale as a standard national economic resource procedure under the former Soviet system. In Narayanganj, investigations were at the other scale extreme, limited to estimates of safe yield funded by Japanese technical assistance for the small municipal wellfield. In effect, groundwater has been developed opportunistically in both cities. This situation is so common as to be almost the norm for urban groundwater, and not just in developing countries.

The completion of an adequately scoped and funded master-plan type of resource study is of course a most desirable and logical stage to complete before developing a city groundwater protection plan. However, unfortunately it cannot be afforded the luxury of being a prerequisite. This is because few developing world cities already possess such a study (there is no prospect of such a study in either Bishkek or Narayanganj, for instance), and much can be achieved in planning terms with only a partial understanding of the local aquifer system. Instead, pragmatic protection plan design criteria need to be developed if planning is not to be so delayed as to irretrievably prejudice resource sustainability. Such criteria, which need to be targeted from the outset for a subsequent policy development and aquifer management stage, include:

– *Use of available data:* The typical situation would be that projects of this type would be resourced only to use existing. This places a premium on identification of either basic data arrays already collected for other purposes, or simple parameters easily collated from operational records. In Narayanganj, the standard of basic hydrogeological data was relatively poor, being limited to a handful of borehole logs in the centre of the city. In Bishkek, the standard of basic hydrogeological data was good, being comprehensive in parameters covered (geology, hydrogeology, water levels, location of wells etc), internally consistent and relatively up to date (mostly less than 20 years old). In both cities however routine monitoring information was poor, so that trends in aquifer usage and water quality are unknown.

– *Employs transparent tools:* The tools used need to be simple and robust so they can be generalised to many different city situations with relatively little modification. This will facilitate their uptake by making the process relatively rapid, low cost and easy to undertake with limited human, technical and financial resources. For example, while digital GIS techniques were used in these case-studies to permit easy overlay of thematic material for map production, the number of stages was small enough and the ranking system simple enough for manual overlay techniques to have been employed if local resources had so dictated. A corollary is that the use of now widely-available GIS software packages should not obscure the quality (or sparseness) of underlying data.

– *Comprehensible to stakeholders:* In many cases important and influential stakeholders involved in urban water management decisions do not have a technical background either in engineering or in resource planning. Professional hydrogeological expertise in city water management is generally absent, and municipal water supply utilities may be more focussed on day-to-day operational needs of the present system, even where groundwater is a major urban resource. This was the case in both Narayanganj and Bishkek, where urban water management decisions do not appear to involve resource-knowledgeable institutions. Thus while the underlying rationale may be subtle, and the technical background complex, an urban water management discussion document needs to be simple, clear and concise enough to engage municipal decision-makers with a minimum of technical jargon.

3.3 RATIONALE FOR POLLUTION RISK ASSESSMENT

The above criteria guided what type of pollution risk assessment to use. The commonly adopted approach (from Foster and Hirata, 1988 [20]) employs the interaction between hazard from contaminant load and aquifer vulnerability to determine the risk of pollutants reaching the aquifer (Figure 1). The risk can then be conceived as the interaction between:

– the aquifer pollution vulnerability resulting from the natural characteristics of both the aquifer and the strata separating it from the land surface and

– the contaminant load that is, will be or might be applied to the sub-surface as a result of human activity.

Adopting such a scheme, it is quite possible to have high contaminant load but no significant pollution risk because the aquifer's intrinsic vulnerability is low, and vice versa. As the intrinsic vulnerability relates only to the properties of the aquifer with its overlying layers, and not to the properties of the potential contaminants (because these are numerous and highly variable), the approach is most helpful when dealing with persistent mobile contaminants not readily susceptible to attenuation. As such, the scheme is necessarily a pragmatic approximation because "general vulnerability to a universal contaminant in a typical pollution scenario is a meaningless concept" [21].

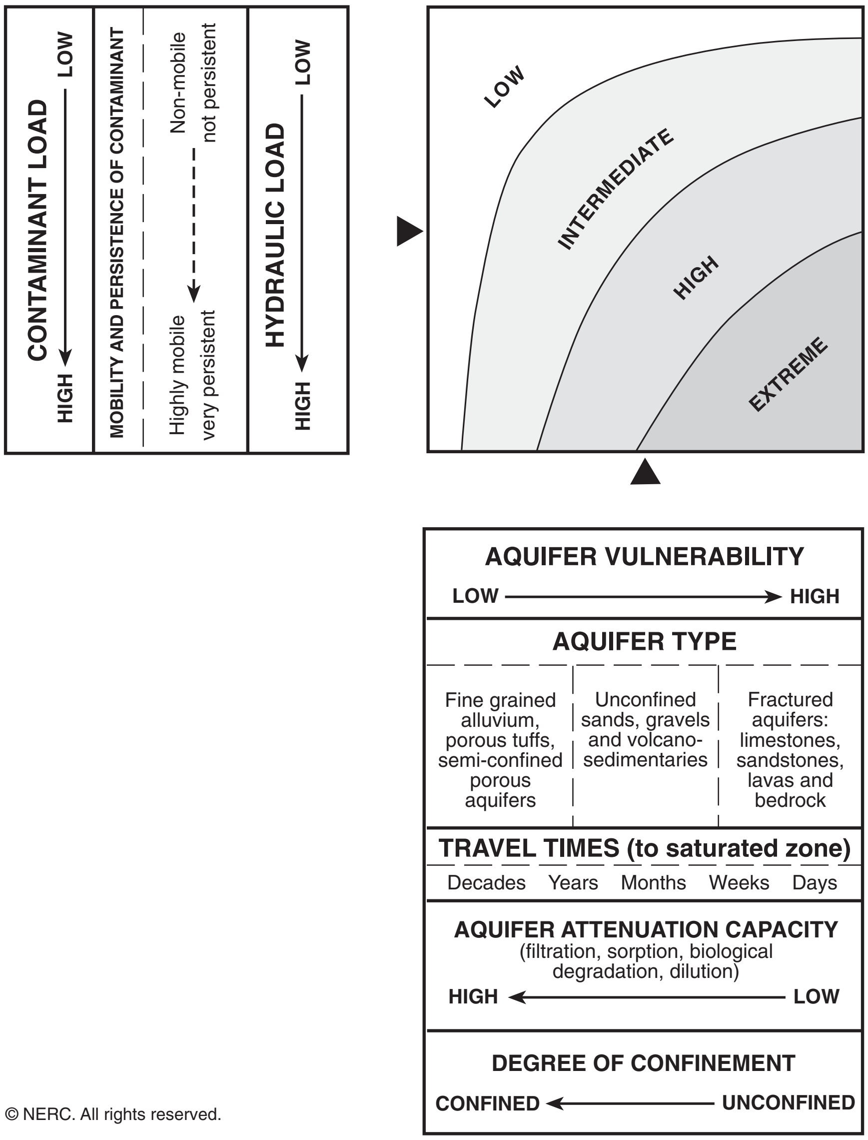


Figure 1. Conceptual scheme of groundwater pollution risk (modified from Foster and Hirata, 1988)

For the purposes of developing groundwater protection and management policies, the assessments of aquifer vulnerability and contaminant load are presented in the form of a groundwater resource planning map (GRPM). This is derived from a groundwater vulnerability map (GVM) and a potentially hazardous activities map (PHAM, Figure 2).

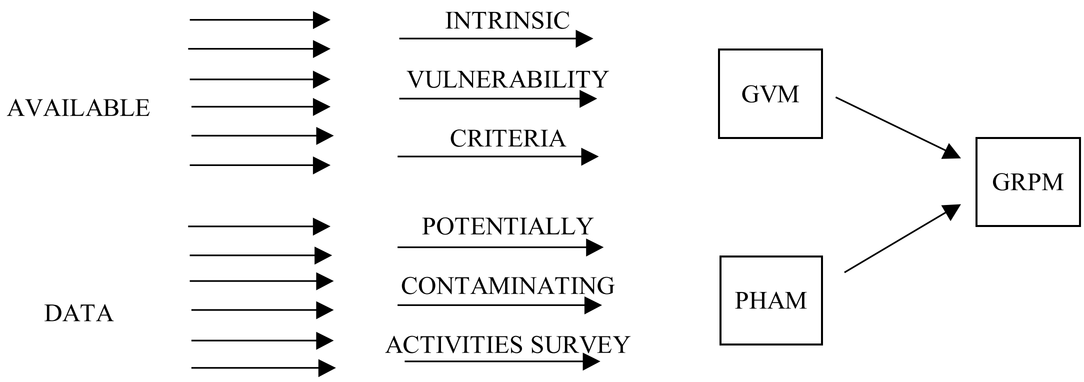


Figure 2. Evolution of component parts of a groundwater resource-planning map (GRPM)

3.4 DATA COLLECTION STAGE

In both cities the collection of available data formed a vital first stage. Table 2 summarises the types of agency that provided data used for

– the conceptualisation of the hydrogeological setting

– the development of an aquifer vulnerability scheme appropriate for existing city groundwater use, and likely future trends

– the mapping of activities within the urban area likely to generate a subsurface contaminant load. These might generate an actual diffuse load (such as districts with on-site sanitation) or a potential point-load (certain industries and some services such as solid waste disposal sites or fuel-filling stations)

Clearly other cities will have their own national and municipal arrangements and the locations of data will reflect these differences, but two features were noteworthy at the data collection stage in both Narayanganj and Bishkek.

– Firstly, that for historical reasons of state security, in both cities it proved difficult to obtain modern large-scale map coverage suitable to use for basemap purposes. Despite the particular political history of both Bangladesh and Kyrghyzstan, it is suspected that this mat be a more widespread hurdle for urban planning than is generally anticipated.

– Secondly, that although government organisations at both national and municipal level were invariably the principal locations for groundwater-related data, information produced primarily for commercial or economic statistics reasons could be fruitful sources for potentially polluting activity assessments. For instance, a database of businesses and industry funded by the German technical assistance programme to help Kyrghyz business development in Bishkek and an investment funding register in Dhaka were both discovered by accident. Each proved helpful aids to identifying the location and nature of industrial activities in their respective project areas.

TABLE 2 Pollution risk assessment information sources in Narayanganj and Bishkek

Organisation/Agency	Narayanganj	Bishkek
Municipal Water Supply Utility	√√	√
State Geological/Hydrogeological Survey	✕	√√
State Water Resources Agency	√	√
National Environment Agency	✕	✕
National Map Survey Department	✕	✕
National Government Census/Statistic Agencies	√	√
Other State Ministries/Departments/Agencies	√	✕
National/Municipal Public Health Department	√	√
University or Other Water Research Institute	√	√√
Municipal Planning/Public Works Departments	✕	✕
Chamber of Commerce/Trade Organisation	✕	✕
Consultants report	✕	✕
Commercial directories/institutions	√	√√
External Support Agency e.g. UNDP, JICA	√	✕

Key:

√√ Important source of data
√ Provided some data
✕ Unable to provide relevant data/not available

The information was collected using a questionnaire format devised for urban groundwater diagnostic purposes [3], subsequently collated into an urban groundwater profile for each city summarised in the following sections [22,23],. This stage showed that there were adequate data to undertake a groundwater vulnerability assessment for Bishkek, but insufficient for Narayanganj, where it was necessary to undertake a 21-well manual drilling programme to establish the extent and thickness of the near-surface aquitard.

3.5 CASE-STUDY CITY PROFILES

Narayanganj, Bangladesh

Physical setting. Narayanganj is a small city of about 1 million population located some 20 km south-east of Dhaka on the flat Ganges-Brahmaputra-Megna alluvial plain of central Bangladesh, at an elevation of 0 to 10 m PWD. It is flanked by the Sitalakhya River on the east and the Buriganga River on the south and south-west. The project area is crossed by many small seasonally-filled man-made drainage canals fed by monsoon rain which averages 2550 mm annually.

A long-established river port, and jute trading centre, Narayanganj is now a national textile manufacturing centre, with factories undertaking all stages of production from spinning, dyeing/bleaching and weaving through to the making of garments and other finished cloth products. Other industries include soap-making, metal re-rolling and metal & wood furniture manufacture. The rapid and unchecked growth of Dhaka into a megacity of 10 million inhabitants has seen inexorable encroachment on the rural hinterland west of Narayanganj, and the city is likely in the mid-term to become an industrial satellite suburb of Dhaka. It had itself a high estimated annual growth rate of 5.8% per annum during the 1990s.

Hydrogeological setting

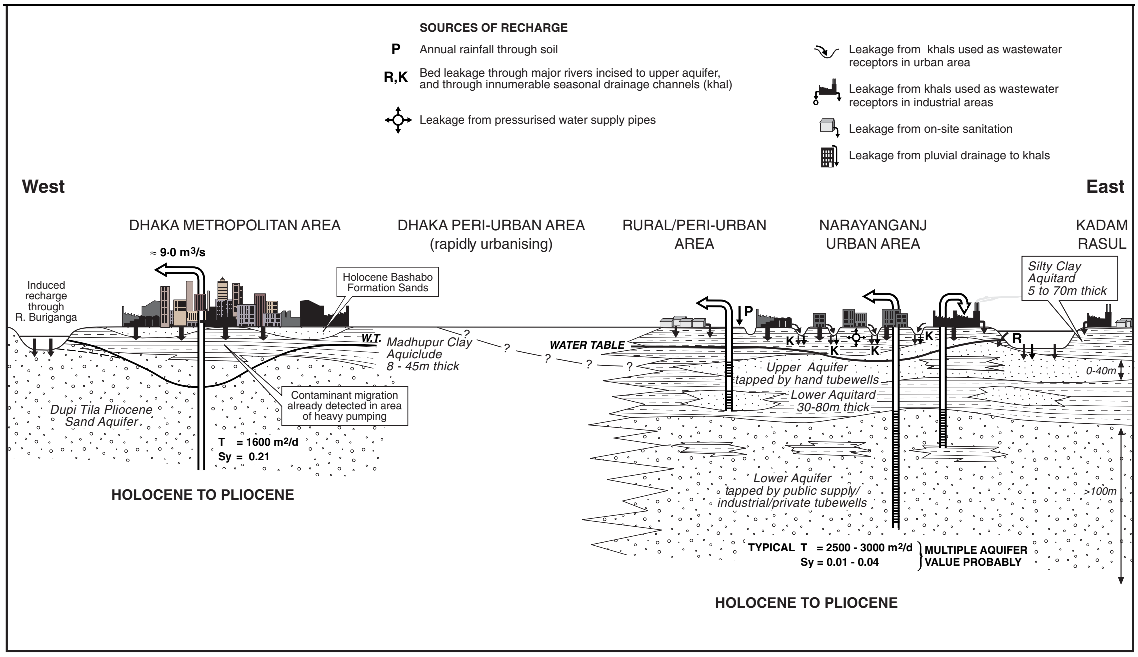


Figure 3. Groundwater setting of Narayanganj, Bangladesh

Narayanganj is underlain by an unconsolidated alluvial aquifer system of Quaternary age which is many hundreds of metres thick across the entire project area but in which only the top 250 m (and principally the top 150 m) is utilised for groundwater supply purposes. Complex lateral interdigitation of medium grain-size clastics (medium to coarse sands) occurs with finer-grained clastics (fine sands, silts, clays). As a first approximation the system is considered to comprise an upper aquitard covering a shallow aquifer which is separated from a deeper more productive aquifer by a lower much thicker aquitard (Figure 3)

With a monsoonal tropical climate, there are extensive opportunities for recharge not only directly from local rainfall but also from the Sitalakhya River and numerous khals and rainfed ponds. Annual monsoonal floods inundate much of the periurban area while the urban area can be affected on average about once every decade by abnormally high floods. Unconsolidated sediments provide intergranular flow conditions, and it is probable that there is hydraulic connection with the Sitalakhya River whose channel is deep enough to incise into the upper aquifer sequence.

Vertical connectivity is likely to be variable, depending on thickness and frequency of occurrence of fine-grained strata at any given location.

Groundwater development setting. Groundwater provides more than 90% of drinking water supplies in the study area and there is a similar high dependence on groundwater for industrial and commercial needs. Large-scale groundwater abstraction for public supply and industrial use is mainly from the lower aquifer, and the public water utility's boreholes are located mainly within the urban area of Narayanganj. Broadly similar designs are employed for public supply and private industrial/commercial use wells alike, so the deeper aquifer horizons are not reserved for potable use.

It appears that the piped water supply does not extend beyond the urban heart of Narayanganj, where it provided at the time of national census a per capita supply equivalent of about 70 l/p/d. Actual per capita usage is almost certain to be widely supplemented with private supplies from either the shallow or (less frequently) the deep aquifer.

While the groundwater productivity in the shallow aquifer is thought to be too low for large abstractions, it is tapped by numerous narrow diameter boreholes equipped with hand pumps for drinking water and domestic supply purposes. The total volume abstracted is unknown but there seems little doubt that the upper aquifer is the primary source of potable supply for the rural and periurban population of the project area as well as a supplement for urban households.

The resultant supply network is therefore diffuse, with piped water-supply coverage within much of urban Narayanganj but numerous handpump-equipped shallow boreholes in rural and periurban districts. A large number of private and industrial wells (non-potable use) abstract an unknown volume of groundwater from the lower/main aquifer.

There is no modern waste water and sewerage disposal system in the study area and dispersed on-site sanitation is widespread in urban, periurban and rural areas alike. Opportunistic use is made of the storm drainage system in central Narayanganj, mainly for sullage but illegal foul-water connections are said to be common. There is no wastewater treatment plant in the study area. Drainage problems result in frequent waterlogging of many parts of the town; this becomes acute during the monsoon.

Bishkek, Kyrghyzstan

Physical setting. Bishkek is the capital city of the Kyrghyz Republic, a former republic of the USSR and an independent state since 1991. The city lies on the outermost northern flanks of the foothills of the Alatau range of the Tien Shan mountains at an elevation of 725-900 m above sea level. The population of Bishkek is approximately 600,000. It is the country's industrial centre and has witnessed changes since independence, notably the decline of the once-dominant Soviet military-industrial sector, and the increase in small private businesses, often with foreign investment. The city is 100% aquifer dependent for potable, domestic, commercial and industrial water supplies which are provided by both intraurban and periurban wellfields.

Hydrogeological setting. The urban groundwater setting is hydrogeologically complex (Figure 4), with a laterally heterogeneous fluvioglacial/alluvial multi-aquifer system of Quaternary age which is in excess of 350 m thick in northern districts of the city. There is strong lateral and vertical variability but as a first approximation the system fines laterally northwards away from coarse clastic piedmont deposits composed of coalesced alluvial fans fronting the foothills into more stratified deep alluvial plain sediments (Figure 2).

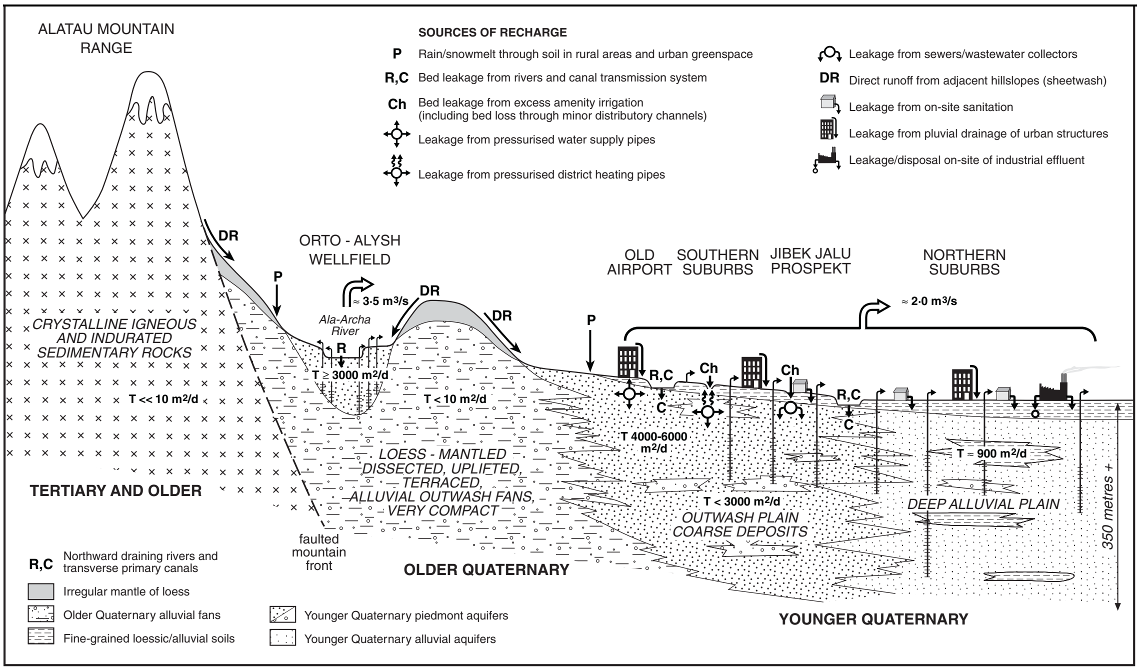


Figure 4. Groundwater setting of Bishkek, Kyrghyzstan

Despite the semi-arid climate there are extensive opportunities for recharge from snow-melt rivers and associated canal systems, draining the nearby Alatau range of the Tien Shan Mountains. Hydraulic connection with surface flow is thought to be strong across the southern piedmont area where the aquifer system is both unconfined and possesses strong vertical connectivity. More complex semi-confined conditions are present in the northern part of the city where 3 aquifer systems have been identified by other resource investigation projects. Scope for significant pumping-induced vertical leakage exists, especially in the southern parts of Bishkek where low permeability horizons in the alluvial tract are thinner and less numerous. Unconsolidated sediments provide intergranular flow conditions, and the coarse alluvial and fluvio-glacial deposits comprising the aquifers have high transmissivity and significant vertical permeability. Urban boreholes abstract water at widely different depths.

Groundwater development setting A highly productive but very localised periurban valley-fill wellfield located 8 km south of the urban area provides about two-thirds of the city's water demand, the balance coming from boreholes of various depths distributed throughout the city. These urban wells are screened extensively in the middle aquifer (typically >120 m intake depth), but the lower part of the upper aquifer (40 m-120 m) is also widely tapped.

The majority of abstraction boreholes are operated by the municipal water supply agency, and provide water for both domestic and industrial processes. There are three separate extensive reticulated systems for domestic water: cold water (domestic potable use), hot water to taps (domestic non-potable use) and hot water for radiators (non-potable district heating use). The last of these appears to be a closed (non-consumptive) system which is operated only during the winter. All come under the description 'public water supply'. The private urban water use categories are less important both in number and volume of water pumped; a small number of factories have private wells, for potable or non-sensitive water supplies and there are also small numbers of private domestic and public municipal irrigation wells. Significant amenity irrigation of communal parts of residential areas is undertaken, using both canalised surface water and pumped groundwater.

The wastewater disposal system comprises a widespread piped sewerage element, to which industrial, commercial, apartment and public buildings together with some low-rise residential housing are connected, and a dispersed on-site sanitation element in many low-rise residential areas. The relative importance and geographical extent of the latter is not well documented, but may be significant. A wastewater treatment plant receiving domestic and industrial sewered effluent is located on the northern fringes of Bishkek.

Supply well water level and water quality trends within the municipal area are unknown as apparently no regular monitoring is carried out apart from some microbiological testing. Even the latter may be limited to the distribution system rather than the pumped raw water supply.

3.6 GROUNDWATER VULNERABILITY ASSESSMENTS/MAPS (GVMS)

As illustrated in Figure 2, the groundwater vulnerability map is an important theme used in the preparation of a groundwater resource planning map. Using intrinsic vulnerability principles [24,25] a parametric rating system (termed overlay and index system by some authors) was devised for each city to make the best use of available data. The components are shown in Table 3.

TABLE 3. Groundwater vulnerability mapping criteria in case-study cities

Components of aquifer vulnerability used in rating system	Narayanganj	Bishkek
Presence and thickness of a low-permeability surface layer/ upper aquitard	✔	✔
Geology of the aquifers		✔
Depth to water table/thickness of unsaturated zone	✔	✔
Influent reaches of rivers/canals*		✔
Presence of excavations into the upper aquitard**	✔	

* Hydraulic feature important in Bishkek where upper aquifer is unconfined

** Hydraulic feature important in Narayanganj where upper aquitard is thin and could be physically removed e.g in brickearth quarries

In each case, a simple relative vulnerability index was applied to each component (High/Moderate/Low scored 3, 2, 1 respectively) then a vulnerability classification based on the sum of component theme scores. The Narayanganj example is shown in Table 4 and a vulnerability map derived from them in Figure 5.

TABLE 4. Point scoring and vulnerability classification system for the Groundwater Vulnerability Map of the upper part of the Narayanganj aquifer system

Vulnerability Theme	Classification (i.e. component zones)	Relative Vulnerability	Vulnerability Score
Depth to groundwater	0 – 5 m	High	3
	5 – 10 m	Moderate	2
	>10 m	Low	1
Depth to base of upper aquitard	0-10 m	High	3
	10-25 m	Moderate	2
	>25m	Low	1
Upper aquitard excavations	Present where aquitard <10 m thick	High	3
	Present where aquitard 10-25 m thick	Moderate	2
	Present where aquitard >25 m thick	Low	1
Groundwater vulnerability map classification (see Figure 5)	Sum of three theme scores*	Vulnerability classification of upper aquifer system	
	2-3	LOW	
	4-5	MODERATE	
	6-9	HIGH	

* Theoretical minima and maxima are 2 and 9, actual range in Narayanganj is 2-8

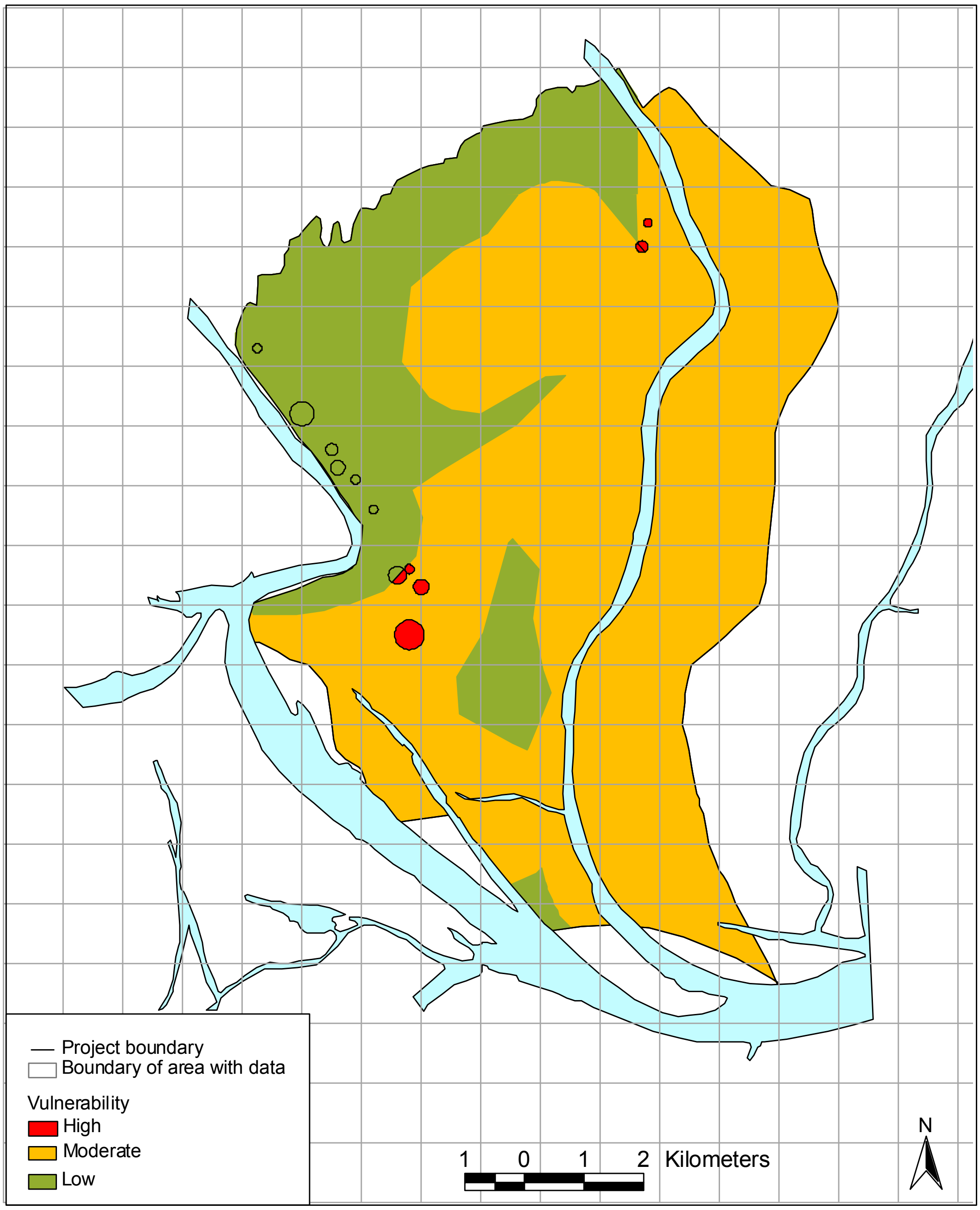


Figure 5. Narayanganj groundwater vulnerability map.

3.7 POTENTIALLY HAZARDOUS ACTIVITY SURVEYS/MAPS (PHAMS)

For first-pass risk assessment purposes, subsurface contaminant load can be conveniently subdivided into two classes:

– Diffuse/multiple point sources; these are loadings arising from the known presence of a widespread activity or urban disposal practice, usually wastewater from on-site sanitation or leaking sewers. Surveys of such sources rely for quantification on water balance/sanitation practice statistics obtained from water supply and waste disposal utilities and municipal public health departments, from which city-wide contaminant loadings can be estimated using mass-balance calculations [26,27,28].

– Point sources; these cannot be identified without detailed field investigations and so surveys concentrate on identifying industries and other activities which generate effluent loads or handle products which would have significant potential to contaminate shallow aquifers if they entered the subsurface. Such surveys do not of course imply that every site identified is contaminating the underlying aquifer, merely that the potential exists for significant contamination of a subsurface receptor if the products of the activity are not correctly disposed.

Diffuse sources. In Narayanganj the absence of piped sewerage implies that on-site sanitation is ubiquitous. In practice, the situation is more complex because of the use of urban storm drains as de facto collectors via illegal connections and the widespread practice in urban and periurban areas alike of wastewater disposal to drainage canals. In Bishkek, piped sewerage and on-site sanitation intermingle in residential areas, where sewered apartment blocks coexist alongside low-rise housing on latrine/septic tank systems. Industrial wastewater disposal practices proved difficult to disentangle, in part because many sites, although now partially or totally moribund were formerly sensitive military-industrial plants. Periurban irrigated areas under intensive horticulture could however be identified.

In both case-study cities, wastewater disposal practices were too complex, compared to the project resources available to disentangle them, for other than first-pass contaminant load calculations to be undertaken. However, enough information was gathered to identify the likely role of subsurface wastewater disposal on the urban water balance.

Point sources. While a wide range of human activities generate some contaminant load on aquifers, often only a few activities are responsible for the major groundwater pollution hazard. The industrial characterisation system compiled from Foster and Hirata [20] Table 9, is one of several compilations of potentially polluting activities, was adopted and used in Bishkek to locate and classify key sites (Table 5).

TABLE 5. Classification of potentially polluting industrial types

Activity codes for industry types					
0*	Administration/retail	9	Organic chemicals	17	Food and beverages
1	Iron and steel	10	Inorganic chemicals	18	Pesticides/herbicides
2	Metal processing	11	Pharmaceuticals	19	Fertilisers
3	Mechanical engineering	12	Woodwork	20	Sugar and alcohol
4	Non-ferrous metals	13	Pulp and paper	21	Electric power
5	Non-metallic minerals	14	Soap and detergents	22	Electric and Electronic
6	Petrol and gas refineries	15	Textile mills	23	Fuel filling stations
7	Plastic products	16	Leather processing	24	Other**
8	Rubber products	.			

* Includes all service/tertiary activities not likely to generate a significant pollution load

** Other includes any industrial activity that may be potentially polluting and is not covered by the other 23 codes

In Narayanganj, available industrial statistics were more simply subdivided and the activity classification was reduced to seven principal activity groupings from the all-industry types shown in Table 6. These were used to generate the PHAM shown in Figure 6.

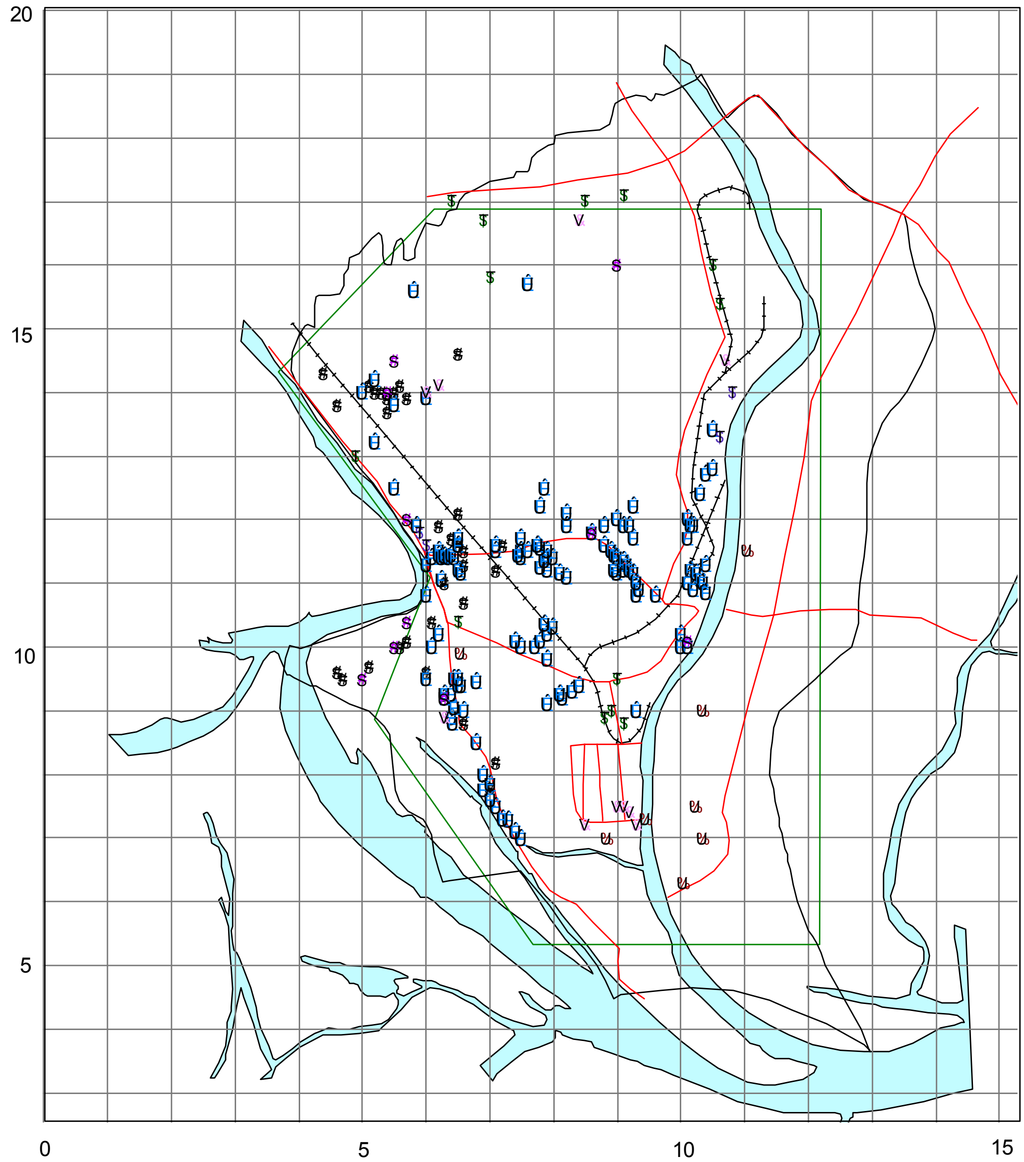
TABLE 6. Simplified potentially polluting industry classification employed in Narayanganj

Activity codes for industry types in Narayanganj			
2	Metal processing factories involving plating, galvanising or battery making	15	Textile processing factories (involved in dyeing, bleaching and proofing)
6	Petrol and gas refineries/storage depots	23	Fuel filling stations
9/10	Organic/inorganic chemical manufacturing plants	24	Informal/unofficial domestic /industrial solid waste disposal
14	Soap and detergent factories		

Note: code refers to activity identified in Table 5

3.8 GROUNDWATER RESOURCE PLANNING MAP (GRPM)

A precursor of the groundwater resource-planning map was produced for each city by overlaying the potentially contaminating activities theme on the groundwater vulnerability map. At this point it was considered that the technical information had been collated into a form which would be transparent and comprehensible to stakeholders, in that groundwater protection plan discussions could be informed by a single medium (A4 size colour map).



Point Source Codes (from Table 2.1)		Point Source Activity	No. of sites
#	2	Metal Processing (plating, galvanising, battery making)	31
$	6	Petrol & Gas Refineries / Storage Depots	4
$	9/10	Organic/ Inorganic Chemicals	10
V	14	Soap & Detergents	10
Ů	15	Textiles (dying, bleaching, processing)	132
$	23	Fuel Filling Station	13
Ȣ	24	Municipal / Industrial solid waste disposal	8

Major Roads
Railway
Major rivers
Boundary of area with data
Project boundary

Figure 6. Potentially hazardous activity map of Narayanganj

4. Engaging stakeholders in a groundwater protection plan

4.1 STAKEHOLDER IDENTIFICATION

Concurrent with the technical assessment previously referred to, the project team identified the principal groundwater stakeholders: those individuals and institutions that are concerned with, or have an interest in, the city's groundwater resources and their management. They include groundwater users who have a direct interest in groundwater resources, as well as those indirectly involved in groundwater development, management and planning, including public sector agencies and ministries, private sector organisations and firms, non-governmental organisations (NGOs), and external sector agencies. The number of stakeholders can be significant (18 in Narayanganj and 10 in Bishkek) and it was helpful to divide them into primary and secondary stakeholders [3], as illustrated in Table 7. This instructive classification showed in both cities that engaging with primary stakeholders is difficult and this is likely to be typical experience.

TABLE 7. List of main Stakeholders with roles in water infrastructure of Bishkek, Kyrghyzstan

Stakeholder name	Role	Type
1. Bishkekvodokanal	Responsible for most of city's water supply wells, distribution network and city sewer system	2
2. Bishkek City Administration	Responsible for infrastructure development in Bishkek	2
3. Department of Water Economy of Kyrghyz Republic	Responsible for management of national water resources	2
4. Kyrghyz Hydrogeological Expedition	Groundwater resource evaluation, monitoring of groundwater	2
5. Ministry of Ecology of Kyrghyz Republic	Responsible for ecology of water and land resources	2
6. Office of the Kyrghyz Republic Land Reform Project	Preparing land reform in Kyrghyz republic (including some water resource problems)	2
7. Sanitary and Epidemic Survey of Kyrghyz Rep.	Responsible for sanitary situation in KR (public health dept).	2
8. Bishkekremstroy	Mediator between Bishkekvodokanal and public users (flats and houses)	1
9. Chamber of Commerce and Industry	Apex body of leading industries and commercial organizations, influential pressure group.	1
10. Bishkekglavarhitektura	Responsible for urban planning and some city development plans (City Administration Department)	2

Key:

1. *Primary stakeholders:* those with a direct resource interest and whom groundwater degradation, or its threat directly affects, or who may be affected (positively or negatively) by policy implementation. Includes groundwater users.

2. S*econdary stakeholders* Those who are intermediaries in the delivering of policies, projects and services to primary stakeholders. Includes those with expertise on urban groundwater issues, and those who have the power to make decisions influencing the way groundwater is used and managed.

4.2 PROBLEM ANALYSIS, DRAFT POLICY FORMULATION AND STAKEHOLDER CONSULTATION

Stakeholders are likely to have very different and possibly conflicting interests in the urban subsurface, stemming from its simultaneous use for the provision of water supply, the elimination of wastewater and the location of engineering infrastucture and buildings [18]. To help establish dialogue, a bilingual newsletter was established in each city setting out the key issues and keeping stakeholders informed of progress. Also, urban water infrastructure problems and issues were progressively ‘unpacked’ in a series of analyses, so that stakeholders could start to appreciate the diversity of use and the standpoint of other user groups (Figure 7).

Figure 7. Developing policy background to inform stakeholder consultation process

An important first step was strength-weakness-opportunity-threat (SWOT) analysis, conducted on different aspects of the urban water infrastructure (Figure 8).

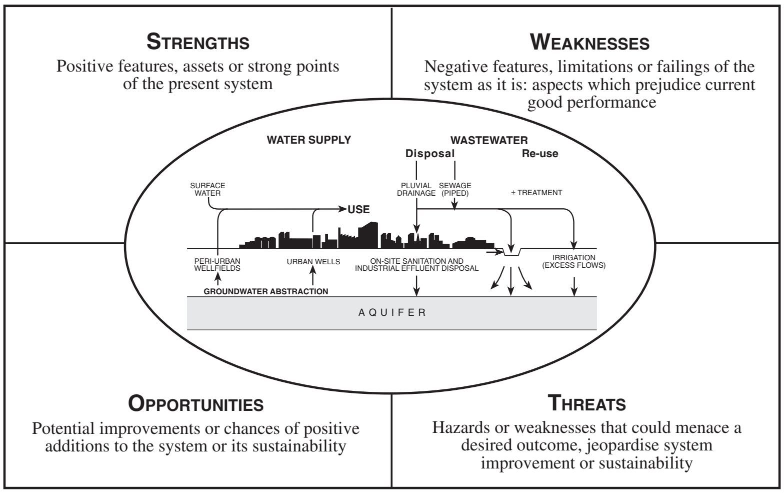


Figure 8. ‘SWOT’ analysis of urban water infrastucture

Table 8 is an example of one of the SWOT analyses for the periurban wellfield area of Bishkek.

Comparison of the SWOT analyses led to a problems and targets analysis (see Table 9 example from Bishkek) and these are being progressively introduced to stakeholders via periodic editions of the newsletters. The culmination of the consultation process will be a one-day stakeholder workshop to be held in each city in late 2001, by which time a concise draft policy guideline document comprising a map and a policy synopsis will have been produced for discussion

5. Conclusions and Recommendations

As the project is still ongoing at the time of writing this paper, extensive conclusions and recommendations are premature. However the following observations can be made:

– Standard groundwater protection policy tools of aquifer vulnerability mapping and pollution load assessment have been successfully developed for two groundwater-dependent developing cities employing available data almost entirely

– In each city, a clear conceptual model of the groundwater setting, in terms both of aquifer system and status of exploitation, had to be evolved to inform the pragmatic decisions required to develop working tools. This was the more necessary because neither city enjoyed the benefit of a master-plan type urban water resource appraisal on which this project could draw as background.

– These two tools are currently being actively used to inform and engage stakeholders in each city in a dialogue aimed at developing a consensus urban groundwater protection policy

– Given the inexorable rise in urban populations in the developing world and the important role of urban/periurban aquifers in supplying hundreds of cities worldwide, aquifer protection should not be overlooked if cities are to move towards resource sustainability as a core dictum of development policy.

TABLE 8 Sample 'SWOT' analysis: inner city water supply boreholes, Bishkek

WATER-SUPPLY INFRASTRUCTURE: INTRA-URBAN (CITY) AREA	
STRENGTHS	WEAKNESSES
1. Many widely dispersed wells: less susceptible to single pollution event. 2. Sanitary control zones around immediate wellhead area already in place. 3. Supply costs economic due to proximity of wells to users. 4. Suspected major distribution losses through pipe leakage provide high quality recharge to dilute pollutants which may have entered subsurface. 5. Wells take from several different depths/aquifers, but many are deep and relatively remote from transient pollution events. 6. High water-table in northern zone reduces scope for deep penetration of contaminants: high evapotranspiration in central irrigated areas reduces hydraulic loading and risk of downward leaching of contaminants. 7. Widespread amenity watering from canalised upland streams provides high quality additional recharge for contaminant dilution.	1. Utility does not control well catchments, only wellhead (sanitary control) areas, which are arbitrarily defined 2. Land in central part of city highly vulnerable due to shallow water table and negligible low permeability layer at surface. 3. No segregation of use between upper and lower parts of aquifer system., so some wells partly tap more contamination-prone upper aquifer. 4. Some wells in heavy industry areas 5. No controls on location/expansion of private boreholes, risk of interference effects. 6. Water quality data not stored in form amenable to resource management; e.g. quality trends of key constituents difficult to identify. 7. Sewerage and on-site sanitation structures likely to be closer to wellhead (sanitary control) areas than in periurban areas, and many other local sources of potential pollution at/near land surface.
OPPORTUNITIES	THREATS
1. Most wells operated by utility: private sector abstraction still small. 2. Still relatively easy to assign use categories by geographical area or by depth. 3. Water quality analyses exist and could be databased to identify trends for resource management 4. No evidence yet of over-abstraction and falling water-levels.	1. Urban density of activities/land use categories increases likelihood and frequency of contamination incidents compared to periurban area. 2. Uncontrolled leakage will increase unit water costs and lead to apparent water deficit, encouraging premature investment in additional more expensive periurban supplies. 3. Over-irrigation in south of city may drive contamination downwards. 4. Leakage due to breaks increases risks of supply interruption and introduction of contamination into pipework during low pressure periods; detrimental to quality of supplied water and to service.

TABLE 9 Sample objectives-problems-consequences-targets analysis for periurban water supply, Bishkek

Objectives	Actual/potential problems affecting groundwater resource	Consequences	Targets to mitigate the problems	Requirements to reach targets
Intra-urban (city) area:				
Maintain groundwater supplies	**Interference effects from uncontrolled private wells:** Not yet a resource problem but there are few controls on new wells near existing public supplies	Interference effects increase drawdown and energy costs and eventually reduce well yields as screen sections are dewatered	- Protect existing potable supply wells from derogation by new wells - Encourage use of upper aquifer for non-potable purposes; conserve underlying aquifers for potable use	Control of private well-drilling (especially depths) but avoidance of unnecessarily restrictive policies
Safeguard water quality	**Lack of control of pollutant load in well catchments:** No land use/activities control, arbitrarily defined wellhead protection zones not related to groundwater setting	Inadequate control of subsurface contaminant load	- Identify likely nature and proximity of main contaminants - Reduce/control excessive loads	- Control over contaminant loadings in well catchments using protection zones and better effluent monitoring - Technically defensible wellhead protection zones - Better information on aquifer separation/leakage in urban area.
	Some wells susceptible to deep penetration of pollutants: Diverse well designs tap very productive patchy multiple aquifer with probable high vertical permeabilities. Some wells part-screened in upper aquifer.	- Deep penetration of mobile, persistent pollutants would affect deeper aquifers water quality in time. - Hazard even to apparently deep wells if screened in upper aquifer or located in high vulnerability zones.	- Minimise hazard of deterioration of water quality of deeper aquifers - Avoid more problem wells by using designs appropriate to end-use of water and to aquifer setting.	- Identify existing problem wells by better raw water monitoring - More use of monitoring data for proactive aquifer management - Restriction of deep drilling to potable-use wells only.

Acknowledgements

This paper is published by permission of the Director, British Geological Survey (BGS-NERC). The study has been made possible by the support of the UK Department for International Development (DFID). The views expressed are not necessarily those of DFID.The paper is also published by permission of the Kyrghyz Scientific and Research Institute for Irrigation (KSRII) and the University of Dhaka Department of Geology (UoD). The authors would like to thank BGS-KSRII-UoD project team staff B É Ó Dochartaigh, J Cunningham, E J Nemaltseva , I. Podubnaia, A Ali Seddique and M K Hasan.

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