Groundwater ethics for its sustainability

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With rapid growth in population, urbanization, industrialization and competition for economic development, groundwater resource has become vulnerable to depletion and degradation. Management of this valuable resource is determined by its accessibility and utilisability in terms of quantity and quality. Due to imbalance between demand and availability, management approaches are facing various ethical dilemmas. For an effective, efficient and sustainable groundwater resources development and management, the planners and decision makers have future challenges to assess the inextricable logical linkages between water policies and ethical consideration. In this context, some key issues on groundwater ethics, which are crucial for its protection have been described.

Keywords: Contamination, ethics, groundwater, sustainability.

LESS than 1% of the earth's water is available for human consumption and more than 1.2 billion people still have no access to safe drinking water. Over 50% of the world's population is estimated to be residing in urban areas, and almost 50% of the mega-cities having populations over 10 million are heavily dependent on groundwater, and all are in the developing world. Nearly 40% of global food production is attributed to irrigated abstraction, and 70% of the world groundwater withdrawals are used for irrigation purposes. In India, there are over 20 million private wells, in addition to the government tubewells. While the urban clusters look for low to moderate volumes of high-quality water, rural clusters look for large quantity of high-quality water, in inefficient field distribution and drainage systems. Farmers adopt groundwater irrigation due to apparent reliability of storage offered by mechanized drilling and pumping, and flexibility of groundwater exploitation, but remain indifferent about quality unless the groundwater is saline. Groundwater will continue to be used intensively, in spite of decreasing land area of irrigated production, as a consequence of physical depletion, low-quality water, economic depletion, waterlogging and salinization.

Thus, the large-scale need for food security and urban drinking water supply is dependent on groundwater. On the other hand, domestic use is extended to potable water, personal hygiene use, stock watering and small-scale irrigation for gardening. The dependency becomes acute particularly during summer, when demand of water for different purposes increases dramatically as compared to not so elastic supply position. This grim situation is likely to aggravate further with rapid growth in population, urbanization and industrialization. The availability of this important natural resource has been taken for granted. Increasing groundwater use and pollution generation has crossed the sustainable limits in many parts. The story of each city may be different, but the main reasons for the water crisis are common, such as, increasing demand, zonal disparity in distribution of water supply, lack of ethical framework, inadequate knowledge and resources, major land-use changes, long-term water level declines, increase in salinity and pollution. In order to achieve the goal of sustainable development of water resources, it has to be managed taking into account the environmental as well as economic, social, geographical and political aspects and treat social and practical decisions ethically. Ethics are moral principles and values that govern the actions and decisions of an individual or group. Ethical behaviour comprises of honesty, trust, treating others fairly and loyally. Ethical perception may vary from person to person, among societies and countries. Hence, it has become a matter of concern for the planners and decision makers to search for an alternative approach for water management completely subservient to environmental and ethical considerations.

The issue of water management is multidimensional, related to reliable assessment of available water, its supply and scope for augmentation, distribution, reuse/recycling, its existing depletion, pollution, and its protection from depletion and degradation. However, like surface water resource management, not much concerted efforts have been made for management of the hidden complex underground water resources. The classical hydrological studies on measurements of water table fluctuations and pumping tests do not provide all the necessary information that is needed for finding solution to the problems outlined above. In this context, key ethical issues linked to the resource sustainability have been described, through a case study example of the highly urbanized semi-arid Delhi region[1]. Evaluation is based on the knowledge (although, may not be comprehensive) of the groundwater renewal characteristics, and the processes controlling contamination, obtained by extensive investigations using isotopic methods, in integration with hydro-chemical, environmental and socio-economic information.

Profile of the study area

One tenth of the semi-arid tropics of the world is located in India, occupying almost 1.23×10^6 km^2 (37% of the

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total geographical area), which include Delhi and parts of the surrounding States of Punjab, Haryana, Uttar Pradesh and Rajasthan[2]. The population in the National Capital Region (area: 30,242 km^2), covering Delhi and parts of Haryana, Uttar Pradesh and Rajasthan, increased from 10.58 million in 1961 to 37.03 million in 2001. In Delhi and parts of Haryana and Uttar Pradesh, population density (persons km^{-2}) increased from 6352, 475 and 430 in 1991 to about 9103, 600 and 500 in 2001 respectively, with more and more people flocking the city, driven out of home by poverty and unemployment. In Delhi, the number of small and medium scale industrial units increased from 26,000 in 1971 to 1,37,000 during 1999, and during 1990–1997, quantity of solid waste almost doubled to 5500×10^3 kg/d[1]. The municipal sector discharges about $1.99 \times 10^6\ m^3\ d^{-1}$ of wastewater and industrial sector $0.32 \times 10^6\ m^3\ d^{-1}$. About 3948×10^3 kg d^{-1} solid wastes are produced in the UP, Haryana and Rajasthan parts of the NCR. The region experiences erratic spatial and temporal distribution of annual rainfall (average: 500–1000 mm), periodic droughts, and 30–40°C mean maximum temperature during summer (March–May), which falls by 5–10°C with the onset of monsoon period (June–September).

The region's economy is mostly based on agricultural activities, the largest abstractor of groundwater, and is generally the highest volume user, with changes in cropping systems to raise cash crops, and competition for economic development. In the NCR (except Delhi, where urbanization is more prominent), the agricultural land and cultivated area increased[3] from 50–60% in 1986, to 80–87% in 1999. In Delhi, the net irrigated area and canal-irrigated area also show a downward trend during the last decade. However, tubewell irrigated area clearly indicate an upward trend, mainly due to irregularity of canal water supply, suggesting more dependency on groundwater. Groundwater development is about 106% in Delhi, 94% in Punjab, 84% in Haryana, 60% in Uttar Pradesh, 41–51% in the western states, 17–30% in the central states, and 24–60% in the southern states[4]. In Punjab, number of tubewells increased from 0.192 million in 1970–1971 to 0.896 million in 1996–1997.

The river Yamuna, the only major source of surface water (with an annual flow of 10000 m^3 and usage of 4400 m^3), does not have always enough water to meet the requirements of Delhi and its surrounding areas, in the 25 km stretch along Delhi, and has turned into a polluted drain, contaminated with faecal, garbage and toxic effluent. Because of the surface water pollution and inadequate water supply, people are overusing the groundwater in both organized and unorganized sectors. Drinking water, processed and treated by the State Government, is consumed by less than 30% of the city's 15 million inhabitants. There are areas which get 650 litre per capita per day, while some other areas receive as little as 25 lpc/day[1]. The upper- and middle-income groups implement a variety of personal solutions to access, and ensure safe drinking water for themselves. These solutions range from sinking deep tube wells into their own backyard, through buying and installing small technique water failure gadgets to potable mineral and catapulted water, putting individual overhead tanks of 200–500 litre capacity. In fact, in Delhi region, most low-income settlements, which account for between 60 and 70% of the population, is plagued by water and sanitation crisis. They lack proper infrastructure, civic amenities and social income generation opportunities.

Consequences of growth of human activities

Unbalanced recharge and decline in water table – Availability problems

In Delhi area, occurrence of moderately to highly saline groundwater in more than 60% of the area suggests that the groundwater flushing is incomplete[5]. Due to excessive concretization of land surface, contemporary recharge is very limited and ranges from <5 to 30%, with most parts receiving negligible to <5% recharge[5]. Extensive urbanization induced changes in landuse have caused compaction of the top sub-soil and significant decrease in exposed land area for direct infiltration of rainfall[6], resulting in differences in recharge from location to location. The average recharge from rainfall has been reported to be 18% in Punjab, 15% in Haryana, 20% in western Uttar Pradesh and 1–14% in Rajasthan[6]. Groundwater recharge from rainfall varies widely from region to region and within the parts of a region, depending on the frequency, intensity and distribution of rainfall, evaporation, soil clay content and landuse. The isotope signatures of Delhi rainfall ($\delta^{18}O$: –15.3 to +8.0‰ and δD: –120 to +55.0‰) indicate depleted ^{18}O generally associated with heavy rainfall, and groundwater recharge show a selection effect in favour of isotopically depleted rainfall, with a wide range of variations in the ^{18}O signatures of groundwater ($\delta^{18}O$: –2.8 to –8.6‰), both laterally and vertically[5,6]. This suggests occurrence of an inhomogeneous and stratified system. In comparison to direct recharge from rainfall, lateral flow from surrounding areas, canal/river seepage and localized infiltration of isotopically enriched and highly degraded agricultural and urban surface run-off through stagnant water pools and depression focused, are the main contributors to the recharge.

Groundwater development being primarily through individual farmers or farmers cooperative, owing to various subsidy programmes and credit facilities from financial institutions, 59% of the blocks in Punjab, 47% in Haryana, 24% in Rajasthan are over-exploited[4]. Against a critical level of 85%, there are blocks in Punjab, Haryana and Rajasthan, where over-abstraction is 100–260%. In Delhi area, annual recharge being very small, as compared to the total groundwater withdrawal, water table declined by 2–8 m in different parts during the last decade and 2–

20 m during 1960–2000 (refs 1, 5). During June, 1979 to June, 1997, water table declined by 3–5 m in 77% area of the Punjab state. Increase in cropping intensity and replacement of less water consuming crops with more water requiring crops yielding better economic return has resulted in more water demand[4,6]. During the last decade, groundwater table declined by 0.2–3.0 m in Uttar Pradesh, 3–8 m in Haryana, and 7–10 m in Rajasthan. In different blocks of the northwestern Uttar Pradesh, during 1977–1996, water table declined from 1 m to 10 m. In Gujarat, decline in the groundwater table increased from 1 m yr^{-1} in 1970 to 2–8 m yr^{-1} in 1997 (ref. 4). The practice of sale of water, either in cash or on crop sharing basis has also encouraged rich farmers constructing deep tubewells and over-pumping the groundwater.

These influences decreased productivity of wells, increased pumping cost, energy requirement (additional 0.13 kWh per unit decline in water table), seepage losses from canals/rivers and intermixing of contaminated groundwater with fresh water[4,7]. Under pricing of groundwater (through subsidized power) has also resulted in social implications like inter-personal spatial inequalities in access to the resource, and inter-regenerational inequity implied by the depleting reserves[8]. Farmers with large land holdings and better access to credit, have tendency to tap groundwater at subsidized rates and sell it at higher price to small landholders.

Groundwater contamination

The groundwater in different parts of Delhi area is severely affected and has also become considerably vulnerable to pollution with a wide range of contaminants, such as fluoride (<1–16.0 mg l^{-1}) and nitrate (<20–1600 mg l^{-1})[9,10]. During the last decade, fluoride and nitrate levels in groundwater increased by 2–6 times. Due to public ignorance to environmental considerations and lack of provisional basic social services, indiscriminate disposal of increasing anthropogenic wastes on land, into river and unlined drains, and unplanned application of agro-chemicals and improperly treated sewage water continued, resulting in excessive accumulation of pollutants on the land surface[1]. Sub-surface leaching of contaminants from landfills as well as seepage from canals/river and drains caused severe degradation of the groundwater, at many places, exceeding the WHO prescribed maximum permissible limits in drinking water. In Punjab and Haryana, groundwater nitrate level ranges from <25 mg l^{-1} to 1800 mg l^{-1}, and fluoride level 1.5–45.8 mg l^{-1}. Highly skewed distribution and wide range of fluoride and nitrate suggest contamination from both point and non-point sources. In the absence of known major geological source of fluoride and nitrate in the NCR, excessive application of agri-chemicals and discharges from steel, aluminum, brick and tile industries, barn-yard and silo wastes, and disposal of crop residues is major causes of pollution[9,10].

Trace to excessive amounts of heavy metals, such as, Zn (3–41 μg/l), Cu (5–182 μg/l), Fe (279–1067 μg/l), Mn (<1–76 μg/l), Pb (31–622 μg/l), Ni (<1–105 μg/l) and Cd (<1–202 μg/l) is found mostly in the groundwater at some places of Delhi near industrial sites[11], Haryana and Uttar Pradesh. Increase in ^{18}O isotope with contaminants contents in groundwater indicates that slow infiltration of agricultural and urban surface run-off, carrying along with pollutants present in agro-chemicals and wastes generated by human activities, causes contamination[9,10]. Adsorption/dispersion processes in the soil zone, degrees of evaporation/recharge and lateral inter-mixing of groundwater determine the level of contaminants in groundwater. Over-exploitation induced changes in hydraulic head causes intermixing of contaminated groundwater with fresh water along specific flow-pathways[7], increasing lateral extension of contaminated groundwater and decrease in the available fresh water potential. Obviously, limit of vulnerability to depletion has reached. Based on the distribution of ^{18}O and Cl in groundwater, three different flow systems seem to exist vertically: (i) Uppermost local flow, rapidly circulating, low salinity, more vulnerable to overexploitation and least vulnerable to salinization, (ii) Relatively slow circulating intermediate zone and more vulnerable to salinization and depletion, and (iii) Deeper, highly saline, stagnant pockets of regional system, most vulnerable to salinization and least vulnerable to depletion[7].

Concepts of groundwater management

The aggregate impact of millions of individual pumping decisions, and of emerging groundwater problems, the hydrogeological, social, economic, cultural and political factors can vary greatly at local or regional scales, and no single template for management can be developed. The two generally acceptable approaches are: (i) Optimal yield, which allows for the deliberate short-term controlled use of storage between recharge events, and (ii) Controlled over exploitation, which recognize that some permanent depletion in storage may be necessary to promote socio-economic development where recharge is very limited, whilst for example, water conservation measures are introduced. The management options of groundwater in urban areas are generally based on the patterns of groundwater use, and the responsibility remains largely with municipal supply utilities, as well as with individuals. While, rural users generally abstract groundwater themselves through wells that they own and control. However, large-scale, publicly funded tubewell development tend to be supply driven; legal and regulatory provisions at national level cannot be policed adequately; and, enhancement of indirect recharge may work for shallow groundwater circulation, but recovery of deeper systems requires sophisticated injection and alternative sources of high-quality water[12].

From among these characteristics, two broad types of management approaches for groundwater emerge: (i) approaches encompassing tools such as power pricing, subsidies for efficient technologies, economic policies that discourage water intensive crops, etc. and (ii) approaches dealing with specific aquifers on the basis of command and control management through a resource regulator. Whichever approach is adopted, the development and management of these resources must be based on an adequate knowledge of a clear aggregate status/situation of groundwater aquifer system and its replenishment. In the context of the impact of climate variability and spatial variability in drought, two major gaps in groundwater management emerge, with significant implications for sustainable development[13]: (i) inability to cope with the acceleration of degradation of groundwater systems by over-abstraction, and effective resource depletion through quality changes (pollution, salinity), and (ii) failure to resolve competition for groundwater and aquifer services between sectoral uses and environmental externalities.

Critical gaps

Groundwater below the land surface being invisible, the common man judges its availability in terms of the depth to groundwater table and quality in terms of colour, odour and taste, and thus determines their land use characteristics. Their demands on land and groundwater and the consequences of these demands have been characterized scarcely. Attention has been paid mostly towards drilling tubewells, rapid rural electrification with subsidized power to agriculture, credit facilities from financial institutions, and creation of many additional landfills[1,4,8]. Groundwater exploitation is regulated mainly through control of borehole drilling or licensing their pumping. Due to absence of any pricing mechanism and strict regulation, indiscriminate groundwater exploitation, its wasteful utilization, and land disposal of wastes continued[1,5]. For example, water tariffs in Delhi area are very low for public supply and the level of subsidy is extremely high (79%) for domestic consumption[1], resulting in low revenue collection.

Some of the important parameters of interest to the planners and managers are recharge ability of groundwater; quantity and quality; location of recharge intake areas; inter-linkage between groundwater and surface water; sources of pollution, etc. However, research on groundwater use in the socioeconomic context being relatively small, the highly technical knowledge of the aquifer systems (presented in the literature) is of relatively little use for practical management purposes. Most of the hydrogeological and groundwater development research has been largely fragmented, technocratic and relates to groundwater flow and remediation. Aquifer systems are known imperfectly, there are no clear solutions of continuity[14], and responses are highly nonlinear in terms of geological heterogeneity. In some places, groundwater is linked to land ownership while in others it is viewed as a 'common property'. Decline in water tables in key grain producing areas of northern India (e.g. in Delhi area, 2–20 m decline[1,5] during 1960–2000, in Uttar Pradesh 0.2–3.0 m and in Haryana 3–8 m decline during the last decade) resulting in adjustment of local agricultural systems, is causing migration from the land and social disruption[15]. The perception and understanding of hydrogeological processes among groundwater users appear to vary considerably[16].

For practical management practices it is important to examine: (i) people's adaptive strategies, when they face with groundwater scarcity problems; and (ii) the policy implications, like drought relief, climate-change response, investment directions, institutional forms, etc. However, no comprehensive analysis related to groundwater has been carried out so far. Some limited information with respect to the impacts of irrigation and poverty is being compiled for an FAO study[17,18]. For valuation of groundwater, key elements that may be necessary to consider are: (i) The strategic value of groundwater located near 'high-value' uses such as urban or prime agricultural areas, as opposed to aquifers located in less strategic locations and (ii) aquifers with high-quality water that is not vulnerable to pollution and the types of uses. Internationally, approaches and methodologies for quantifying the economic value of groundwater resources include[17,18]:

- Estimating the amount that the people would agree to pay to maintain the resource or services dependent on it under carefully specified conditions.
- Assessing the value from differences in the value of lands with and without access to groundwater.
- Evaluating the contribution of water to profits within a set of economic activities, based on demand and production cost analysis.
- Measuring the value of water as equivalent to the total social costs incurred when drought or depletion constrain economic activity.
- Calculating the investments made to avoid water shortage.
- Searching for the least cost alternative source of supply for meeting the same set of services.

Strategies for groundwater protection

Recharge–withdrawal balance and protection of recharge zones

To protect the groundwater from further depletion, water extraction has to be somehow balanced by (what is estimated to be) the recharge, calculated not only on the basis of the intensity and distribution of modern seasonal rainfall but also by improved direct methods. All such estimates should be revised time to time and reconsidered.

Wherever feasible, newer approaches need to be adopted to enhance recharge through low-lying areas, where surface run-off gets collected during high intensity rainfall, instead of allowing the water to stagnate. Legal provisions need to be introduced to restrict indiscriminate withdrawal of groundwater, with emphasis on enhancing water-use-efficiency for various specific purposes. The zones of groundwater recharge need to be clearly identified and revised in relation to landuse changes, in order to restrict or eliminate waste disposal activities in these areas.

Ensuring water for agriculture

The future challenge is appropriate prioritization of water allocation considering the ethical ground, increase irrigation efficiency in an affordable cost, and increase rain fed agriculture productivity. The issue is to decide how much water should be utilized directly for people for domestic use, agriculture and industry and how much to maintain ecosystem. It is therefore necessary to quantify the costs and benefits of allocating water for different use, adapt and improve water productivity, through improvements in crop yields, irrigation efficiency and post-harvest processing. For example, in India, with its nationwide policies governing the support price for rice and wheat, national-level policies could be tailored to reflect regional water availability differences. Thus, there is scope for savings in agricultural water demand by encouraging production of water intensive and less water intensive crops in areas with different comparative advantages. This may make possible the use of more effective approaches such as –

- Encourage the non-sensitive groundwater users to switch from exploitation of high quality aquifer to bad quality groundwater for major groundwater use.
- Restrict withdrawal of abstraction rights from industries that have not installed water-efficient technologies.
- Provide subsidies for improving the efficiency of irrigation water use in peri-urban areas in exchange for groundwater abstraction rights.

Suggested use of contaminated groundwater

Because the use of such groundwater for irrigation is likely to increase with time, the high levels of the contaminant constituents in groundwater should be taken into consideration for recommending the fertilizer nitrogen, sulphur and potassium doses for crops[9,10]. Since the availability of fertilizers is limited, the use of groundwater (with elevated nitrate, sulphur and potassium levels) would minimize the requirement of inorganic fertilizer applications. While the use of these poor quality waters may require only minor modifications for existing irrigation and agronomic practices and strategies in most cases, there may be major changes in the crops grown, the methods of water application and the use of soil amendments[9,10]. The groundwater protection from pollution can be ensured by several other ways, such as:

- Preparing vulnerability maps, based on distribution of travel times, chemical parameters, types of topsoil, sub soil and land use.
- Delineating and prioritizing areas of high ground water vulnerability for main sewerage extension.
- Restricting residential development served by inciting sanitation.
- Locating of landfill facilities to areas of low groundwater vulnerability.
- Restricting the disposal of industrial discharges to the ground in vulnerable areas through introduction of discharge permits and appropriate charging to encourage recycling and reduction.

Concluding remarks

Over a period of time, the growth of Delhi and its surrounding regional areas, for example, has developed a great deal of mutual dependency with respect to water. Human activities induced consequences, such as, groundwater over-exploitation and its decline, are linked with non-availability of adequate water and its distribution, increase in population density and socio-economic development, associated with public attitude and perception towards environmental issues, the amount of waste generated, changes in settlement pattern and land use. Two types of action are being usually attempted to solve the problem: (i) promoting action to make more freshwater available and depleting demand, and (ii) protecting groundwater reserves and preventing further degradation by contamination. Sustainability of long-term water use is compatible with limited depletion of aquifer reserves only in the short term. Choice lies between merely tapping an often-minimal renewable resource or exploiting a more plentiful non-renewable resource until it is exhausted. However, there is no single way to evaluate the maximum exploitable volume in advance or in absolute terms. Research is needed to recognize these inextricable linkages, especially aggressive to depletion and degradation.

The overview suggests that the standard management approaches depend heavily on the presence of basic data and on institutional capacities for regulation, scientific research, etc. In most of the regions, even order-of-magnitude estimates for extraction, recharge, evapo-transpiration, etc. are not available. More field research is needed on responses and dynamics of pollutants in the groundwater flow, aquifer's attenuation capacity for contaminants under natural and exploited conditions, based on well-designed regular monitoring network. It is necessary to bridge many gaps to collect data on generating, refining and monitoring the hydrological, hydrochemical, bio-hydrological parameters, with changes in landuse pattern around major catchment areas. Crop or cropping sequences with lesser evapotranspiration and better nutrient use efficiency and improved method of irrigation and agronomic practices should be preferred in areas affected by falling water table[1,5,6,14,15] and contamination[7,9–11].

It is imperative to link groundwater resource management with changing use, to harmonize medium and long-term actions and to restrict or eliminate waste disposal activities and unplanned agro-chemicals application in the potential groundwater recharge zones. The users need should be categorized in two groups: (1) where consumptive use is a high percentage of the total water demand (e.g., irrigation) and (2) where this ratio is almost negligible (practically all other water users). With these distinctions, new principles in groundwater resource assessment have to be developed, based on detailed scientific information. Case studies should be carried out on: (1) groundwater management failure; (2) specific socio-economic impacts resulting from over-abstraction and pollution; (3) pattern of competition among water users (private and public); between irrigated agriculture and urban water supplies, between communities located at recharge and discharge areas; and competition over trans-boundary aquifers (in terms of exploitation and pollution).

To restrict wasteful use, economic principles should be applied to the allocation of water. For effectiveness, development effort must have the competent, capable and transparent institutions. Corrupt and unscrupulous practices, working hand-in-hand with greedy investors, should not put private gain before the welfare of citizens and the economic development. Strong anti-corruption rules and regulation have to be enforced. Although the suggested alternative approaches appear feasible in principle, implementation of such proposals is likely to face several financial, technical and legal difficulties, with respect to the jurisdiction of different agencies. The benefits from the suggested approaches can be assessed only after the system has worked efficiently for a few years. By the time these proposals are put into operation, the pressure on groundwater is likely to increase further. Enhancement in water availability and safe water supply will be guided by the policies, plans and technologies at our disposal, in addition to political, socio-economical, biological and other factors. Choices based on the best obtainable detailed scientific information, guided by ethical considerations, offer the best hope to protect groundwater from depletion and pollution.

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