Allocation and Pricing Policy for Groundwater Resources

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Abstract: Availability of water critically determined the emergence of life, and its sustenance depends largely on uninterrupted and adequate supply of water. Lack of water leads to serious conflicts among individuals and groups but could cause even the Third World War when nationalities are involved. Hence allocation and pricing policy for water (and especially the ground water component) deserves serious thoughts and very careful considerations to take wise decisions for long-term benefits of mankind.

Ground water forms a major source of fresh water in the deserts, dry lands and especially in summer seasons when surface waters either dries up or is unavailable. It is Nature's gift to mankind for emergency storage, and supply at times of acute necessity. Nature of conflicts for groundwater ownership, development and supply are vastly different in urban and rural contexts. In urban areas it could be ownership, allocations for municipal versus industrial uses and pricings, whereas in rural areas it could be ownership, development and supply for municipal versus agriculture as well as supply to water-intensive croppings and its pricing policies, small versus large farmers and their demand etc. Obviously ground water is most valuable resource for mankind to sustain life, and hence, adequate conservation measures must be planned including water harvesting, water recharging, recycling of wastewater, drip farming etc. Groundwater management is a complex, dynamic, and nonlinear process, which should adapt to nature of problems/conflicts, and risks/gains involved; and optimal solutions are often site or time specific rather than fixed. Since groundwater data are often linguistic, imprecise, inaccurate and uncertain, optimal solutions can be attained through use of latest technology of soft computing based on fuzzy logic, neural networks and stochastic (probabilistic) reasonings in order to ensure greater economic growths and better quality of life. Optimal decisions should be risk-effective allocations for greater productivity and long-term growth potential. Pricing policy should include factors like ownership issues, supply versus demand, and cost effective with built-in incentives for conservative use of groundwater.

INTRODUCTION

Water forms an integral part of the ecosystem and plays an important role in the socio-economic development of the country. It is a natural resource whose quantity and quality determine its utilization in social and economic activity. It is well known that the availability of water entirely determined the emergence of life on earth and developed its sustainable ecology. Existence of life depends largely on uninterrupted and adequate supply of good quality water among other needs such as air, food, shelter etc. Lack of water would not only lead to serious conflicts among individuals and social groups but could even result in Third World War when nationalities are involved. Presently, ground water meets nearly 85%, 55%, and over 50% of the freshwater requirements for domestic, irrigation, industrial cum urban uses in India. Therefore, allocation and pricing policy for fresh water (especially the groundwater component) deserves serious and very careful considerations in order to take wise and sustainable decisions for the long-term benefit of the society and mankind.

Ground water is Nature's gift to mankind for emergency storage of good quality water and for supply at times of acute necessity such as summers and drought periods. It forms a major source of fresh water in the deserts, dry lands, and semi-arid regions especially when surface water is either unavailable or dried out. It is locally available, remains fresh (good quality), easy to tap, and can be drawn on demand. However, these advantages should be properly maintained through avoidance of over pumping, and by recharging with pollution-free (Fetter, 1993) clean water. Obviously, conservation of valuable groundwater resource is a must, especially through water harvesting, recharging and recycling of waste water, drip farming etc. Nature of conflicts regarding the ownership, development and supply of ground water are site specific and are vastly different in urban and rural contexts. In urban set up, these could be ownership and allocation for domestic, municipal, and industrial uses as well as for pricing. In rural set up, these could be ownership, development or supply of domestic versus agriculture, supply to normal versus water-intensive cropping or to small versus large farmers, and to cooperative farmers as well as to regarding pricing policies. Conflicts would arise both in urban and rural areas regarding proper implementation of water conservation measures mentioned in the previous paragraph. Groundwater management is a very complex, dynamic and nonlinear process, which should be solved scientifically by carefully considering (i) restoration of natural equilibrium of hydrologic cycle (Bear, 1972) and ecology, (ii) nature of problems and conflicts, (iii) risks versus gains for different decisions/objectives, and (iv) optimal pricing policy to prevent ecological damage. It may be mentioned that optimal solutions are often site- and time-specific and stochastic (dynamic) in nature rather than static (fixed). Since most geological, hydrological, and groundwater data are often soft, qualitative, sparse, imprecise, inaccurate, uncertain and linguistic; optimal solutions will not be feasible through using routinely available multiple-objective optimization softwares in the market that are applicable only to hard data sets. Sustainable and optimal solutions should account for groundwater system behaviour as to quantity and quality of resource, safe yield, annual recharge and integration of surface and groundwater development. It is suggested that optimal and sustainable solutions could be obtained by using latest technology (Yen and Langari, 1999) of soft computing (Jang et al., 1997) based on fuzzy logic (FL) (Klir and Yuan, 1997), neural networks (nonlinear)(NN) (Bose et al., 1996), genetic algorithms (GA: global maximum) (Goldberg, 1989) or probabilistic (stochastic) reasoning (dynamic). This would result in sustainable decisions for better quality of life and for ensuring greater rate of economic growth.

CHARACTERISTICS OF GROUNDWATER RESOURCE

Ground water occurs in continents and is an important part of natural hydrological cycle consisting of precipitation, evapotranspiration, runoff, infiltration and subsurface flow. Based on its quality, it is used for drinking, domestic, irrigation, and industrial purposes. Current freshwater demand of 5000 km^3/yr with a world population of six billion yields an average renewable freshwater discharge from continents exceeds the demand with a value of 45,000 km^3/yr. However this is not a happy situation since quality of discharge is not good and 9 m^3 of discharge yields 1 m^3 of drinking water. In addition, 3 m^3 of water is required to maintain ecology of natural hydrological cycle. Thus, our ecosystem and we are now close to the limits of freshwater availability from water-quality requirements and standards. Moreover, since the horizontal (spatial) distribution of freshwater (and groundwater) is uneven, large declines in river discharge and groundwater tables are very common. This has led to increasingly distant water sources for its procurement, much water scarcity and consequent diseases from use of polluted waters. In India, 30% of discharge is already used and this could be a limiting factor for our economy especially from a global economic development/growth viewpoint.

Table 1. Groundwater flow and transport problems with their soft computing solutions

Inputs Available	*Outputs Required*
(i) Geology (soft) (ii) Remote sensing (soft to hard) (iii) Ground water (soft to hard) (iv) Geophysics (hard) resistivity profiles/logs, synthetic well logs, wavelet studies, seismic (hard) (v) Core studies/logs (hard) in production stages	(a) Exploration Stage • Total thickness of aquifer, water column, total contaminants. • Aquifer stage: interconnected or not. • Φ, k, Kt, Ws, S_y, etc. • Confidence intervals of above aquifer parameters. • Optimal well sites for target drilling.
(vi) Water production (hard) in test wells, producing wells, pressure decline curves (vii) Soft computing (SC) 1. NN, supervised $y_i(x) = E\omega f_i(x)$ $f_i = RB f_n$ 2. FL: Location interval, linear estimation (minimum, maximum) Fuzzy linear estimation (minimum, maximum, mode) 3. GA 4. Monte Carlo simulation	(b) Development and Production Stages • Effective Φ, k, Kt, Ws, S_y • Pressure (head) decline rates • Correlation of core analysis with well logs and resistivity/seismic data. • Targets for artificial recharge and methodology to be adopted if any. • Contaminants, remediations, measures and targets.

So far, water management strategies or practices focused in local scales such as flood protection, water quality, and water supply assuming rates of the components of water cycle were non-varying constants. This ignored maintenance of equilibrium in the ecosystem and sustainability. However, in the 21st century we are faced with accelerated rates of water consumption due to global change because of rapid urbanization, increased agricultural production and industrialization, that result in severe ecological damage. Triggering forces for these new challenges are economic globalization, population growth, awareness for the welfare of the common man, warming due to Quaternary glaciations etc. Success can be achieved by taking an integrative Earth System Sciences approach to these problems, including those of groundwater problems.

Global changes are highly complex, dynamic, evolving and nonlinear processes whose magnitudes and distributions are mostly unknown. Large scale integration of all the components of hydrological cycle such as distributions and intensities of precipitation in continents, groundwater storage in continental ecosystems, global climate and sea level changes, would be required to yield realistic models and forecasts for quantity and quality of ground water at the required sites and times. This challenging work can be achieved by making groundwater hydrology more integrative and interdisciplinary than hitherto. We should study, analyze and learn much from the historical (time series) impacts of global climatic changes (Issar, 2003) on hydrological regime of different regions. We have learnt that in regions of summer monsoons (as in India), global cold periods were characteristically dry and prone to famines, while global warm periods were of high precipitation with occasional catastrophic floods. Since we are now passing through a global warming period after the Little Ice Age (one million years ago), it is expected that warm and humid climate would continue for a long period of time in India and bring prosperity in the fields of agriculture, industry, and economy. However, the associated occasional flash and dangerous floods should be remediated and the excess runoff should be allowed to infiltrate so as to augment our depleting groundwater resources. Ground water is Nature's gift to mankind for emergency storage and supply of freshwater of good quality at times of acute scarcity and necessity. Conservation of this precious commodity (both as regards quality and quantity) is a must and all concerned must cooperate in this venture. This is absolutely necessary in order to maintain the natural equilibrium of the environment and ecology at the pre-existing levels and thereby bringing the desired sustainable social and economic prosperity of India.

CONFLICTING ISSUES

Conflicts among individuals, social groups, nations as regards water or groundwater use arise whenever there is a shortage or temporary shortage of its supply or if water quality is below the expected standards. Conflicts should be resolved in time and to the satisfaction of all the concerned parties, otherwise it could lead to dangerous situations (even possibly Third World War). However, human society till date have shown great resilience and most conflicts have been amicably resolved including those for the past two World Wars and Cold War. Therefore, groundwater conflicts, mostly local or at best regional, should be resolvable. However, the nature of conflicts is vastly different in an urban set-up as compared to a rural set-up. But, trans-boundary conflicts for groundwater development and utilization exists and perhaps may not be that serious.

In urban areas conflicts could arise because of

(i) ownership of individual, groups, industrial users.
(ii) allocations for domestic, municipal and industrial purposes.
(iii) conservation measures and pollution control that are required for domestic and industrial purposes.

In rural areas conflicts could arise due to

(i) ownerships of individual, co-op groups, industrial users.
(ii) allocation for domestic, municipal, agricultural and industrial purposes.
(iii) water allocation for normal vs water intensive cropping; small versus large farmers and crop irrigation societies.
(iv) conservation measures and pollution control required of all users.

Obviously, most conflicts can be easily resolved, if we have adequate groundwater resources of good quality and many different aquifers at a given site. However, this ideal situation may not exist, and strict monitoring of groundwater supply with proper allocations, pricing and pollution control measures must be implemented.

GROUNDWATER MANAGEMENT

This includes both scientific as well as socio-economic management. It is a complex, dynamic, stochastic and nonlinear system, comprising aquifers as well as domestic, industrial, and agricultural users. Key concept is to maximize profits (or minimize costs) at spatial and/or time points by using dynamic stochastic optimization programmes. Groundwater modelling is most important for assessment of resource potential of the aquifers and for prediction of future impact under different forcing. Linear and nonlinear seasonal time series models could be obtained by use of classical univariate/multivariate stochastic methods (Sahu, 2002, 2003b) with inputs from hydrological, geological, soils, and watershed data. Accepted model must be validated with independent data set before predictions are made and used for management decisions. However, classical technologies using hard data for deterministic or artificial intelligence (AI; Russell and Norvig, 1995) are deficient/imprecise as crisp sets (0/1) in the probability space (0-1) are utilized. Unfortunately, geological and hydrological data are mostly soft linguistic, and imprecise for which fuzzy sets in possibility space (0 to < 1) forms a more realistic model. Soft computing technologies use both soft and hard data (Sahu, 2003b, 2006) and utilize fuzzy logic (FL; Klir and Yuan, 1995, Yen and Langari, 1999, Bogardi et al., 2004) for imprecision, neural networks (NN; Bose and Liang, 1996) for non-linearities, genetic (evolutionary) algorithm (GA, Goldberg, 1989) for global optimization and probabilistic (stochastic) reasonings (Sahu, 2003b, Zhang, 2002) for uncertainties, wavelets (for local stationarity) in order to obtain faster and better results. Soft computing is highly versatile, interactive, scale independent and precise for realistic solutions to varying complex geological and computing situations which require dynamic optimization/continuous updating to take quick, and online managerial decisions. More details on soft computing application to groundwater modelling for exploration, development, and exploitation are given by Sahu (2006), and for oil reservoirs by Sahu (2003b), (also see texts by Jang (et al., 1997) and Sahu (2003a, 2005)). Optimal soft computing solutions to an aquifer flow and transport problems at different stages of groundwater exploitation are included in Table 1. A hybrid soft computing system including NN, FL and GA could model and predict more precisely the groundwater resource and flow parameters for undertaking optimal decisions in regard to production, supply, recharge and pollution control on demand and with (online) updates as required for managerial decisions.

PRICING POLICY

Pricing for groundwater supply should not only include the costs of exploration, and exploitation, maintenance of supply and purification systems but also risks for pollution (Fetter, 1993) and recharge etc. Usual present day water pricing includes only the first part of the two costs as mentioned above, and hence is not sustainable as the present price is transient and dynamic. The true value of groundwater supply should also include costs of removing pollutants in runoffs, wastewater, and industrial discharge water but cover the risks to the present and future societies of human beings. Thus, environmental or ecological costs of pollution could be many fold (at least 2 to 3 times) the present price of water supply.

It is well known that the trace elemental fractional concentration of pollutant elements/components are log-normally distributed (Sahu, 2005). Therefore, logarithm of fractional concentrations of pollutants in water sample would have Gaussian distribution from which statistics can be computed and various statistical hypotheses as desired, could be tested. Concentrations of pollutants above the WHO safe limits and/or above the natural ecological average are harmful. Hence, we should perform one-tailed t-tests at the 5% or 1% levels for detecting any significant pollution effects (Sahu, 2005). In case the original fractional concentration of pollutant is needed, the antilog of log-mean and log-standard deviation is computed to give geometric mean and geometric standard deviation of the pollutant distribution. If the concentration is above WHO safe limit, then remediation measures must be undertaken till natural average below WHO safe limit is obtained. Polluter must pay for all remediation costs as well as for the risks to current and future societies. Authorities should make a cost-effective pricing (2 to 3 times of present costs) with built-in incentives for groundwater conservation measures such as water harvesting, rainwater and used water recycling, recharging to ground water, drip farming etc. However, we also require active cooperation and participation of all concerned (both authorities and users) to make farsighted sustainable decisions. This requires serious efforts to bring in awareness among rural and urban users to conserve ground water as well as to bring in the required social and institutional changes to implement the suggested water conservation measures.

CONCLUSIONS

Sustainable groundwater management through optimal allocation and pricing policy is a dynamic (time-varying) and site-specific practice which avoids irreversible or quasi-irreversible damage to groundwater and other natural resources linked to it such as surface water, soils, ecosystems as well as the social environment. This helps to conserve its ability to provide its services to all the users and conservation of the present fragile ecology. It is well known that though the environmental disturbances, affect the natural ecosystem with considerable delays, environment (ecology) unfortunately has a long-term memory and cannot get back its natural equilibrium as quickly as we desire for long-term sustainability. Population explosion, rapid urbanization, intensive cultivation, and industrialization, as well as poverty in considerable proportion of the world population, may cause depletion and pollution of groundwater resources, which must be avoided at all costs. While science and technology (soft computing) can possibly give optimal decision supports, the actual decisions for or against sustainability are normally made in the political arena. Here, it is very important that scientific and technological decisions are correctly and forcefully presented at the appropriate forum by the scientific-bureaucracy, so that better and optimal decisions regarding groundwater allocation and pricing are accepted and adopted at the national level.

REFERENCES

Bear, J. (1972). Dynamics of fluids in porous media. Elsevier, N.Y.

Bogardi, I., Bardossy, A. et al. (2004). Fuzzy logic in Hydrology and water resources (pp. 153-190) *In:* (eds Demicco, R.V. and Klir, G.J.), Fuzzy Logic in Geology. Elsevier (Acad. Press), Amsterdam.

Bose, N.K. and Liang, P. (1996). Neural Network. Macmillan, N.Y.

Fetter, C.N. (1993). Contaminant Hydrology, Macmillan, N.Y.

Goldberg, E.D. (1989). Genetic Algorithms. Addison Wesley, Reading, MA.

Issar, A.S. (2003). Climate change in Holocene and its importance in Hydrological Systems. Cambridge University Press, UK.

Jang, J.S.R., Sun, C.T. and Mizutani, E. (1997). Neruo-fuzzy and soft computing. Prentice-Hall, New Jersey.

Klir, G.J. and Yuan, B. (1995). Fuzzy sets and fuzzy logic. Prentice-Hall, New Jersey.

Russell, S. and Norvig, P. (1995). Artificial intelligence. Thompson.Edu., N.Y.

Sahu, B.K. (2002). Groundwater modeling in hard rock terrains. *In:* Proc. International Conf. Groundwater, Dindigul, India, Oxford & IBH, New Delhi, pp. 437-442.

Sahu, B.K. (2003a). Time series Modeling Earth Sciences. A.A. Balkema, Lisse, Netherlands.

Sahu, B.K. (2003b). Methodologies for reservoir modelling: A comparison. *SGAT, Bull.*, **4:** 1-32.

Sahu, B.K. (2005). Statistical models in earth sciences. B.S. Publications, Hyderabad, India.

Sahu, B.K. (2006). Groundwater modeling in hard rock terrains. *In:* (eds N.C. Ghosh and K.D. Sharma), Groundwater modeling and management. Capital Publ. Co. New Delhi.

Yen, J. and Langari, R. (1999). Fuzzy Logic. Pearson Edu. N.Y.

Zhang, D. (2002). Stochastic methods for flow in porous media. Academic Press, San Diego.