the conditions. One is that groundwater recharging mechanisms like percolation tanks would enhance the availability of water (supply side adjustment). Another is shifting the cropping pattern towards less water intensive crops (demand side adjustment). It may be noted here, that contrary to the popular belief, there are crops like mulberry, grapes, citrus, etc, which are as renumerative as sugarcane and have lower water requirements, but they have marketing and/or processing requirements (Vincent, 1989)[5]. Moreover, some of these crops are suitably adopted to the conditions of these regions. Therefore, more concerted efforts are required on the part extension service department in order to educate farmers on various alternatives available for them within the given resource constraints. And, the role of non-governmental organisations (NGOs) in this regard would be vital.

REFERENCES

Shah, T. (1990) Sustainable Development of Groundwater Resources: Lessons from Amrapur and Husseinabad Villages, India, *ODI-IJMI Irrigation Management Network Paper 9013d,* Overseas Development Institute, London.

Vincent, L. (1989) Assessing and Developing Irrigation Potential from Groundwater in Low Rainfall and Hardrock Areas: Case Studies from Andhra Pradesh State, paper presented at the workshop on Groundwater use and Management in Low Rainfall Hard Rock Areas, 4-6 October 1989, Water Technology Centre, Tamil Nadu Agricultural University, Coimbatore, India.

[5] *These crops also have high cultivation costs, and thus can only be grown by farmers with available capital, and the tenure security to produce tree crops. With good water supply, groundnuts, vegetables and fodder can be profitable (although at a lower level than fruit crops or sugarcane): they have lower cultivation costs and are less demanding on operational budgets. With unreliable irrigation, net returns are low on most crops, and fanners will not risk extensive use of inputs. Editor.*

GROUNDWATER DEVELOPMENT AND DEPLETION: PROSPECTS AND PROBLEMS IN A POCKET AREA OF BANGLADESH[1]

M S U Talukder, M Ahmed, and M A Mojid
The authors are Professor, Associate Professor and Lecturer, respectively, in Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Bangladesh is mostly underlain by unconsolidated to poorly consolidated thick sediments. In addition, the tropical monsoon climate characterised by high temperature, heavy rainfall and often excessive humidity is very favourable for extensive development of groundwater resources in the country. Groundwater, a renewable natural resource, is observed in Bangladesh to be in dynamic equilibrium consistent with the extraction by natural and artificial means and recharge from rainfall, flood waters and surface water bodies. Different techniques and concepts for the development of groundwater are being practised without detailed investigation of the resources and its overall management policy. For example, the groundwater development programme using deep tubewells (DTWs) started in the country in late sixties. But tubewells were installed initially almost without evaluating the hydrogeologic characteristics and development potentialities of the local aquifers. There are important factors in determining the amount and cost of groundwater that can be developed and in forecasting the consequences of development.

The groundwater development programme in Bangladesh has been suffering due to various reasons, of which insufficient hydrogeological data, poor and widely variable estimates of potential recharge and improper matching of well numbers and types to the identified groundwater resources are all very important. Although many authors have called for better planning (Rust, 1983; Haque, 1984; Radosevich 1983), little attention has been given to the after-effects of heavy groundwater withdrawal and consequently many alarming situations have been anticipated (Khan, 1988). Often individual events are extrapolated without scientific foundation. For example, reactions began when in Bogra, Jamalpur, Pabna and Chittagong (four

[1] A full version of this paper, complete with hydrological data, is available from the authors.

districts of the country) groundwater level failed to return to the previous year's level at the end of recharge period (Bhuiyan, 1983). In Joydebpur (an *upazila)* region, the groundwater levels dropped 15 m below suction pump capacity during dry season and it was estimated that the groundwater table might go 50 m below the pump capacity at the end of this century (Anik, 1984). At the same time, due to depletion of groundwater level the moisture content in the top layer of the soil diminished causing the land to become dry and sandy. If this trend continued without control, then certain parts of the country, especially the northern part could become deserts in the long run (Anik, 1984). Heavy pumping of groundwater in the northern part of Bangladesh exhausted soil moisture within the upper shallow aquifer affecting agricultural crops, many fruit and deep rooted trees and thus upsetting the natural econological balance (Khan, 1988).

However, many researchers did not agree with these predictions. It was observed that the highest and lowest static groundwater level at some locations in the northwestern part of Bangladesh (Rajshahi Barind area) came nearer the ground surface during 1987 after installing many deep and shallow tubewells, than during 1965-66 when there were no tubewells (Asaduzzaman, 1987). Asaduzzaman also reported that all types of trees and vegetation that grew in the area before installation of tubewells are still growing and no ecological imbalance have been observed.

We have completed a study of the Muktagacha upazila in Mymensingh, using test drillings and pumping tests. We studied monthly data on static water levels in 18 representative deep tubewells over eight years (1983-1990). We also estimated present requirements of groundwater based on total agricultural and domestic activities, made a field survey of existing vegetation in the dry season and interviewed experienced local inhabitants.

The aquifer in question is a single unit, layered with a mixture of fine, medium and coarse sands and sometimes with layers of gravels at the base. The aquifer was of the semi-confined/leaky type and possessed a good potential for development by 56 l/s (litres per second) to 85 l/s capacities deep tubewells. The thick clay layer above the aquifer limited the volume of storage in the upper part that restricted operation of suction lift pumps. The quality of groundwater in the aquifer was within the safe limit for irrigation purposes.

GROUNDWATER POTENTIAL

The overall development of the resources must be based on safe-yield which is actually the useable portion of the total dynamic component of the groundwater available within the zone of water table fluctuation. This component in the study area was essentially the result of the annual rainfall, seepage from surface water bodies and return flow from irrigated fields. The hydrologic safe-yield of the aquifer under study was estimated to be 621 millimetres (194.62 million cubic meters, MCM) for the dry season irrigation period with an allowable fluctuation of static water level of 12.42 meters. In fact, this safe-yield could be significantly increased by creating more recharge facilities through extending irrigation command area by abstracting more groundwater during dry season. The calculated safe-yield would allow water level fluctuation above mean sea level and would not create any possibility of saline water intrusion from coastal areas.

CURRENT UTILISATION STATUS OF GROUNDWATER AND EXTRACTION RATES

The utilisation of groundwater in the study area were being done by deep tubewells, shallow tubewells and hand tubewells. At present, 370 deep tubewells of capacities carrying from 56 l/s to 85 l/s, 50 shallow tubewells of capacities ranging from 14 l/s to 28 l/s and a large number of hand tubewells are operating over the groundwater basin. The amount lost from storage increased from 104.58 MCM in 1983 to 142.88 MCM in 1989, due to increasing extraction by continuous installation of new deep tubewells.

The effect of current rate of extraction was mainly focused on the position of static water level. The static water level started rising during March/April in response to monsoon rainfall, and started falling during September/October of the same year with recession of rainfall. The water table dropped very rapidly when irrigation wells started extracting groundwater. During the year the maximum and minimum depth of static water level from the ground surface in 18 locations were recorded to be 14.29 meters and 1.00 meters, respectively. The dry season water level dropped below suction lift capacity of suction mode pumps eliminating the possibilities of operation of these pumps. The lowest water level progressively declined from year to year due to increased extraction from storage by installing additional deep tubewells every year. However, the lowest values of static water level at the aforesaid locations indicated a fully recharged aquifer *at the end* of the rainy season except in 1989 (because of the severe drought in the same year). The long-term static water level trend also showed that whatever depletion of groundwater level occurred in dry season due to abstraction was completely recharged during the wet season indicating no mining of underground water. The results of this study clearly indicated that the groundwater reserve of the study area was in a stable equilibrium condition for the last 8 years (1983-1990) although a continuous annual withdrawal at an accelerated rate was made. Furthermore, almost in every year, the depleted aquifer was completely recharged from rainfall before the end of rainy season and a part of recharge opportunity time remained unused causing rejection of recharge.

AGRO-ECOLOGICAL EFFECT OF GROUNDWATER EXTRACTION

Attempts were made to evaluate the impact of heavy pumping on the agro-ecology of the study area. The large scale irrigation applied in high yielding variety (HYV) rice and other crops increased atmospheric water vapour and may have reduced temperature and increased the possibility of rainfall. Though static water level dropped beyond the extraction capacity of the roots of many fruit and other trees during the dry months of February to April, there remained sufficient soil moisture within the rootzone of these trees during the rest of the months of the year. The only problem encountered was the non-functioning of hand tubewells during the dry months which made stopped availability of potable water for drinking as well as household purposes. The deep tubewells served the purpose of hand tubewells during this period. The rural-based well-experienced people did not see any harmful effect on the growth of any type of vegetation including large trees, because of groundwater extraction. In some cases they were encouraged to grow some necessary vegetation through having facilities for continuous supply of water during dry months.

We know that the techniques of groundwater evaluation are relatively subjective, and that questions may be asked about the accuracy and reliability of our initial results. We suggest the evaluation studies should be continued for reassessment and refinement until a database is available which is suitable for long-term planning.

The main impact of current levels of development (which are still below the full aquifer potential) has been on shallow watertable conditions in the dry season, and it appears that local people have been able to adapt to these.

However, on-going monitoring is required. We know we are actually still pumping within the safe regional limits of the aquifer, but we must ensure that development stays within this limit.

REFERENCES

Anik. (1984) Irregularities in Irrigation Management, *The Sangbad*, May 27, (a daily newspaper), Bangladesh.

Assaduzzaman, M. (1987) Development and Utilisation of Water Resources in Barind Area, *The Sangbad*, June 8, (a daily newspaper), Bangladesh.

Bhuiyan, S I. (1983) Groundwater Irrigation in Bangladesh: Development at the Cross-Roads, paper presented at the Institute of Engineers, Dhaka, Bangladesh.

Chowdhury, A K M J U. and Bhuiyan, S I. (1977) An Inflow-Outflow System Analyses for Evaluating the Groundwater Potential of Mymensingh and Tangail Area, paper presented at the Second Annual Conference of Bangladesh Association for the Advancement of Science (BAAS), BAU, 23-27 January.

Khan, L R. (1988) Environmental Aspects of Groundwater Development in Bangladesh: An Overview, *ODI-HMI Irrigation Management Network Paper 8812c*, Overseas Development Institute, London.

Pitman, G T K. and Haque, M. (1984) Groundwater Development and Planning: Problems and Prospects, paper presented at the Second National Water Plan Workshop, 7-10 October, Bangladesh.

Rahman, M A. Haque, M M. Haque, M R. and Talukder, M S U. (1979) Recharging and Depletion Characteristics of Mymensingh Aquifer, *Agricultural Science 6(2): 161-166* (Bangladesh journal).

Rust, H. (1983) A consultancy report to United States Agency for International Development (USAID), Dhaka.

Radosovich, G E. (1983) Groundwater Development and Management in Bangladesh: Institutionalizing a Strategy.