CHAPTER 11

SYNTHESIS OF DATA AND RECOMMENDATIONS
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11.1 HIGHLIGHTS OF THE STUDY
The study area is a part of the Krishni - Hindon inter-stream region, which itself is a part of much larger Ganga - Yamuna Basin, a distinct physiographic unit of India. The area exhibits a gentle southward slope with altitude varying between 224 and 256 m a msl, as revealed by the Digital Elevation Model (DEM). Average annual rainfall is between 588 and 697 mm and its intensity, in general, decreases from east to west. It is the only source for the recharge of the groundwater system and sustaining it. Rather erratic rainfall, much below the average, during the last 5 years has been felt in the area in the form of lowering of water table and drying of some dug wells.

Change Detection Analysis of land use/land cover for the years 1992 and 1999 reveals that areas of agricultural land and wasteland have decreased. The area occupied by settlements has correspondingly increased, and is obviously related to an increase in the population. This is a pointer to the alarming threat to the groundwater system of the area.

Geologically, the area is characterized by thick pile of Quaternary alluvium (>1000 m), which rests unconformably over a basement comprising quartzites of the Delhi Super Group. The study area consists of two types of soil, i.e. loam, and sandy loam. The former is found in an elongated track and almost covers 75 % of the western part of the area, while the latter occurs in a narrow elongated tract.

Four tier aquifer systems are reported to occur to depth of 450 m bgl. The first group of aquifer which extends to 185 m bgl is taken for detailed study.

The fence diagram shows occurrence of single aquifer down to depth of 121 m bgl. The top clay layer is persistent through out the area varying in thickness from 5 to 45 m bgl. The top clay bed is underlain by a single granular zone which extends downwards to different depth varying upto 121 m bgl. The granular zone is intercalated by local clay lenses. The granular zone is composed of medium to coarse sand and form about 60 to 75% of the total formation encountered particularly in the upper central part of the study area.

Depths to water table during pre- and post-monsoon periods range between 9.87 to 27.78 m bgl and 8.9 to 27.46 m bgl, respectively, in 2006. During same
periods in 2007, the water level varies between 9.76 to 29.44 m bgf and 9.67 to 29.28 m bgf. Water table contour maps have revealed that the movement of groundwater is, in general, N to S. However, local variations do exist, which in all likelihood are related to over abstraction of groundwater. Two significant groundwater troughs, which seem to be a persistent feature of the groundwater regime of the area, are observed at Mohammadpur Raising and Lank. This feature also seems to be related to excessive withdrawal of groundwater. Hydrographs, prepared on the basis of the data available from five permanent monitoring wells, show declining trend, average annual decline of groundwater in the area being 0.07 to 1.1 m.

An isopermeability map prepared using the approach of Logan (1964) shows that permeability range of 20-30 m/day covers the bulk of the area. The values obtained by permeameter, however, ranges from 1.07 to 3.84 m/day. These laboratory determined values are lower than the values obtained from pumping tests carried out in the adjoining area by Government agencies. The possible reason for these marked variations lie in sand samples being fine grained. Moreover, the natural setup is also altered because of compaction of the sand grains in confined environment. The transmissivity values arrived at through pump tests range between 720 and 1820 m²/day.

The groundwater budget of the area rings the alarm bells. Total recharge is 185.13 Mcum, whereas the total discharge from the area is 253.2 Mcum. Thus, change in groundwater storage in the area of interest is -68.07 Mcum. The stage of groundwater development is worked out to be 137%. The numbers given here are not significant as such calculations often have an element of error due to many rather uncertain parameters. What is important is that the area is showing definite indications of a negative budget. It is obvious, therefore, that the situation has reached an alarming stage which may only be expected to deteriorate further in the coming years.

The vulnerability map categorizes the area in low to very high vulnerability zones. Major portion of the study area comes under the moderate category. The vulnerability increases towards both the rivers and therefore these areas are more susceptible to groundwater pollution.

The groundwater of the area is characterized by relatively high TDS values, averaging 900 to 1000 mg/l, in the two sampling seasons. Variation range for pH is
from 6.8 to 8.5. On the basis of L-L diagram, 4 different types of water are identified, i.e. 1) Ca-Mg-HCO₃ type, 2) Ca-Mg- HCO₃ dominating mixed type, 3) Na-K-HCO₃ type, and 4) mixed type. The majority of the samples, however, plot in Na-K-HCO₃ field. This classification is consistent with that on the conventional Piper’s Trilinear diagram. The majority of the samples are fit for human consumption. Water from the deeper aquifers is relatively safe for drinking purpose.

The SAR values range from 0.56 to 11.07 and 2.79 to 29.13 in November, 2005 and June, 2006, respectively. The majority of the samples fall in good to excellent class. On the basis of RSC, 35% samples are with in the limits of suitability. Values of the remaining samples are found above the limits prescribed. In general, the water from shallow aquifer is not fit for agricultural purposes.

The samples from Krishni river show very high values of TDS and particular enrichment of HCO₃, SO₄ and Na. The bicarbonate content alone is as high as about 1000 mg/l. Concentration levels for sulphate reach up to 500 mg/l. This is clearly a case of a highly polluted river, a common situation in the Ganga plain, which has attained its present composition due to mixing of discharges from sugar, paper and acid factories and also sewage and other organic wastes. River Hindon is polluted too but to a lesser extent, the TDS though is higher than 1000 mg/l.

Chemistry of the water-soluble component of soils has indicated that it is affected by the excessive use of fertilizers in the area. Water percolating through these soils is likely to impart these chemical signatures on groundwater. Groundwater is characterized by the abundance of alkalis and relative enrichment in sulphate and this is its characteristic feature. Sodium and K would form alkali chlorides and Ca and Mg would form alkaline earth bicarbonate complexes. Alkalis would be associated with HCO₃, the most abundant anion, in alkali bicarbonate complexes. Some Ca + Mg could form sulphates. Various ionic complexes, i.e. Na-Cl, K-Cl, Na-HCO₃, Na-SO₄, Ca-Mg-HCO₃ and Ca-Mg-SO₄ are, therefore, likely to be present in the groundwater of the area, however, alkali bicarbonates would probably be the most dominant ionic complex in the area.

Analysis of some samples for silica has revealed that the groundwater could have residence in aquifers lying 800 to 1000 m bgl. Plot of silica with TDS and Cl suggest that the source for chemical species in groundwater is not predominantly through water-rock interaction.
It appears that the source of major cations and anions is dominantly through anthropogenic activities. For sulphate there is convincing evidence that it is contributed by sugar factories. The other anions, and all the major cations, may be contributed through natural processes as well as through factory and sewage discharges, discarded leachate and chemicals, fertilizers and organic waste.

There is temporal, as well as, spatial variation in the chemistry of groundwater. The former is particularly pronounced for cations. Post-monsoon period seems to be characterized by relative dilution. Spatial variations are discernible in the form of changes observed in samples collected from near the rivers and those from the central part of the area. Chemical alteration of meteoric water is conspicuous in the form of significant increase in TDS, but these alterations are predominantly anthropogenic rather than geogenic.

Higher concentration of trace metals Fe, Mn, and Pb are attributed to industrial pollution. The increasing concentration of these undesirable metals in the groundwater of the study area is mainly contributed by industrial effluents of sugar mills, pulp and paper factories, cooperative distilleries, municipal waste and other miscellaneous industries.

11.2 SYNTHESIS OF HYDROGEOLOGICAL AND HYDROGEOCHEMICAL DATA

The present study encompasses two major spheres of the study of a groundwater system, i.e. hydrogeology and hydrogeochemistry, and therefore it is imperative that an attempt should be made to understand the relationship between the two. As hydrogeological parameters include groundwater movements laterally as well as vertically, its interaction with river water during influent and effluent conditions and its residence in various aquifers with diverse lithologies, these are bound to influence the spatial variation in the chemical quality of groundwater and its tendency to acquire various cations and anions of geogenic or anthropogenic origin.

Here, in this section, TDS is taken to represent the cumulative effect of all the chemical constituents and used to relate chemical attributes with those related to hydrogeology.

One of the characteristic features of the groundwater in the area is its high TDS value of >500 to about 1500 mg/l, averaging around 900 mg/l. These are, in
general, very high compared to the data available from other parts of the Ganga plain. Such high values, at the first sight, may not be related to water-rock interaction process alone.

Very high TDS values at times may be observed in groundwater system due to mixing of saline water or dissolution of readily water-soluble material, such as, rock salt, gypsum/anhydrite and to some extent carbonates. There is no chemical indication of mixing of saline water or dissolution of rock salt due to relative paucity of Cl and lack of its stoichiometric association with Na. Similarly, dissolution of naturally occurring gypsum is ruled out too.

Under such circumstances, the most logical explanation is that groundwater has acquired its TDS content through a combination of processes among which natural processes (water-rock interaction and dissolution) have only a trivial role to play and the dominant effect is that of anthropogenic influences. This is one of the major inference of the present study and gets credibility by the fact that the area is dotted with various industries, such as, sugar mills, paper and pulp factories, acid manufacturing units and distilleries. In addition, large scale cultivation of the land with excessive use of chemical fertilizers, presence of underground septic tanks and disposal of sewage and municipal wastes, provide additional sources for groundwater to acquire its dissolved constituents. It is natural to expect that all such processes of acquisition of chemical constituents by groundwater would depend on its mobility-related parameters.

To start with, the distribution of TDS values in the area (Figure 9.1) seems to be broadly related to the distribution of soil types (Figure 3.5). Higher TDS observed along river Hindon is confined to the zone characterized by sandy loam. This speculation gets support from the fact that the sand percent map (Figure 5.4), prepared on the basis of lithologs available from the area, depicts relatively higher sand content of >60% all along river Hindon. These relationships between high TDS and relative enrichment of sand proportion tend to suggest the role of hydraulic conductivity and transmissivity in dissemination of chemical constituents. It has been established beyond any doubt in chapters dealing with hydrogeochemistry that rivers, receiving all kinds of pollutants from industrial, municipal and domestic discharges, are one of the major source of groundwater pollution. This phenomenon of groundwater - river water interaction, therefore, is bound to be influenced by
hydrogeological parameters. Thus, there seems to be some relationship of proportionality between higher TDS values of >850 mg/l and higher sand content. Rather fortuitously, the highest TDS value of >1550 mg/l at Gagnoli, along river Krishni, is associated with the highest estimated sand content of 74%.

As shown in previous chapters, Krishni is relatively more polluted than Hindon and is indicated to be influent nearly throughout its course. Higher TDS zones in groundwater, however, are more pronounced along the right bank of the latter than along the left bank of the former. This may possibly imply that under the given conditions, hydrogeological parameters are more important in spatial distribution of the chemistry underground than the chemistry of the contributing water body.

Another factor that seems to affect the distribution of TDS is the depth to groundwater level. Higher TDS values tend to confine shallow ground levels (Figures 6.2a and 6.2b). Such a relationship is not surprising as shallower groundwater that are peripheral to rivers would be more prone to contaminations. When compared to water table contour maps (Figures 6.5a and 6.5b), no clear relationship emerges. As a matter of fact, except for the southern tip of the area to some extent, water table contours cut across those of TDS values (Figure 9.1).

There does not seem to be a relationship between the isopermeability map (Figure 6.9) and TDS values. As a matter of fact, distribution of TDS should be as comparable to the isopermeability map as to the sand percent map (Figure 5.4), but this is not the case. Mutual inconsistencies between the isopermeability and sand percent maps have already been discussed in Chapter-6.

There is a good relationship between TDS and the map showing distribution of groundwater vulnerability (to pollution) index (Figure 8.1). Higher TDS values of >1200 mg/l tend to coincide with the vulnerability index of 170 to 180, whereas TDS values of 500 to 850 mg/l fall in zones of vulnerability index of 140 to 160. This is good that chemical parameters are relatable to attributes of groundwater to pollution vulnerability, which have been estimated using the DRASTIC model taking into consideration hydrological and hydrogeological parameters only. This also increases the confidence level in the hydrogeochemical data and the approach in preparing the vulnerability map.

The relationship that emerges between the distribution of TDS (Figure 9.1) and silica (Figure 10.11) is interesting. Silica values of > 30 mg/l are seen in the
northern and the southern parts of the area. These coincide with TDS values of 500 to 850 mg/l. On the other hand, SiO₂ values of < 30 mg/l tend to occur in zones with zones with higher TDS values of 850 to 1200 mg/l. This is exactly the relationship that is expected. This implies that relatively lower TDS samples have a larger proportion of groundwater of deeper origin and those with higher TDS have a substantial component of low-silica water derived from the surface. The low-silica water may either be from the rivers or may be contaminations-enriched rain water descending underground.

In general, therefore, it may be summarized that the distribution of chemical parameters is controlled by hydrogeological factors. Another point that emerges is that silica values provide important information on the proportions in which groundwaters of deeper and surface origin mixed, and in ideal conditions plots of silica against TDS and CI may be helpful in writing mass balance equations for such mixing.

11.3 FINDINGS OF THE STUDY

Some significant findings of the present study are given below:

1. Lowering of water table by up to 2.32 m has been recorded during the period from June, 2006 and June, 2007. Hydrographs have shown an average annual decline of groundwater level by 0.07 to 1.1 m.

2. Two significant groundwater troughs have been observed at Mohammadpur Raising and Lank in the northern part of the area. These, and the steep hydraulic gradient in the area observed at a number of places, are related to excessive pumping.

3. Groundwater budget studies have rung the alarm bells. The total recharge is calculated at 185 Mcum, whereas the total discharge rate is estimated at 253 Mcum. Thus a negative budget of 68 Mcum is indicated. The stage of groundwater development is estimated 137%. This necessitates regulating the future groundwater development in the area by employing strategic management and imposing stricter policies.
4. The study indicates that the zones adjacent to the left bank of Krishni and right bank of Hindon are more vulnerable to groundwater pollution than the area lying between the two rivers.

5. Groundwater is predominantly Na-K-HCO₃ type, its characteristic feature being high TDS, relative enrichment in SO₄ and abundance in alkalis.

6. Both the rivers are polluted, Krishni being more polluted than Hindon. The source of contaminants is in factory and sewage discharges, discarded leachate and chemicals, fertilizers and municipal and organic wastes. It has been established beyond doubt that sulphate is being added to the rivers from sugar factories.

7. Soils of the area have high concentration of water-soluble ions, such as, Na, K, Ca, Mg, Cl and HCO₃. Bulks of these have been derived from NPK and sulphate fertilizers.

8. Silica concentrations range from <10 to 45 mg/l. Nine out of 12 samples analysed, however, have values of >30 mg/l. These values may be translated to temperature levels of about 50 to 66 °C. On the basis of average subsurface thermal gradient of about 30 to 35 °C/km, the groundwater seems to represent the levels of 800 to 1000 m. This, in other words, imply that the groundwater sampled have residence in the granular zone only.

9. Source of almost all the major ions is through natural processes, such as, water-rock interaction and dissolution, and industrial, municipal and domestic wastes and discards. The role of anthropogenic sources is rather overwhelming.

10. There are temporal, as well as, spatial variations in the chemical quality of groundwater. Temporal variations are seen in the form of relative dilution in post-monsoon period and are more pronounced for cations. Spatial variations are in response to hydrogeological influences.

11. The area provides a characteristic example of a situation which is being witnessed in many parts of the country, in general, and Ganga – Yamuna plain, in particular. Both quality and quantity of the precious groundwater resource are being detrimentally affected and a situation has arrived when nothing can probably be done except regulating the future course of
groundwater development and minimizing the deterioration caused to the system by industries.

11.4 RECOMMENDATIONS

Groundwater management is the prerequisite for the groundwater protection. The quantification of the available groundwater resource of an area is important for evolving a sustainable development strategy and that is why a water balance study has been carried out in the area. This study has indicated a substantially negative budget, which, as a matter of fact, was expected in view of the observations in the area over a period of three years on ever increasing rate of withdrawal of groundwater through various means. With this background, following recommendations are being offered for better water management:

➢ **Further groundwater developments**: The water balance calculations indicate that even the present rate of withdrawal may not be sustainable. Therefore, no further groundwater exploitation should be allowed.

➢ **Controlled abstraction**: In order to reduce total abstraction even the present rate of pumping has to be carefully controlled. It is recommended that a constant watch be kept on water levels in the dug wells and tube wells to check the over drafting.

➢ **Augmentation of water resources**: Suitable measures for augmentation of groundwater resources may be adopted e.g. artificial recharge and rain-water harvesting may ease the situation.

➢ **Further investigations**: Several components of the groundwater balance are time dependent and further scientific investigations should be carried out for periodic update of data.

➢ **Groundwater quality**: It is possible that further pumping may lead to a deterioration of groundwater quality leading to its unsuitability as a drinking water source. Groundwater quality investigations are required periodically.

➢ **Propagation of efficient irrigation methods**: Water management practices including modern methods of irrigation like sprinkler, drip have to be
implemented with immediate effect. Farmers of the region can be made aware of these facilities so as to minimize the consumption of water for irrigation.

- **Stopping subsidized power supply:** The pumping mainly depends on the electric supply. The electric supply in the study area is at a very subsidized rate and due to this lot of water is wasted. Moreover, frequent power theft instances also encourage farmers for indiscriminate pumping.

- **Night irrigation:** Irrigation during day time in summer season when the sun heat is at maximum peak should be avoided.

- **Construction of recharge structures:** Percolation ponds and community tanks are the potential techniques for recharging the groundwater aquifer utilizing the excess water available during monsoon season.

- **Betterment of canal network:** In the present position the canal system in the study area is unplanned and confined to the neighborhood of main canal. The canal system of lower part does not receive water from the chief canal. Moreover, canals are not properly constructed. Suitable management policy is needed in this regard.

- **Quality of soil:** To restore soil fertility and organic matter, various soil management practices have to be propagated through Government agencies.

- **Waste Management:** The contamination of groundwater is continuously increasing due to industrial effluents, garbage dumps, septic tank, municipal waste water and pesticides. This requires a serious concern as retrieval of aquifers, once polluted, is not possible. It is suggested that the urban land fill, garbage dumps and effluent channels should be lined to prevent the percolation of contaminants in the aquifer. One critical aspect of preventing groundwater pollution is the identification of the recharge areas of aquifers.

- **Silica distribution:** It is recommended that silica determinations should be taken up in all groundwater investigations. This study has revealed that SiO₂ values are of great significance in understanding the level of origin of groundwater and aquifer-related processes, such as, mixing of two end-member waters. Its plots against Cl and TDS may provide information which may be substantiated by hydrogeological data.
Legislation: Groundwater-related situation is precarious not only in the area under the present study, but in the entire Ganga plain, in particular, and country, in general. What is required now is that a strict groundwater legislation should be brought in to regulate harnessing of groundwater resources as per the guidelines laid down by the Government.