Chapter 6

Conclusion and Recommendation
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CONCLUSION AND RECOMMENDATION

6.1 Conclusion

For sustainability of water resources in Gurgaon district, extensive research plan was worked and implemented. Different components for demand for water were determined based on the standard professional practice in the field. These components were agricultural, domestic, industrial, and institutional and water requirement for domestic and other animals. Recharge due to irrigation and rainfall has been estimated in accordance with CGWB (2009) methods. Irrigation recharge has been estimated using return flow factor method and rainfall recharge has been estimated using rainfall infiltration factor method as well as water table fluctuation method. Recharge quantities has been normalized according to standard recommendations of respective methods. Using calculated pumping and recharge quantities inputs for Modflow model were generated.

Total Gurgaon district area of 1254.62 km$^2$ was modeled using 102 column and 66 rows. Each grid cell had 570.03 m length by 570.03 m width making 324934.20 m$^2$ areas. Out of total 6732 grid cells, 3861 cells were coming within the boundary of Gurgaon district. To understand the water budget of four blocks of Gurgaon district, available data from 1974 to 2008 was divided in to five year average periods. Thus total seven five year average periods were formed. Modflow model (Version 5.3.1 © Chiang, W. H. and Kinzelbach, W., 1991-2001) has been calibrated using four temporal observations of four blocks and validated for 10 temporal observations of four blocks. Data of 70 tube well observations have been used for calibration and validation. Then model was calibrated to match the observed drawdown with model calculated drawdown using different values of hydraulic conductivity ($k$) and specific yield ($s$). Values of aquifer constants viz. $k$ and $s$ have been obtained by the analysis of pumping and recovery test data of four representative villages in Gurgaon district. For each test data, analysis was carried out.
using Theis Method, Cooper-Jacob Method, Chow Method and Recovery Test Method. Average values of answers by all methods have been used in the analysis.

Calibrated and validated model was used to find out 1974 to 2008 period as well as for future predictions at 2025 and 2050. Existing water was analyzed to understand different component of water pumping, recharge and change in water levels. Various scenarios viz. normal rainfall and no-pumping, roof top water harvesting with recharge and water conservation structure recharge were formulated for sustainable planning and management. 3-D graphical analysis was carried out to understand spatial drawdown patterns, flow patterns as well as to identify potential recharge sites. Following major conclusions were found from the study:

i. Block wise analysis of rainfall has been carried out and presented for future use. Normal annual rainfall in Gurgaon, Farukhnagar, Pataudi and Sohna blocks was 721, 382, 478 and 489 mm, respectively. It was also observed that out of total annual rainfall about 80.62% rainfall was occurring in Monsoon season. Total annual rainfall showed decreasing trend over the span of last 35 years (1974-2008). This situation is alarming for water resources sustainability in the future.

ii. From rigorous review of literature carried out for sustainability of ground water resources for Gurgaon district, it was found out that more than 95% of total requirement of water was from ground water alone. Very high residential and industrial growth as well as growth potential was observed for Gurgaon block in Gurgaon district. Industrial growth has started spreading to other blocks viz. Sohna, Farukhnagar and Pataudi since 2005.

iii. Potential agricultural water demand has been estimated based on Priestely-Taylor method of evapotranspiration calculation. This is significant contribution to the existing knowledge base of demand side management of water resources in Gurgaon district as agriculture is the largest consumer of water.
iv. It was found out from cropping pattern of Gurgaon district that during Kharif season major crop was Bajara which occupied about 54% of total area. Next favorable crop of farmers in Gurgaon district after Bajara was vegetable and oil seed crops. This cash crop was grown in slightly more than 30% of total kharif irrigated area. It is also important to note that rice crop was found to be grown in almost 4.5% area of total kharif irrigated area. Rabi cropping pattern of Gurgaon district revealed that during Rabi season, wheat was mostly grown crop followed by vegetables & Rabi oil seeds. Together these two crops comprised about 93% of total Rabi irrigated area. Remaining crops were grown in merely 7% of total irrigated area. It was also found out that total irrigated area in Kharif season was 36% of total geographical area and 50.5% of total geographical area in Rabi season. It can be seen from estimations that potential crop water requirement for crop in Kharif season grown in 2004-08 in Gurgaon and Sohna block was about 12000 ha.m and Farukhnagar and Pataudi block was about 10000 ha.m. If we consider that 25% of total crop water requirement in Kharif (rainy) season is satisfied by ground water and remaining requirement is satisfied by rainfall then demand for agricultural crop water in Kharif season for Gurgaon and Sohna block would be around 3000 ha.m and for Farukhnagar and Sohna block would be around 2500 ha.m. Estimations also showed the potential agricultural water demand for crops grown in Rabi season in 2004-08 in Block Gurgaon and Sohna needed about 10000 ha.m water and crop grown in Farukhnagar and Pataudi block needed about 8500 ha.m water. These water demand quantities can be used for broad planning purpose.

v. It was also seen that for year 2025 water demand for agriculture in Kharif was increasing by 2000 ha.m for blocks Pataudi and Farukhnagar and by 4000 ha.m for Gurgaon and Sohna blocks. Thus total agricultural water demand in 2025 Rabi season would be 10000 ha.m for Farukhnagar and Pataudi blocks and 11000 ha.m for Gurgaon and Sohna block.
vi. Trend of population increase from 1971 to 2011 indicated that there was a sharp increase in population density since 1990’s. Total population is increasing in increasing order and there is no sign of population stagnation in near future in Gurgaon district.

vii. Recharge estimation by return flow factor suggests that irrigation recharge quantities for blocks Pataudi and Farukhnagar were about 400 ha.m and for blocks Gurgaon and Sohna 500 ha.m for Kharif season of 2004-08. As area under irrigation will increase by 2025, it can be seen that for all blocks recharge quantities will be increased by 75 ha.m. Thus total recharge for 2025 kharif season is expected to reach to 475 ha.m for Pataudi and Farukhnagar blocks and 575 ha.m for Gurgaon and Sohna block. It was also observed that for 2004-08 Rabi period recharge quantities from Pataudi and Farukhnagar block were nearly 1000 ha.m and for Gurgaon and Sohna block they were nearly 1200 ha.m. It was seen that for Rabi period of 2004-08, recharge will increase by almost 200 ha.m for all blocks making total Rabi recharge to the tune of 1200 ha.m for Pataudi and Farukhnagar block and 1400 ha.m for Gurgaon and Sohna block.

Calculation of recharge due to rainfall by rainfall infiltration method suggests that for monsoon season in which almost 80% of total annual rainfall occurs, recharge from rainfall for Pataudi, Gurgaon, Sohna and Farukhnagar blocks was 2868, 3707, 2489 and 1522 ha.m, respectively for 2004-08 average scenario. Nearly one fourth of these quantities were seen to recharge during non-monsoon season. Thus total annual recharge respectively for Pataudi, Gurgaon, Sohna and Farukhnagar blocks were 3557, 4597, 3087 and 1887 ha.m. But under high water withdrawal conditions (exploitation of ground water resources), which was seen in almost all blocks of Gurgaon, non-monsoon recharge might not reach ground water resources. Therefore only dependable recharge quantities will be monsoon recharge. Under normal rainfall condition, recharge from Pataudi, Gurgaon, Sohna and Farukhnagar would be 2499, 4716, 3119, and 2148 ha.m, respectively in Kharif and 3101, 5853, 3871 and 2664 ha.m respective total annual recharge.
viii. Extensive analysis of pumping and recovery tests data was carried out using four methods viz. Theis Method, Cooper-Jacob Method, Chow Method and Recovery Test Method for determination of transmissibility, specific yield, storage coefficient and hydraulic conductivity. This analysis showed that average transmissibility was varying from 62.03 to 329.8 m$^2$/day and average transmissibility was 163.44 m$^2$/day. Corresponding values of hydraulic conductivity were varying from 1.03 to 5.5 m/day with average of 2.72 m/day. Storage coefficient was varying from 0.004 to 0.02 with an average of 0.011. These values have been used for calibration of model.

ix. Precise estimation of water balance of Gurgaon district revealed that there was increase in water level by almost 31 cm per month in 1974-78 which in 2004-08 was decreasing by almost 24 cm per month. For Sohna block water levels in monsoon were increasing (at 1974-78) by almost 21 cm per month which were found out to be decreasing (at 2004-08) by 4 cm per month. For Pataudi block rate of increase in water level was observed to be decreasing from 18.2 cm/month in period 1974-78 to 36.2 cm/month in period 2004-08. For Farukhnagar block water levels were increasing at slow pace of 0.5 cm/month in 1974-78 while water level was decreasing by 10.8 cm in 2004-08. Same situation was observe in non-monsoon season and rate of water level decrease was from 16.3 to 63.4 cm/month for Gurgaon block, 15.7 to 40.3 cm/month for Sohna block, 24.9 to 48.6 cm/month for Pataudi block and 17.1 to 26.6 cm/month for Farukhnagar block.

x. It can be clearly observed from the water balance of Gurgaon block that availability of water in Gurgaon block was dependent on the horizontal exchange of the water quantities. It was found out from the given out horizontal water quantities that over the years from 1974 to 2008 that in both monsoon and non-monsoon season, given out quantities were reducing irrespective of recharge quantities. Gurgaon block was donating water quantity of 16777 m$^3$/day in 1974-78 monsoon period which was observed to donate meager 2884 m$^3$/day in 2004-08 monsoon period. In non-monsoon season, Gurgaon block was observed to give 12923 m$^3$/day in 1974-78 was found to give very little 1784 m$^3$/day in 2004-08.
xi. It can be clearly observed from the water balance of Sohna block that water balance of this block was dependent on the horizontal exchange of the water quantities received from other blocks. It was found out from the received horizontal water quantities in Sohna block that over the years from 1974 to 2008 that in monsoon and non-monsoon season, received quantities were reducing irrespective of recharge quantities. Sohna block was receiving water quantity of 9267 m$^3$/day in 1974-78 in monsoon period was observed to receive 2222 m$^3$/day in 2004-08 monsoon period. In non-monsoon season, Sohna block was observed to receive 7493 m$^3$/day in 1974-78 and it was found to take very little 1626 m$^3$/day in 2004-08.

xii. It can be clearly observed from the water balance of Farukhnagar block that availability of water in Farukhnagar block was dependent on the horizontal exchange of the water quantities. Clear impact on the flow pattern change was observed on the Farukhnagar block. Due to exploitation of water in Gurgaon, Sohna and Pataudi block, water generated and received in the block was seen to go to other blocks. It was found out from the given out horizontal water quantities over the years from 1974 to 2008 that in both monsoon and non-monsoon season, given out quantities were increasing irrespective of recharge quantities.

xiii. It can be clearly observed from the water balance of Pataudi block that availability of water in the block was dependent on the horizontal exchange of the water quantities. Clear impact on the flow pattern change was also observed on the Pataudi block. Due to exploitation of water in Gurgaon and Sohna block, water from Farukhnagar was observed to be divided between Pataudi block and Gurgaon block. It was found out from the given out horizontal water quantities that over the years from 1974 to 2008 that in both monsoon and non-monsoon season, given out quantities were decreasing irrespective of recharge quantities.

xiv. Two distinct phases of water balance trend of Gurgaon district can be clearly identified during study period of 1974 to 2008. In monsoon season, from 1974-78 to 1994-98 there was water deficit water budget and from 1999-03 onwards surplus
water budget was observed. In non-monsoon season exact opposite trend was seen. Water deficit in non-monsoon season presents huge challenge in future water sustainability of the Gurgaon district. All blocks in Gurgaon district except Farukhnagar block had good rainfall in 1999-03 and 2004-08 periods. These rainfall quantities were unable to satisfy water requirement over the entire year. Rainfall has shown effect on only monsoon season, in which water balance was little surplus. Unless prohibition on water withdrawal and compulsory recharge in Gurgaon district is implemented, water sustainability of Gurgaon district will be in jeopardy.

xv. Future prediction using Modflow model suggest that in 2025 monsoon season all blocks in Gurgaon district will have little water quantities remained after satisfying all needs under normal rainfall condition. It was also observed that in 2025 non-monsoon season, Farukhnagar and Pataudi block will have little water quantities remained after satisfying all needs and Gurgaon and Sohna blocks will have deficit water budget under normal rainfall condition.

xvi. Future prediction using Modflow model suggest that Gurgaon block will have maximum drawdown of 9.61 meter in 2025 followed by Pataudi block with 6.41 meter. Drawdown of Farukhnagar and Sohna will be lowest in district in 2025 with values of 3.31 and 3.61 meter, respectively. Average monthly drawdown in monsoon and non-monsoon will be 51 and 94 cm/month for Gurgaon block. There will be negligible positive drawdown of few millimeters in monsoon season and 45 cm/month drawdown in non-monsoon season for Sohna block. Calculations show that Farukhnagar block will have about 14 cm/month and 34.5 cm/month drawdown in monsoon and non-monsoon season. Pataudi will have second highest drawdown of 26 cm/month in monsoon and about 66cm/month drawdown in non-monsoon season. These demands are considerably higher than 2004-08 period in both monsoon and non-monsoon period.

xvii. Year 2050 Modflow model prediction for monsoon season indicates that all blocks in Gurgaon district except Farukhnagar block will have surplus water budget under normal rainfall condition. This surplus quantity will be very little.
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Compared to this in 2050 non-monsoon season suggest that all blocks in Gurgaon district except Pataudi block will have surplus water budget. Even though surplus water quantities will be very little considering prolonged period of eight months, surplus water budget has importance. Reduction in total area under irrigation will have clear impact on water budget of 2050 monsoon and non-monsoon season. But if equivalent amount of irrigation water will be required by agro based and other industries then there will be alarming situation in Gurgaon district. By 2050, it was seen that, target block to be considered will be Pataudi block which was showing deficit water budget.

xviii. Year 2050 Modflow model prediction for Gurgaon district shows that Gurgaon, Sohna, Farukhnagar and Pataudi blocks will have drawdown of 13.98, 4.24, 3.64 and 7.13 meter, respectively.

xix. Under normal rainfall condition with no-pumping there will be huge rise in water table of all blocks in Gurgaon district. Increase in water table in monsoon season for Gurgaon, Sohna, Pataudi and Farukhnagar blocks will be 6.14, 5.56, 5.07 and 1.92 meter, respectively. It was also found out that recharge of normal condition rainfall with no-pumping will produce 0.5775, 0.3959, 0.3128 and 0.3799 ha.m/ha water respectively for Gurgaon, Sohna, Pataudi and Farukhnagar blocks. This water quantity is equivalent to 19949, 13337, 9285 and 10470 ha.m respectively for Gurgaon, Sohna, Farukhnagar and Pataudi blocks. Year 2004-08 has calculated water withdrawal of 25851, 13931, 12276 and 11394 ha.m respectively for Gurgaon, Sohna, Farukhnagar and Pataudi blocks.

xx. Scenario of normal rainfall and no-pumping suggest that there will be 1.46, 1.22, 1.68 and 0.58 meter rise in water table respectively for Gurgaon, Sohna, Pataudi and Farukhnagar blocks in monsoon season due to roof top water harvesting done on 100 km$^2$ equivalent roof top area and water was recharged. It can be also be seen from this scenario that there will be 1.12, 0.94, 1.29 and 0.44 meter rise in water table respectively for Gurgaon, Sohna, Pataudi and Farukhnagar blocks in
monsoon season due to water conservation structure assisted recharge done on 100 km$^2$ equivalent drainage area and water was recharged.

Both water conservation scenarios suggest that even one third area of total block area is brought down under water recharge methods, total recharge quantities will not be sufficient to replenish the yearly demand of water. Normal rainfall along with one third of total block area under recharge structures will be able to satisfy only two third of total water demand. Therefore right strategy for sustainability of groundwater resources of Gurgaon district will be to decrease demand and increase recharge simultaneously. Top most water demanding sector viz. agriculture and industry should be supplied with water resources from outside the district areas.

For effective planning and management activities which will ensure sustainable water development in Gurgaon district, 3-D drawdown contour diagrams were prepared with the help of Surfer program. With the help of these diagrams spatial change in water table, water flow pattern and identification of potential sites for recharge has been carried out and presented for possible future use.
6.2 Recommendation

By extensive analysis of various types of data viz. cropping pattern, population, number and types of industries, animal census, water level observations, geological formations, soil properties, aquifer parameter etc. and use of different methodologies viz. water budgeting, calibration and validation, simulation, normalization, programming, model formulation, scenario generation, graphical analysis, regression etc.; different components of water intake and withdrawal were studied for sustainability of water resources of Gurgaon district. Because of this comprehensive and holistic approach, various facts were revealed which might help for future research, analysis, planning, management as well as policy making. Following points cover these various facts:

i. In older times Gurgaon was considered as the barren land only. Even in this barren land various water courses and drainage networks were present. But with the development of this area to world class city, these networks have been vanished. With the planned development of sewerage water lines older natural sewerage courses has been vanished and benefit of recharge water has been reduced. Therefore modern plans of sewage treatment plants should consider for treating water for recharge purpose.

ii. It was observed that lot of water is flowing out of district through storm water drainage network. These water quantities can be used for domestic and recharge purpose very effectively.

iii. Because of huge water deficits and comparable water table fall in the Gurgaon district, there is need of specific strategy for recording tube well observations in the district. Existing observation wells should be classified according to dominant type of water use in the surrounding area. If such classification is not possible in some areas then special observation wells should be identified or installed for specific type of water use. Main idea behind the classification of observation wells should be evaluation of total draft for specific use in the area.
iv. Existing and new observation wells should be identified in accordance to the water flow direction in and among the different blocks of Gurgaon district.

v. For effective planning of natural resources in Gurgaon district, there is need to carry out natural surface elevation as well as land use map at maximum 10 meter by 10 meter grid.

vi. It was observed that water balance of all blocks in Gurgaon district were dependent on the horizontal exchange of water quantities. Therefore for identification of water flow pattern and water quantities in underground layers, there is need of use of modern technologies like tracer technologies.

vii. Agriculture and Industrial water use were the dominant water use sector in the Gurgaon district. For sustainability of water resources arrangement of alternative canal irrigation should be planned for both industrial and agricultural water use.

viii. Water resources of Gurgaon district should be analyzed for surface water and underground water resources together.

ix. Water recharge schemes should be immediately implemented in Gurgaon district not only for the water use in the area but also to stop salt water intrusion in to drinkable water resources. There were some areas identified in the Gurgaon district with salty water and these need special attention.

x. Immediate actions for water recharge should be taken in the area as there is danger of underground water system closure and destruction of natural flow pattern. This will also impose threat to the caving-in of land at many places due to collapse of empty porous aquifers in the region.