CHAPTER 7
RESULTS AND DISCUSSION

7.1 Introduction

This chapter discusses results obtained from the application of the model. The simulation of various possibilities provided us water balances and crop areas under different sets of scenarios. By incorporating possible water management interventions as inputs, the study arrived at the water use net benefits. Various sustainability and productivity statistics are computed.

After choosing the model, the study simulated various scenarios as follows:

(i) Base line scenario: In this scenario, it was assumed that the current water use status would remain unchanged for the future years.

(ii) Low irrigation scenario assumed that a 10 percent reduction in total irrigated area with yearly changes.

(iii) Master scenario assumed that a 25 percent irrigated area for the winter, summer crops are under drip irrigation, and 25 percent irrigated area for the kharif crops are under sprinkler irrigation. It was also assumed that there is no increase in irrigated area.

(iv) High irrigation scenario assumed that a 25 percent irrigated area for the winter, summer crops are under drip irrigation, and 25 percent of the kharif crops are under sprinkler irrigation. It is assumed that there is a 10 percent increase in total irrigated area.

7.2 Groundwater Balance

In the baseline scenario, the current water use pattern is followed throughout the modeling period. In a normal year most of the available water is utilized. Only in the case of good rainfall year, groundwater balancing occurs. Hence, if a drought year is followed by a normal year or a drought year, the situation becomes vulnerable. In the low irrigation scenario where 10 % decrease in irrigated area shows the water balance position better than
baseline scenario. However, this scenario fails to meet the water requirements of drought years. In master scenario and high irrigation scenario, water balance positions show significant improvements even in drought years. In the Figure, ‘g’, ‘n’, ‘d’ represent a good year, normal year and a drought year respectively. Figure 7.1 shows water balance positions over the modeling period from 2003 to 2033.

![Groundwater Balance Under Various Scenarios (2003-2033)](image)

**Figure 7.1 Groundwater Balance under Different Scenarios**

### 7.2.1 Groundwater Balance under Baseline and Master Scenarios

In the modeling period, some drought years are appeared and out of which 2018 and 2024 are the worst years. In master scenario crops are under sprinkler / drip irrigation and hence, more water saving occurs. In this scenario, there is no rise in irrigated area. Hence, the water balance situation is much better compared to baseline scenario. Figure 7.2 compares the water balance situations in baseline scenario and master scenario.
7.2.2 Groundwater Balance under Low Irrigation and High Irrigation Scenarios

There are marked differences between the high irrigation and low irrigation scenarios. In high irrigation scenario, the groundwater balance is significantly higher than low irrigation scenario. This is due to the reason that most of the irrigated crops are under sprinkler / drip irrigation. In drought years, these differences are more due to improved water availability in high irrigation scenario. Figure 7.3 shows the groundwater balance situation under these two scenarios.

Figure 7.2 Water Balance Situations in Baseline Scenario and Master Scenario

Figure 7.3 Groundwater Balance under High and Low Irrigation Scenarios
7.2.3 Groundwater Balance at Different Reaches under Various Scenarios

The groundwater balance positions at upper, middle and lower reaches show significant changes in all the scenarios. The groundwater balance position is the highest in the middle reaches in all the scenarios. In master and high irrigation, scenarios show that the area under irrigation can be increased further in this reach. In upper and lower irrigation, the situation improves in master scenario and in high irrigation scenario. However, in baseline scenario and low irrigation scenario show very poor water balances in the years 6-10 and 11-15. These are shown in Figures 7.4, 7.5, 7.6 and 7.7.

![Groundwater Balance at Different Reaches (5 Year Average)](image)

Figure 7.4 Groundwater Balance at Different Reaches in Baseline Scenario
Figure 7.5 Groundwater Balance at Different Reaches in Low Irrigation Scenario

Figure 7.6 Groundwater Balance at Different Reaches in Master Scenario
7.3 Crop Area

Total six crops are considered in the present study. They are kharif-groundnut, rabi / winter - wheat, bajra, others, summer crops and horticulture crops. The irrigated crop area for these crops is determined by the model considering the objective function to maximize the water use net benefits at each year by considering the water availability. The maximum irrigated area is in upper reaches and the minimum is in the lower reaches. Irrigated area in all years shows significant increase in master and high irrigation scenario. In baseline scenario and low irrigation scenario, irrigated area has shown year-to-year variation in tune with water availability. The irrigated crop area for all the crops under various scenarios in each reach is shown in Figures 7.8 to 7.31 given below.
KHARIF - GROUNDNUT

Figure 7.8 Crop Area at Different Reaches in Baseline Scenario

Figure 7.9 Crop Area at Different Reaches in Low Irrigation Scenario
Figure 7.10 Crop Area at Different Reaches in Master Scenario

Figure 7.11 Crop Area at Different Reaches in High Irrigation Scenario
CROP AREA – WHEAT (RABI)

Figure 7.12 Crop Area at Different Reaches in Baseline Scenario

Figure 7.13 Crop Area at Different Reaches in Low Irrigation Scenario
Figure 7.14 Crop Area at Different Reaches in Master Scenario

Figure 7.15 Crop Area at Different Reaches in High Irrigation Scenario
CROP AREA – BAJRA (RABI)

Figure 7.16 Crop Area at Different Reaches in Baseline Scenario

Figure 7.17 Crop Area at Different Reaches in Low Irrigation Scenario
Figure 7.18 Crop Area at Different Reaches in Master Scenario

Figure 7.19 Crop Area at Different Reaches in High Irrigation Scenario
CROP AREA – OTHERS (RABI)

Figure 7.20 Crop Area at Different Reaches in Baseline Scenario

Figure 7.21 Crop Area at Different Reaches in Low Irrigation Scenario
Figure 7.22 Crop Area at Different Reaches in Master Scenario

Figure 7.23 Crop Area at Different Reaches in High Irrigation Scenario
CROP AREA – SUMMER CROPS

Figure 7.24 Crop Area at Different Reaches in Baseline Scenario

Figure 7.25 Crop Area at Different Reaches in Low Irrigation Scenario
2.3.6 Understanding Basin’s Water Resources

The major demand from most of the river basins is generated from irrigation. An accurate understanding of the basin’s water resources is necessary for knowing various issues of that basin. A water accounting study helps to identify the water related problems of the basin. A water accounting study of yellow river basin size analyses various issues like the possibility of flood, water scarcity and its economic and environmental consequences and apparent declines in rainfall and runoff (Zhu et al., 2004). This study checks the current supply, demand, changes in supply and demand and ecological needs.

The increasing economic activities and intensive water utilization cause impacts on ecological and hydrological regimes of water resources (Saleth, 2004). A clear understanding of the basin’s water resources will help to know the spatial and temporal variations of the water. To understand basin’s geography, and current water use pattern the basin is divided into three reaches say upper reach, middle reach and lower reach (Zhu et al., 2004; Kumar and Singh, 2001).

2.3.7 Water Uses in River Basins

A river basin system is made up of water resource components, in stream and off stream demand components and intermediate treatment and recycling components. The river basin is characterized by, natural and physical features, physical projects and management policies (McKinney et al., 1999). As the scope for additional water supplies are limited to meet the growing demands of water, greater attention could be given to water allocation between the competing uses (Meinzen-Dick and Mendoza, 1996). Renault and Makin, (1999) identified that the opportunities and constraints in water service are; water quality, recycling of irrigation water, water harvesting and conjunctive management, soil and water salinity and water logging, multiple uses of water, water rights, equity and priorities in distribution, health impacts, location within the system (upstream or downstream).
CROP AREA – HORTICULTURE CROPS

Figure 7.28 Crop Area at Different Reaches in Baseline Scenario

Figure 7.29 Crop Area at Different Reaches in Low Irrigation Scenario
Figure 7.30 Crop Area at Different Reaches in Master Scenario

Figure 7.31 Crop Area at Different Reaches in High Irrigation Scenario
7.3.1 Comparison of Crop Area with Baseline Average Area

The crop areas of all the crops are compared with the baseline average values and shown in Figures 7.32, 7.33 and 7.34. Figure 7.32 shows that the later years the crop areas are decreased in low irrigation scenario. In the other two scenarios, the crop areas were above the base line average values.

![Crop Area Graph](image)

Figure 7.32 Comparison of Crop Areas of Low Irrigation Scenario with Baseline Average Area
Figure 7.33 Comparison of Crop Areas of Master Scenario with Baseline Average Area

Figure 7.34 Comparison of Crop Areas for High Irrigation Scenario with Baseline Average Area
7.4 Water Use Net Benefits

In the baseline scenario and low irrigation scenario, the water use net benefits vary and in drought years, the benefits are very less. The master scenario and high irrigation scenario show upward trend in benefits. High irrigation scenario provided the highest water use net benefits. Figure 7.35 shows the water use net benefits under various scenarios.

![Water Use Net Benefits (2003-2033)](image)

**Figure 7.35 Water Use Net Benefits under Various Scenarios**

7.4.1 Comparison of Water Use Net Benefits under Baseline and Master Scenarios

A comparison of baseline scenario and master scenario shows that in master scenario, which assumed 25 percent of the crops are under sprinkler / drip irrigation, the water use net benefits show an upward trend.
7.4.2 Comparison of Water Use Net Benefits under Low Irrigation and High Irrigation Scenarios

Water use net benefits under low irrigation scenario and high irrigation scenarios are compared and it was found that the benefits are consistently improved in high irrigation scenario. In low irrigation scenario irrigation benefits decreases after the first drought period (year 2008) and it gives a reasonably better values after a good rainfall period (year 2020). However, the benefits are again decreased in the next drought years showing fluctuations.
7.4.3 Water Use Net Benefits at Different Reaches under Various Scenarios

The water use net benefits in upper, middle and lower reaches under four scenarios are shown in the Figures 7.38 to 7.41. In baseline scenario and low irrigation scenarios the benefits are inconsistent and very much depends upon the water availability at that particular year. This is due to the reason that not much water balance is there from the previous years except during good and normal surplus rainfall years. In master scenario and high irrigation scenario, the benefits show better trends in all the reaches.
Figure 7.38 Water Use Benefits at Different Reaches in Baseline Scenario

Figure 7.39 Water Use Benefits at Different Reaches in Low Irrigation Scenario
Figure 7.40 Water Use Benefits at Different Reaches in Master Scenario

Figure 7.41 Water Use Benefits at Different Reaches in High Irrigation Scenario
7.5 Sustainability Criteria

Different sustainability criteria are quantified as explained in Cai et al., (2002) for various scenarios and a comparison was done. The sustainability criteria are classified into two categories. They are: (i) the risk criteria, and (ii) the equity criteria. Various risk criteria are the reliability criteria (REL), the reversibility criteria (REV) and the vulnerability criteria (VUL). The equity criteria are classified as spatial equity criteria and the temporal equity criteria. All these terms are defined and explained in chapter six. The estimated values for these criteria are shown in Table 7.1 and Table 7.2.

7.5.1 Risk Criteria

Table 7.1 Risk Criteria under Various Scenarios

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Scenario</th>
<th>REL</th>
<th>REV</th>
<th>VUL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Base Line Scenario</td>
<td>0.795</td>
<td>0.355</td>
<td>0.000</td>
</tr>
<tr>
<td>2.</td>
<td>Low-Irrigation Scenario</td>
<td>0.840</td>
<td>0.323</td>
<td>0.230</td>
</tr>
<tr>
<td>3.</td>
<td>Master Scenario</td>
<td>0.972</td>
<td>0.000</td>
<td>0.880</td>
</tr>
<tr>
<td>4.</td>
<td>High – Irrigation Scenario</td>
<td>0.953</td>
<td>0.097</td>
<td>0.820</td>
</tr>
</tbody>
</table>

The highest reliability is observed in master scenario and the lowest in baseline scenario. For agricultural reversibility a failure year is the year where the RA\textsuperscript{Y} is less than 0.85 (i.e., 15% risk threshold). The lowest reversibility value is obtained in master scenario. The vulnerability i.e., the minimum RA\textsuperscript{Y} value is zero in baseline scenario, which is in the year 2024. In master scenario, the minimum RA\textsuperscript{Y} is 0.88. In all the three criteria, master scenario is the best.
7.5.2 Equity Criteria

Table 7.2 Equity Criteria under Various Scenarios

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Scenario</th>
<th>TEQ</th>
<th>SEQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Base Line Scenario</td>
<td>0.754</td>
<td>0.286</td>
</tr>
<tr>
<td>2.</td>
<td>Low-Irrigation Scenario</td>
<td>0.414</td>
<td>0.519</td>
</tr>
<tr>
<td>3.</td>
<td>Master Scenario</td>
<td>0.030</td>
<td>0.012</td>
</tr>
<tr>
<td>4.</td>
<td>High – Irrigation Scenario</td>
<td>0.029</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Temporal equity (TEQ) depends on the changes in water demand and the hydrologic fluctuations over the years. Spatial equity (SEQ) describes the distribution of agricultural benefits across various demand sites in the basin. The ideal values for TEQ and SEQ are zero. A larger value of TEQ indicates larger variation of the rate of change of water use benefits over the modeling period. A larger SEQ shows a larger dispersion of irrigation benefits among the demand sites. In the present study, both these values are higher in baseline scenario and low irrigation scenario. Lower values are observed in master scenario and high irrigation scenario. The lowest values are in high irrigation scenario.

These criteria are ranked as per their relative importance and shown in Table 7.3. In the risk criteria, Master scenario is the best one and equity criteria High irrigation scenario is the best scenario.
### Table 7.3 Ranking of Scenarios by Various Sustainability Criteria

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Scenario</th>
<th>REL</th>
<th>REV</th>
<th>VUL</th>
<th>TEQ</th>
<th>SEQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base Line Scenario</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Low-Irrigation Scenario</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Master Scenario</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>High – Irrigation Scenario</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

### 7.6 Productivity of Water

Three different productivity values are estimated and shown in Table 7.3. These definitions are given elsewhere. It is seen that productivity of available water and unit productivity of water for irrigation were higher in high-irrigation scenario where productivity of gross inflow was higher in low-irrigation scenario.

### Table 7.3 Productivity of water under Various Scenarios

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Scenario</th>
<th>Productivity of Gross Inflow</th>
<th>Productivity of Available water</th>
<th>Unit Productivity of Water for Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base Line Scenario</td>
<td>0.194</td>
<td>74.61</td>
<td>71.97</td>
</tr>
<tr>
<td>2</td>
<td>Low-Irrigation Scenario</td>
<td>0.196</td>
<td>71.75</td>
<td>71.08</td>
</tr>
<tr>
<td>3</td>
<td>Master Scenario</td>
<td>0.176</td>
<td>68.46</td>
<td>87.20</td>
</tr>
<tr>
<td>4</td>
<td>High – Irrigation Scenario</td>
<td>0.181</td>
<td>76.1</td>
<td>92.03</td>
</tr>
</tbody>
</table>
7.7 Conclusion

After selecting Genetic Algorithm as an optimization technique suiting to this research problem, various scenarios simulated. The net water use benefits were computed and water balance positions were found out. Several sustainability criteria were arrived helping optimum water allocation among competitive uses. Out of the simulated scenarios, master scenario and high irrigation scenario were found to be sustainable even during drought years. When water use benefits were the consideration, high irrigation scenario was most promising. Criteria related to sustainability; risk and equity were considered, risk factor suggested master scenario and equity factor favoured high irrigation scenario, though the differences between these two scenarios were very low. However, as the water use benefits under high irrigation scenario were significantly high, this preferred to all other criteria considered. As the period simulated was up to year 2033, policy makers can take the results for formulating future strategies.