# Impact of Climate Change on Crop Water Requirements and Adaptation Strategies

**Chapter** · June 2011

DOI: 10.1007/978-3-642-19360-6_24



Abburi VM Subbarao
Indian Council of Agricultural Research



Manikandan Narayanan
Indian Council of Agricultural Research

# Chapter 24
# Impact of Climate Change on Crop Water Requirements and Adaptation Strategies

**V.U.M. Rao, A.V.M. S. Rao, G.G.S.N. Rao, T. Satyanarayana, N. Manikandan, and B. Venkateshwarlu**

**Abstract** Water is an important for all forms of life and it is becoming scarce natural resource in the future owing to climate variability / change which aggravates the situation. Water resources are inextricably linked with climate. Climate change and variability would be the principal source of fluctuation in global food production, particularly in the semi-arid tropical countries of the developing world. In conjunction with other physical, social and political-economic factors, climate variability contributes to vulnerability to economic loss, hunger, famine and dislocation in the developing countries. Climate change impact studies reveal that annual average river runoff and water availability are projected to increase by 10–40% at high latitudes and in some wet tropical areas, and decrease by 10–30% over some dry regions at mid-latitudes and in the dry tropics. Crop water availability shortage and excess affects the growth and development of the plants, yields and quality of produces. Climate change, which affect the water availability resources, which in turn affect agriculture in many ways. For instance in soil plant processes with an increase in soil water deficit by changes in soil water balance. Long term climate change and its effect on crop water requirements of major cereal crops like wheat, maize, sorghum and millet in 1990, 2020 and 2050 were estimated by FAO CROPWAT program and the adaptation strategies to be taken to combat climate change effect were also discussed in this paper.

## 24.1 Introduction

Water is an important for all forms of life and is becoming scarce natural resource in the future owing to climate variability / change. It is crucial for crop production and best use of available water must be made for efficient crop production and high

V.U.M. Rao (✉) • A.V.M.S. Rao • G.G.S.N. Rao • T. Satyanarayana • N. Manikandan • B. Venkateshwarlu
Central Research Institute for Dryland Agriculture, Hyderabad, AP 500 059, USA
e-mail: vumrao54@yahoo.com

S.D. Attri et al. (eds.), *Challenges and Opportunities in Agrometeorology*,
DOI 10.1007/978-3-642-19360-6_24, © Springer-Verlag Berlin Heidelberg 2011

yields. The relationships between crop, climate, water and soil are complex and many biological, physiological, physical and chemical processes are involved. Knowledge on reliable estimates of water required by different crops in a given set of climatological conditions of a region is great help in rational utilization of irrigation water for irrigation scheduling, planning of irrigation schemes and effective design of water saving and management systems. The average global surface temperature is projected to increase by 1.4–3°C from 1990 to 2100 for low-emission scenarios and 2.5–5.8°C for higher emission scenarios of greenhouse gases in the atmosphere (Mall et al. 2006). Warming of climate is observed over the past several decades and is consistently associated with changes in a number of components of the hydrological cycle and hydrological systems such as: changing precipitation patterns, intensity and extremes; increasing atmospheric water vapour; increasing evaporation; and changes in soil moisture and runoff. There is still substantial uncertainty in trends of hydrological variables because of large regional differences, and because of limitations in the spatial and temporal coverage of monitoring networks (Huntington 2006). The investigation by McCabe and Wolock (1992), based on an irrigation model, concluded that the increase in mean annual water use is strongly associated with the increase in temperature. On the other hand, the natural resource base of agriculture, is shrinking and degrading, and also adversely affecting production capacity of the ecosystem. However, demand for agriculture is rising rapidly with rise in population and per capita income and growing demand from industry sector.

India shares about 16% of the global population and 2.3% of global land but it has only 4.2% of the total fresh water resources from rainfall, ground water and rivers and per capita availability of water resources is about 4–6 times less as compared to world average. As per the government of India statistics of 2005–06, the net area sown is 142 Mha; whereas net irrigated area is only 60 Mha. Major part of the Indian food grain production comes from irrigated areas. Apart from that, the rainfed farming practiced in over 87 million ha area of the country contributes 40% of food supports of human and 60% of livestock population. But at the same time, it will not be possible to provide irrigation for more than half the cultivated area in the foreseeable future (Katyal 1998).

Monsoon is the most important climatic phenomenon occurring in the Indian subcontinent and the adjoining regions. It forms the backbone of Indian economy; a high degree of correlation exists between monsoon rainfall and agricultural Production. Almost 65–70% of annual rainfall in India is mainly received from southwest monsoon (June-September). Deficit or failure of southwest monsoon put tremendous pressure on the water resources and food basket of the Country. The impact of variability of the monsoon rainfall on the food grain production has remained large throughout the last century, despite the Green Revolution over the Indian region, (Abrol 1996; Gadgil et al. 1999). Thus, it is imperative that to study the potential impact of climate change on water requirements of crops and to evolve suitable policies for development of water resources and irrigation systems in the context of climate change scenarios. In India per capita surface water availability in the years 1991 and 2001 were 2,309 and 1,902 $m^3$ and these are projected to reduce to 1,401 and 1,191 $m^3$ by the years 2025 and 2050 respectively (Kumar et al. 2005). Therefore, there is a need for proper planning, development of water resources for sustaining food grain production and livelihood of peasants living across India. The present study aimed to estimate the crop water requirements during 1990, 2020 and 2050 for the important cereal crops like wheat, maize, sorghum and millet and adaptation strategies also discussed.

## 24.2 Material and Methods

The crop water requirements (CWR) of crops under study were calculated using CROPWAT 4 Windows v 4.3 (Smith 1992, 1993). This program uses the FAO Penman-Monteith method (Allen et al. 1998) for calculating reference evapotranspiration (ETo). The crop coefficient (Kc) values were taken from the CROPWAT software. These coefficients present the relationship between references (ETo) and crop evapotranspiration (ETcrop) or ET crop = Kc * ETo. Value of Kc varies with the crop, stage of growth, growing season and the prevailing weather conditions.

The required weather input files (Normal monthly weather data files for the period 1961–90 for maximum and minimum temperature, relative humidity, wind speed, sunshine hours and rainfall) for CROPWAT programme have been collected from FAO database software New_LocClimV1.1 (FAO 2005) for the stations under study.

To generate weather data files for 2020 and 2050, HadCM3 GCM (Global Circulation Model) output was used and by using this weather data files, crop water requirements for 2020 and 2050 was estimated. The data on district-wise area (from 1999 to 2006) for all crops taken for study has been collected from website of Directorate of Economics and Statistics, New Delhi.

## 24.3 Results and Discussions

The results of crop water requirements analysis revealed that sizeable increase in water requirement is seen for wheat, maize, sorghum and millet crops during 2020 and 2050 when compared to 1990. However, there is significant differences have been noticed in the percent increase in crop water requirement and reference evapotranspiration (ETo) among the stations selected for this study and values are furnished in the tables. It is significant to note at this point is projections of water demands of India for the year 2025 and 2050 which is worked out by IWMI said that even with lower estimates projected by IWMI, there shall be substantial future increase in irrigation water requirements (Sharma 2006).

In general, the crop water requirement and reference evapotranspiration is high in early sown crop and less in late of sown crop i.e., 1 week before and after from the normal date of sowing except for wheat. It can be attributed that in general late sown crop in rabi season will have shorter crop duration than early sown crop. In addition to this, reduction in temperature and high relative humidity also reduces the reference evapotranspiration and crop water requirements. In the case of wheat (being a winter/rabi season) the crop water requirements are low for early sowing crop than the late sowing crop, as the reproductive stage of late sowing crop would coincide the summer period. Besides this, it can be noted here that the NATCOM reported that warming is relatively more during post monsoon and winter season, which is coinciding with the crop-growing season of wheat.

### *24.3.1 Crop Water Requirement and Reference Evapotranspiration for Wheat*

Crop water requirement and reference crop evapotranspiration of wheat for the base year 1990 is more at Hardoi (447–503 mm and 534–599 mm) followed by Vidisha and Sangrur (Table 24.1). It was less at Ganganagar (262–303 mm and

**Table 24.1** Crop water requirement and reference crop evapotranspiration for wheat during 1990, 2020 and 2050

| | 1990 | | 2020 | | 2050 | |
|---|---|---|---|---|---|---|
| Date of sowing | CWR | ETo | CWR | ETo | CWR | ETo |
| **Hardoi (Uttar Pradesh)** | | | | | | |
| 15-Nov | 447.2 | 538.8 | 459.6 (2.8) | 552.9 (2.6) | 473.4 (5.9) | 571.6 (6.1) |
| 22-Nov | 475.0 | 568.2 | 488.2 (2.8) | 583.3 (2.7) | 502.2 (5.7) | 602.1 (6.0) |
| 29-Nov | 503.1 | 599.1 | 516.9 (2.7) | 615.2 (2.7) | 531.3 (5.6) | 634.1 (5.8) |
| **Vidisha (Madhya Pradesh)** | | | | | | |
| 20-Oct | 415.8 | 526.7 | 425.0 (2.2) | 537.3 (2.0) | 438.6 (5.5) | 556.4 (5.6) |
| 27-Oct | 437.1 | 547.3 | 446.9 (2.3) | 558.8 (2.1) | 460.4 (5.3) | 577.6 (5.5) |
| 04-Nov | 462.5 | 573.0 | 473.2 (2.3) | 585.4 (2.2) | 486.5 (5.2) | 604.0 (5.4) |
| **Sangrur (Punjab)** | | | | | | |
| 20-Oct | 368.1 | 476.9 | 381.3 (3.6) | 491.3 (3.0) | 392.0 (6.5) | 506.0 (6.1) |
| 27-Oct | 391.1 | 496.2 | 405.4 (3.7) | 512.0 (3.2) | 416.3 (6.4) | 526.8 (6.2) |
| 04-Nov | 420.4 | 522.5 | 435.9 (3.7) | 539.9 (3.3) | 447.1 (6.3) | 554.9 (6.2) |
| **Sirsa (Haryana)** | | | | | | |
| 20-Oct | 264.6 | 357.9 | 275.2 (4.0) | 370.0 (3.4) | 283.3 (7.1) | 381.4 (6.6) |
| 27-Oct | 281.8 | 369.1 | 293.1 (4.0) | 382.1 (3.5) | 301.4 (7.0) | 393.5 (6.6) |
| 04-Nov | 305.8 | 387.8 | 317.8 (4.0) | 401.9 (3.6) | 326.4 (6.8) | 413.4 (6.6) |
| **Ganganagar (Rajasthan)** | | | | | | |
| 20-Oct | 261.6 | 353.7 | 272.3 (4.1) | 366.0 (3.5) | 280.0 (7.0) | 376.9 (6.5) |
| 27-Oct | 278.9 | 365.0 | 290.3 (4.1) | 378.3 (3.6) | 298.2 (6.9) | 389.1 (6.6) |
| 04-Nov | 303.0 | 383.9 | 315.2 (4.0) | 398.1 (3.7) | 323.4 (6.7) | 409.1 (6.6) |

Figures in parenthesis are percentage increase in crop water requirement and reference evapotranspiration over 1990 values

354–384 mm) and at Sirsa (265–306 mm and 358–388 mm). The percentage increase in crop water requirement and reference evapotranspiration is high at Sirsa and Ganganagar in 2020 (4–4.1% and 3.4–3.7%) and in 2050 (6.7–7.1% and 6.5–6.6%) when compared to base line year 1990 data. The increase is minimum at Vidisha (2.2–2.3% and 2.0–2.2%) in 2020 and in 2050 (5.2–5.5% and 5.4–5.6%). Though the absolute amount of crop water requirement and reference evapotranspiration is low at Ganganagar and Sirsa in 1990, the percentage increase is more in 2020 and 2050 at these places.

### *24.3.2 Crop Water Requirement and Reference Evapotranspiration for Sorghum*

The highest crop water requirement and reference crop evapotranspiration for sorghum in 1990 is noticed at Mahabubnagar (369–399 mm and 532–573 mm) followed by Khargaon and Solapur (Table 24.2). The lowest values are seen at Surat (305–313 mm and 427–439 mm) and in Banda.

**Table 24.2** Crop water requirement and reference crop evapotranspiration for sorghum during 1990, 2020 and 2050

| | 1990 | | 2020 | | 2050 | |
|---|---|---|---|---|---|---|
| Date of sowing | CWR | ETo | CWR | ETo | CWR | ETo |
| **Solapur (Maharashtra)** | | | | | | |
| 25-Jun | 349.3 | 482.3 | 379.5 (8.7) | 535.4 (11.0) | 407.1 (16.6) | 574.4 (19.1) |
| 02-Jul | 348.8 | 481.2 | 373.2 (7.0) | 526.0 (9.3) | 399.9 (14.7) | 563.7 (17.1) |
| 09-Jul | 348.4 | 480.5 | 367.7 (5.5) | 517.4 (7.7) | 393.3 (12.9) | 553.9 (15.3) |
| **Khargaon (Madhya Pradesh)** | | | | | | |
| 25-Jun | 366.6 | 531.7 | 371.5 (1.3) | 538.6 (1.3) | 380.6 (3.8) | 551.5 (3.7) |
| 02-Jul | 350.3 | 509.3 | 355.1 (1.4) | 516.0 (1.3) | 364.1 (3.9) | 528.7 (3.8) |
| 09-Jul | 334.7 | 487.6 | 339.6 (1.4) | 494.3 (1.4) | 348.3 (4.1) | 506.8 (3.9) |
| **Mahabubnagar (Andhra Pradesh)** | | | | | | |
| 25-Jun | 398.8 | 573.2 | 409.6 (2.7) | 588.8 (2.7) | 424.6 (6.5) | 609.0 (6.2) |
| 02-Jul | 383.4 | 552.4 | 393.7 (2.7) | 567.3 (2.7) | 409.1 (6.7) | 587.9 (6.4) |
| 09-Jul | 368.6 | 532.0 | 378.4 (2.7) | 546.3 (2.7) | 394.0 (6.9) | 564.2 (6.0) |
| **Banda (Uttar Pradesh)** | | | | | | |
| 25-Jun | 343.9 | 497.4 | 345.8 (0.5) | 505.7 (1.7) | 364.5 (6.0) | 526.2 (5.8) |
| 02-Jul | 326.7 | 474.9 | 332.5 (1.8) | 483.1 (1.7) | 347.0 (6.2) | 503.3 (6.0) |
| 09-Jul | 309.5 | 452.2 | 315.3 (1.9) | 460.3 (1.8) | 329.6 (6.5) | 480.2 (6.2) |
| **Surat (Gujarat)** | | | | | | |
| 25-Jun | 313.1 | 439.3 | 318.6 (1.8) | 447.0 (1.7) | 326.0 (4.1) | 457.4 (4.1) |
| 02-Jul | 308.9 | 432.9 | 314.3 (1.8) | 440.5 (1.8) | 321.7 (4.1) | 450.8 (4.1) |
| 09-Jul | 305.1 | 427.1 | 310.5 (1.8) | 434.6 (1.8) | 317.8 (4.2) | 444.7 (4.1) |

Figures in parenthesis are percentage increase in crop water requirement and reference evapotranspiration over 1990 values

The percentage increase in crop water requirement and reference evapotranspiration is found maximum at Solapur during 2020 (5.5–8.7% and 7.7–11.0%) and 2050 (12.9–16.6% and 15.3–19.1%) when compared to base line year 1990 data. The increase is minimum at Banda (0.5–1.9% and 1.7–1.8%) during 2020 and at Khargaon (3.8–4.1% and 3.7–3.9%) during 2050.

### 24.3.3 *Crop Water Requirement and Reference Evapotranspiration for Maize*

Crop water requirement and reference crop evapotranspiration of maize is high at Jhabua (404–447 mm and 517–539 mm) followed by Udaipur and Karimnagar for the year 1990. It is less at Begusarai (353–388 mm and 449–489 mm) followed by Bahraich (Table 24.3). The percentage increase in crop water requirement and reference evapotranspiration is found maximum at Karimnagar in 2020 (2.0–2.1% and 2.0%) and at Begusarai (5.1–5.5% and 5.1–5.4%) in 2050 when compared to base line year 1990 data. The increase is minimum at Udaipur (0.9–1% and 0.9–1%) in 2020 and 2050 (3.1–3.2% and 3.1–3.2%).

**Table 24.3** Crop water requirement and reference crop evapotranspiration for maize during 1990, 2020 and 2050

| | 1990 | | 2020 | | 2050 | |
|---|---|---|---|---|---|---|
| Date of sowing | CWR | ETo | CWR | ETo | CWR | ETo |
| **Udaipur (Rajasthan)** | | | | | | |
| 25-Jun | 407.7 | 512.0 | 411.4 (0.9) | 516.7 (0.9) | 420.3 (3.1) | 527.7 (3.1) |
| 02-Jul | 388.8 | 490.6 | 392.4 (0.9) | 495.2 (0.9) | 400.9 (3.1) | 505.8 (3.1) |
| 09-Jul | 369.8 | 468.8 | 373.4 (1.0) | 473.3 (1.0) | 381.7 (3.2) | 483.7 (3.2) |
| **Jhabua (Madhya Pradesh)** | | | | | | |
| 20-Jun | 446.7 | 569.1 | 452.8 (1.4) | 577.1 (1.4) | 464.6 (4.0) | 591.8 (4.0) |
| 27-Jun | 424.5 | 542.6 | 430.6 (1.4) | 550.2 (1.4) | 441.9 (4.1) | 564.4 (4.0) |
| 04-Jul | 403.6 | 517.0 | 409.5 (1.5) | 524.4 (1.4) | 420.4 (4.2) | 538.1 (4.1) |
| **Bahraich (Uttar Pradesh)** | | | | | | |
| 25-Jun | 427.3 | 534.4 | 432.4 (1.2) | 541.0 (1.2) | 447.1 (4.6) | 558.5 (4.5) |
| 02-Jul | 407.4 | 512.4 | 412.1 (1.1) | 518.6 (1.2) | 426.5 (4.7) | 536.2 (4.6) |
| 09-Jul | 387.1 | 489.6 | 391.4 (1.1) | 495.5 (1.2) | 405.5 (4.8) | 512.2 (4.6) |
| **Karimnagar (Andhra Pradesh)** | | | | | | |
| 15-Jun | 444.1 | 560.4 | 453.3 (2.1) | 571.7 (2.0) | 459.7 (3.5) | 579.7 (3.5) |
| 22-Jun | 424.7 | 537.4 | 433.4 (2.0) | 548.3 (2.0) | 440.0 (3.6) | 556.4 (3.5) |
| 29-Jun | 406.0 | 515.0 | 414.4 (2.1) | 525.6 (2.0) | 421.2 (3.7) | 533.7 (3.6) |
| **Begusarai (Bihar)** | | | | | | |
| 17-Jun | 387.5 | 489.2 | 393.2 (1.5) | 496.2 (1.4) | 407.9 (5.3) | 514.4 (5.1) |
| 24-Jun | 370.0 | 467.8 | 374.7 (1.3) | 474.7 (1.5) | 388.9 (5.1) | 492.4 (5.3) |
| 30-Jun | 353.4 | 449.4 | 359.2 (1.6) | 456.4 (1.6) | 373.0 (5.5) | 473.6 (5.4) |

Figures in parenthesis are percentage increase in crop water requirement and reference evapotranspiration over 1990 values

### 24.3.4 Crop Water Requirement and Reference Evapotranspiration for Pearl Millet

The highest crop water requirement and reference crop evapotranspiration of pearl millet is observed at Barmer (324–352 mm and 486–525 mm) followed by Gulbarga and Ongole (Table 24.4). The lowest is noticed at Bhiwani (283–311 mm).

The percentage increase in crop water requirement and reference evapotranspiration is more at Ongole in 2020 (2.7–2.8% and 2.7–2.8%) and in 2050 at Gulbarga (5.6–6.0% and 5.4–5.8%) when compared to base line year 1990 data. The increase is less at Barmer (0.1–0.4% and 0–0.3%) in 2020 and in 2050 (2.6–3% and 2.5–2.9%). It can be noticed that the increment is more at two south Indian stations viz., Ongole and Gulburga and low at northwest Indian station Barmer.

## 24.4 Adaptation Strategies

The results of the study clearly indicate that, the impact of climate change could increase crop water requirement and influence negatively on yield levels unless their need is fulfilled. It is big challenge in the coming decades about increasing

**Table 24.4** Crop water requirement and reference crop evapotranspiration for pearl millet during 1990, 2020 and 2050

| | 1990 | | 2020 | | 2050 | |
|---|---|---|---|---|---|---|
| Date of sowing | CWR | ETo | CWR | ETo | CWR | ETo |
| **Barmer (Rajasthan)** | | | | | | |
| 05-Jul | 351.8 | 524.7 | 352.2 (0.1) | 524.9 (0.0) | 361.1 (2.6) | 537.9 (2.5) |
| 12-Jul | 337.8 | 505.3 | 338.6 (0.2) | 506.1(0.2) | 347.4 (2.8) | 518.9 (2.7) |
| 19-Jul | 323.7 | 485.5 | 325.0 (0.4) | 487.0 (0.3) | 333.5 (3.0) | 499.5 (2.9) |
| **Nasik (Maharashtra)** | | | | | | |
| 15-Jun | 294.3 | 438.3 | 299.9 (1.9) | 446.5 (1.9) | 306.8 (4.3) | 456.4 (4.1) |
| 22-Jun | 284.2 | 424.1 | 289.9 (2.0) | 432.2 (1.9) | 296.9 (4.5) | 442.3 (4.3) |
| 29-Jun | 274.2 | 409.7 | 279.9 (2.1) | 418.0 (2.0) | 287.0 (4.7) | 428.3 (4.5) |
| **Agra (Uttar Pradesh)** | | | | | | |
| 20-Jun | 288.1 | 427.2 | 290.5 (0.8) | 431.0 (0.9) | 300.4 (4.3) | 445.2 (4.2) |
| 27-Jun | 277.5 | 412.9 | 279.7 (0.8) | 416.4 (0.8) | 289.7 (4.4) | 430.7 (4.3) |
| 04-Jul | 266.4 | 397.8 | 268.4 (0.8) | 401.0 (0.8) | 278.4 (4.5) | 415.3 (4.4) |
| **Gulbarga (Karnataka)** | | | | | | |
| 15-Jun | 334.4 | 496.6 | 343.0 (2.6) | 509.2 (2.5) | 353.1 (5.6) | 523.6 (5.4) |
| 22-Jun | 325.2 | 483.4 | 333.5 (2.6) | 495.6 (2.5) | 344.0 (5.8) | 510.5 (5.6) |
| 29-Jun | 316.3 | 470.4 | 324.4 (2.6) | 482.4 (2.5) | 335.2 (6.0) | 497.7 (5.8) |
| **Ongole (Andhra Pradesh)** | | | | | | |
| 15-Jun | 330.5 | 488.6 | 339.6 (2.8) | 502.3 (2.8) | 348.2 (5.4) | 514.7 (5.3) |
| 22-Jun | 320.2 | 474.7 | 328.9 (2.7) | 487.9 (2.8) | 337.6 (5.4) | 500.4 (5.4) |
| 29-Jun | 309.4 | 460.1 | 317.8 (2.7) | 472.6 (2.7) | 326.5 (5.5) | 485.3 (5.5) |

Figures in parenthesis are percentage increase in crop water requirement and reference evapotranspiration over 1990 values

food production with less water particularly when the major river basins will have limited water resources and reduction in ground water availability. Improved water management practices that increase the productivity of irrigation water use may provide significant adaptation potential for all land production systems under future climate change. A number of adaptation policies are suggested in literatures. The policies suggest specific measures for water resources and agriculture that could reduce the potential adverse effects of climate change on crop evapotranspiration and yield. Micro-irrigation and resource conservation technologies (RCTs), economizing on water is to be promoted in a big way. The conjunctive use of water and diversification of rice-wheat is required for solving the emerging problem associated with climate change. At the same time, improvements in irrigation efficiency are critical to ensure the availability of water both for food production and for competing human and environmental needs. High volume of wastewater (18.4 million $m^3$/day) needs to be utilized for irrigation after their proper treatment. Options for autonomous adaptation are already available to farmers and communities to cope with the future water shortage related risk management and production enhancement activities. These include (i) Adoption of varieties with increased resistance to high temperature and drought. (ii) Modification of irrigation techniques, including amount, timing or technology. (iii) Improved water management to prevent water logging, erosion and leaching. (iv) Adoption of efficient technologies to 'harvest' water. (v) Conserve soil moisture (e.g. crop residue retention), and reduce siltation and saltwater intrusion. (vi) Modification of crop calendars, i.e., timing or location of cropping activities (Bates et al. 2008).

In general, projections suggest that the greatest relative benefit from adaptation is to be gained under conditions of low to moderate warming, and that adaptation practices that involve increased irrigation water use may in fact place additional stress on water and environmental resources as warming and evaporative demand increase.

## 24.5 Conclusions

The present study indicates the crop water requirement and reference crop evapotranspiration is high for maize followed by sorghum and wheat and the low for pearl millet in 1990. However, the lowest crop water requirement (260–300 mm) is noticed for wheat at northwest Indian stations like Sirsa and Ganganagar, which could be due to regional weather influence during crop growing season. In the case of percentage increase in crop water requirement and reference crop evapotranspiration, highest is noticed at Solapur for sorghum, Sirsa and Ganganagar for wheat, Karimnagar and Begusarai for maize in 2020 and 2050 respectively, and at Ongole and Gulburga for pearl millet. It is important to notice that though the actual values of crop water requirement and reference evapotranspiration is low at Ganganagar and Sirsa in 1990, the percentage increase is more in 2020 and 2050 at these places when compared to other wheat growing stations. These stations come under water scarcity zone and adequate measures to augment irrigation water availability in order to sustain wheat production. However, given the potential adverse impacts on water resources that could be brought about by climate change, it is worthwhile to conduct more in-depth studies and analyses to gauge the extent of problems that the country may face. Climate change is posing a challenge in front of the scientists concerned with water resources, policy makers and most importantly farmers.

## References

Abrol IP (1996) India's agriculture scenario. In: Abrol YP, Gadgil S, Pant GB (eds) Climate variability and agriculture. Narosa Publishing House, London, pp 19–25

Allen RG, Pereira LS, Rase D, Smith XM (1998) Crop evapotranspiration. Guidelines for computing crop water requirements. Irrig. & Drain. Paper 56 Food and Agricultural Organisation, Rome

Bates BC, Kundzewicz ZW, Wu S, Palutikof JP (eds) (2008) Climate change and water. technical paper of the intergovernmental panel on climate change. IPCC Secretariat, Geneva

FAO (2005) New_LocClim. climatological database of the agromet group of FAO. Food and Agricultural Organisation, Rome

Gadgil S, Abrol YP, Seshagiri Rao PR (1999) On growth and fluctuation of Indian foodgrain production. Curr Sci 76(4):548–556

Huntington TG (2006) Evidence for intensification of the global water cycle: review and synthesis. J Hydrol 319:83–95

Katyal JC (1998) Soil, water and environmental Sciences In: Porceedings of brainstorming session on 'Scientists perception for agriculture-2020 NBPGR New Delhi, India, 4–5 June 1998

Kumar R, Singh RD, Sharma KD (2005) Water resources of India. Curr Sci 89(5):794–811

Mall RK, Gupta A, Singh R, Singh RS, Rathore LS (2006) Water resources and climate change: an Indian perspective. Curr Sci 90(12):1610–1626

McCabe GJ Jr, Wolock DM (1992) Sensitivity of irrigation demand in a humid-temperature region to hypothetical climate change. Water Resour Bull 28(3):533–543

Sharma BR (2006) Crop water requirements and water productivity: concepts and practices. Groundwater governance in Asia. http://www.waterandfood.org/gga/ Lecture%20Material/ B.R. Sharma_CWR&WP.pdf

Smith M (1992) CROPWAT. A computer program for irrigation planning and management. Irrig. & Drain. Paper 46 FAO, Rome

Smith M (1993) CLIMWAT for CROPWAT. A climatic database for irrigation planning and management. Irrig, & Drain, paper, 49, Food and Agricultural Organisation, Rome