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Water Harvesting Potential Prediction for Budelkani Watershed for Design of Runoff Recycling Irrigation Pond

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ABSTRACT

Water harvesting potential was simulated for Budelkani watershed of Sundargarh district, Odisha, India, predicted using water balance model. Model was simulated for 23 years (1983-2015) for short duration variety of rice (108 days). Simulation was done in two variations, firstly in seasonal basis, secondly stage wise. At 50% PE, for 50 mm PWL, SR, rainfall, SI and WHP were best fitted at 120.13 mm, 1144.1 mm, 91.96 mm and 1.52 respectively. They were best fitted by Log-pearson, pareto, EV Type III and pareto respectively. Similarly stage wise, SR also more in stage 1 than stage 2 at quantity of 66.54 and 7.55 mm, respectively and there WHP were calculated to be 1.31. At 50% PE, seasonal values of SR, WHP and SI recorded at 66.23 mm, 1.1 and 79.03 mm, for 100 mm PWL, respectively. They were best fitted by Gamma, Log-pearson and Log normal, respectively. While stage wise, SR at 50% PE were found to be 32.57 to 16.99 mm for stage 1 and stage 2 and WHP at 50% PE, found to be 1.01 in 100 mm PWL. Log-pearson, EV Type III and Log-normal (3-P) PDF were best fitted to SR, WHP and SI at seasonally for 150 mm PWL. At 50% PE, SR, WHP and SI value lies at 65.94 mm, 1.02, 67.72 mm. For 150 mm PWL, best fitted values of SR at 50% PE, for stage 1 and stage 2 were observed to be 15.3 mm, 12.32 mm and likewise, WHP found to be 1.

Keywords Simulation, WHP, Water balance model.

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INTRODUCTION

As the scarcity of water is rapidly increasing everyday particularly during the summer season, the demand for water also substantially increases. It is said that "If third world war take places it will be on water". The shortage of water can be substantially alleviated. A significant amount of precipitation falls on Earth's surface and runs off into rivers, streams, and the sea. Just 8% of all rainfall, on average, replenishes ground aquifers. (Rainwater Harvest Report 2015, IRICE, Pune). The term "rainwater endowment" refers to the entire volume of water that falls as rain over a given area. The quantity that can be efficiently extracted from this is known as the water harvesting potential. The structures that are built for watershed management implies an overall improvement in water scenario (Saha *et al.* 2018).

For the selection of suitable sites, many guidelines have been used by various agencies guidelines from organizations like the Food and Agriculture Organization (FAO), the Integrated Mission for Sustainable Development (IMSD), (Naseef and Thomas 2016). Most of the guidelines are neither comprehensive nor accessible by end user such as farmer, local developer. Hence, present study is under taken to develop comprehensive methodology for determination of water harvesting potential of watershed. Water harvesting potential was determined for farming rice in *kharif* and greengram in *rabi* season.

MATERIALS AND METHODS

Study area

The Budelkani micro-watershed area situated in the rainfed region of Sundargarh district, Odisha, India. It includes three villages namely Budelkani, Majhapara and ledimong with total geographical area of 651.25 ha. The watershed is located 32 kilometers away from the district of Sundargarh. It is situated between N 22° 0' 33'' to 22° 1' 22'' Latitude and E 84° 10' 57'' to 84° 13'14'' Longitude. The information was gathered from the KVK Sundargarh over a 23-year span, from 1993 to 2015. This watershed receives 1138.62 mm of rain annually on average. The maximum temperature was observed to be 45°C in the month of May and minimum was 4°C in the month of December, respectively. The minimum and maximum relative humidity varied from 23.1−94.3% in month of February and September, respectively. The local wind speed in the area was very low at 0.27−1.6 ms^{-1}. The climatic condition of study area is humid and subtropical in nature. The elevation of Budelkani watershed is 265 m from the mean sea level.

Simulation of water harvesting potential (WHP)

Considering the effective root zone of rice (45 cm) as a single layer and assuming the capillary contribution to the rice field from the deep groundwater table as zero and the horizontal seepage inflow and outflow through the rice field bunds as equal, the generalized water balance model of rice under drying or unsaturated phase is:

$$SMC_i = SMC_{i-1} + P_i + SI_i - AET_i - SP_i - SR_i$$

Where, SI = supplemental irrigation and SR = Surface runoff from the field. SMC = Soil moisture content, mm, P = Rainfall, mm, SP = seepage and percolation loss, mm; AET = Actual evapotranspiration, mm, the notation i stand for the time index taken as 1 day in the study.

Supplemental irrigation (SI)

A precious resource in the rainfed farming system is irrigation water. Thus, when applying SI to rice during the Critical Growth Stage (CGS), the water-saving irrigation (WSI) technique must be used. Different WSI methods reduce the SP losses in the field, which improves the water use efficiency of the crop. According to Khairi *et al.* (2015), optimal rice production can be maintained in a farmer's field by applying irrigation water at saturated to 1 cm ponding. In this investigation, SI from RRIP is applied when 20% SMC depletion from SAT is the maximum acceptable deficit (MAD) in the effective root zone during the reproductive stage and the remaining rice periods are regarded as rainfed completely. At each irrigation, a 50 mm depth of water is applied from the RRIP.

Surface runoff from rice field

From sowing to the first 10 days after germination of rice and the last 10 days before harvest, no standing water is allowed in the field. Surface runoff on i^{th} day during these periods is given as (Panigrahi *et al.* 2005).

$$SR_i = SMC_{i=1} + P_i - SAT$$

During the rest of the periods, 50-, 100- and 150-mm ponding depth is taken as the maximum limit in the field (D_{MAX} = 50 mm, D_{MAX} =100 mm and D_{MAX} =150 mm) and any excess ponding above D_{MAX} is taken as the SR and is given as:

$$SR_i = SMC_{i-1} + P_i + SI_i - SAT - D_{MAX}$$

The units of all the parameters of above equations are given in mm.

Actual evapotranspiration

Actual evapotranspiration is computed by the AET model as described as below

$$AET_i = Kc_i - Ks_i - ET_{0i}$$

Where, K_c = Dimensionless crop coefficient, K_s = Dimensionless crop stress coefficient and ET_0 = Reference crop evapotranspiration in mm/day.

Daily ET_0 was estimated by the utilizing the Penman-Monteith technique for simulation period. Values of K_c of rice for the prevailing climate condition of the field of research area assumed as 1.05 throughout the establishment of the crop (CE), 1.10 for both crop development (CD) and mid-season (MS) and 0.95 for the late season (LS) stage (Panigrahi *et al.* 2005).

Ks_i is seen to change linearly with the proportion of SMC that is accessible (ratio of SMC to the saturation moisture content in the crop effective root zone) in the field under the unsaturated condition as:

$$Ks_i = \frac{SMC_i}{SAT}$$

Seepage and percolation

The model relates SP losses with the equilibrium of soil moisture in the effective root zone (Panigrahi and Panda 2001) as:

$$SP_i = -16.45 + 0.145\ SMB_i\ (R^2 = 0.87)$$

However, under the drying phase, the soil moisture balance (SMB) on the i^{-th} day is given (Panigrahi and Panda 2001) as

$$SMB_i = SMC_{i-1} + P_i + SI_i - AET_i - SR_i$$

Under the ponding phase, SMB is:

$$SMB_i = D_{i-1} + SAT + P_i + SI_i - AET_i - SR_i$$

The unit of all the terms of above equation is given in depth units of mm.

Every day in the end, the model computes the value of SP whereas P, SI and SR are believed that this will happen at the beginning of the day.

Simulation technique of WHP

The simulation ran for 23 years (1983-2015) period and thus different parameters of WHP i.e., daily SI and SR calculations were made. The previously mentioned two parameters' daily and weekly values were computed for different years for different ponding water levels i.e., 50, 100 and 150 mm, respectively. Similarly, seasonal values of SI and SR in the growing season, there were calculated for 50-, 100- and 150-mm ponding water levels, respectively. From seasonal data, WHP was calculated simply by taking the ratio of SR while the plants are growing to seasonal SI given to the crop.

Also, WHP was simulated in the current research at two different stages. The length of the first stage (stage 1) is from the time seeds are sown until the last irrigation in the reproductive stage. The corresponding second stage (stage 2) is from the last irrigation in the reproductive stage till the harvest of rice.

The length of these two phases varies from year to year based on when rice was last given supplemental irrigation. Rainfall in the two stages mentioned above, together with the related SR and SI, are derived from the daily simulation research. The phrase "WHP" is denoted by the runoff ratio i.e., the proportion of SR in stage 1 to last SI in the reproductive stage for their respective ponding water level i.e., 50, 100 and 150 mm, respectively.

RESULTS AND DISCUSSION

Water balance model (WBM) parameters at 50 mm ponding water level (PWL)

Stage wise WBM parameters for 50 mm PWL for different PE levels were shown in Fig. 1. Log-pearson, Pareto, Gamma and EV Type III have been found to be best fitted PDFs for WHP, rainfall, SR, and SI, respectively for stage 1. Rainfall and SR has been found

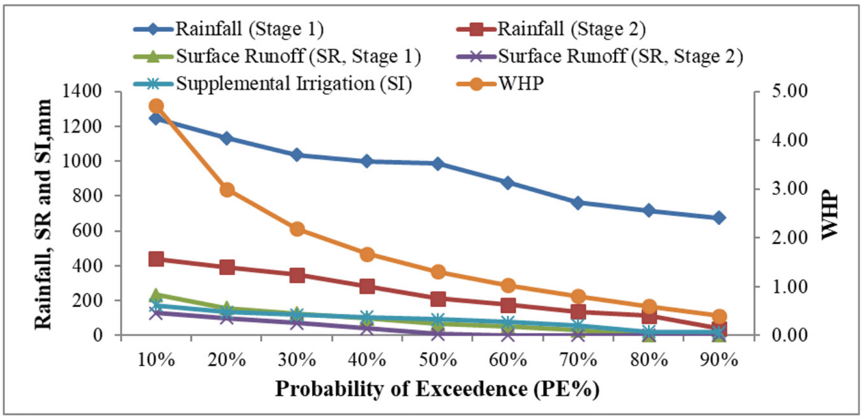

Fig. 1. Stage wise rainfall, SR, SI, and WHP variations at different PE levels for 50 mm PWL.

to be best fitted by RMSE and ME values at 0.037, 0.028 and 0.029, 0.024, respectively. While, in stage 2, Pareto and EV Type III were best fitted with 0.39 and 0.031 for rainfall and 0.061 and 0.051 for SR, respectively by model performance indicator (MPI). AT 50% PE, rainfall in both stages was observed as 985.30 mm and 213.50 mm, which indicated that rainfall in stage 1 is more than four times rainfall in stage 2. However, SR is also more in stage 1 (66.51 mm) than in stage 2 (7.55 mm) and there WHP were calculated and found to be 1.31, which proved that there is the potential for water harvesting.

Total rainfall during the first stage was noted to be in the range of 354.82 to 1471.4 mm in different years. Average rainfall over 23 years for stage 1 and stage 2 became known to be 937.53 and 240.93 mm, respectively, while SR has been determined to be 121.12 mm for stage 1 and 33.01 mm for stage 2. It was detected that SR generated over 23 years were 13.07% of total rainfall. There minimum and maximum WHP of RRIP was found to be 0 and 4.3, respectively.

The probability of exceedance of SR, SI, rainfall and WHP at different probabilities from 10 to 90% for 50 mm PWL at a seasonal level were shown in Fig. 2. The water balance model (WBM) parameter, i.e., rainfall at a seasonal level for different probabilities varied from 1683.1 to 728.74 mm for 10 to

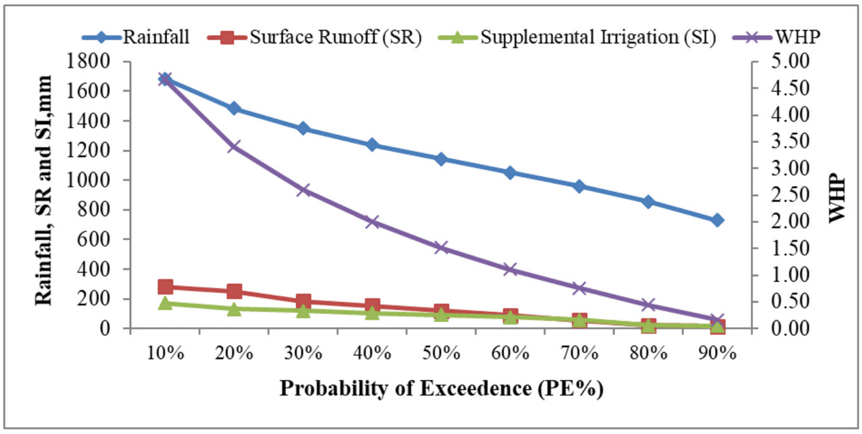

Fig. 2. Seasonal variation of rainfall, surface runoff, supplemental irrigation and water harvesting potential at different PE levels for 50 mm PWL.

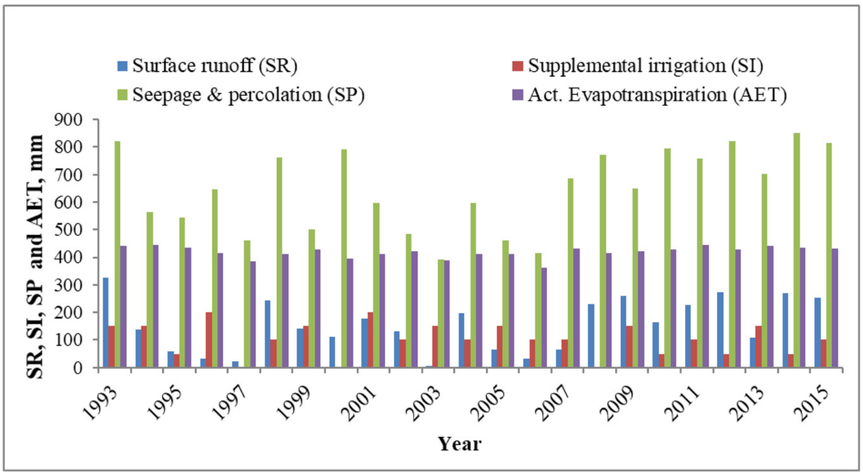

Fig. 3. Simulation results of seasonal values of water balance parameters at 50 mm ponding of water level.

90% PE. Similarly, other parameters such as SR and SI varied from 283.50 to 14.50 mm and 172.44 to 18.40 mm, respectively. Also, seasonal WHP varied from 4.67 to 0.16 at 10 to 90% PE, respectively. From 11 probability distribution functions (PDF), Log-pearson, Pareto, EV Type III and Pareto were found to be best fitted by RMSE and ME values at 0.0402 and 0.0320 for rainfall, 0.0275 and 0.0212 for SR, 0.0784 and 0.0627 for SI and 0.0340 and 0.0271 for WHP, respectively. At 50% PE, for 50 mm PWL, SR, rainfall, SI and WHP were best fitted at 120.13 mm, 1144.1 mm, 91.96 mm and 1.52, respectively. A WHP value greater than 1 indicated that the seasonal rainfall was adequate in the area to harvest, so that it can meet crop water need whenever required.

All simulated result of seasonal values of water balance parameters at 50 mm ponding of water level were shown in Fig. 3.

Water balance parameters at 100 mm PWL

From the record, it was reported that 8.35% of the mean rainfall during stage 1 was converted to surface runoff. But, when it comes to stage 2, 9% of total mean

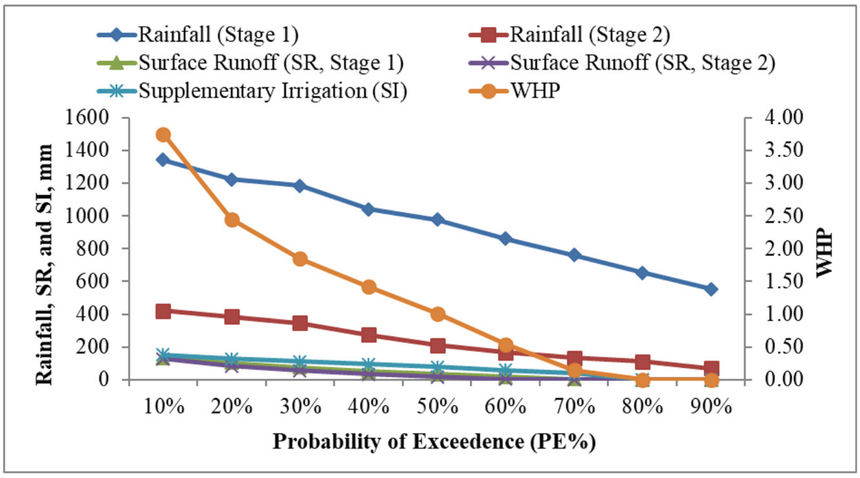

Fig. 4. Stage wise rainfall, SR, SI, and WHP variations at different PE levels for 100 mm PWL.

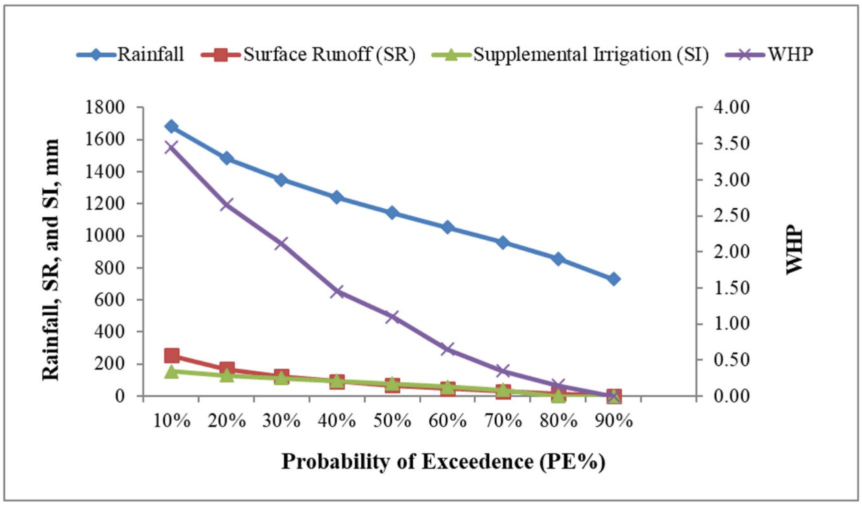

Fig. 5. Seasonal variation of rainfall, surface runoff, supplemental irrigation and water harvesting potential at different PE levels for 100 mm ponding water level.

rainfall was converted to SR. Total SR (stage 1+ stage 2) in 100 mm ponding water level was 8% of total seasonal rainfall. Stage wise variation of rainfall and SI at different probability levels were shown in Fig. 4. The Log-normal and Pareto probability distribution came out to be best fitted to rainfall events in stage 1 and stage 2, respectively, and their RMSE and ME values turned out to be (0.05, 0.39) and (0.045, 0.036), respectively. Similarly, Log-pearson and Pareto distribution were best fitted to SR for stage 1 and stage 2, respectively. Their RMSE and ME values in sequence are (0.059, 0.045) and (0.032, 0.024), respectively.

At 50% PE, values of rainfall at stage 1 and stage 2 were revealed to be 976.4 and 210.5 mm, respectively. While, SR at 50% of the PE level was determined to be 32.57 and 16.99 mm for stage 1 and stage 2, respectively. Comparing 100 mm PWL with that of 50 mm PWL, it has been noted that the SI at 50% PE level was reduced to 79.03 mm from 105.47 mm

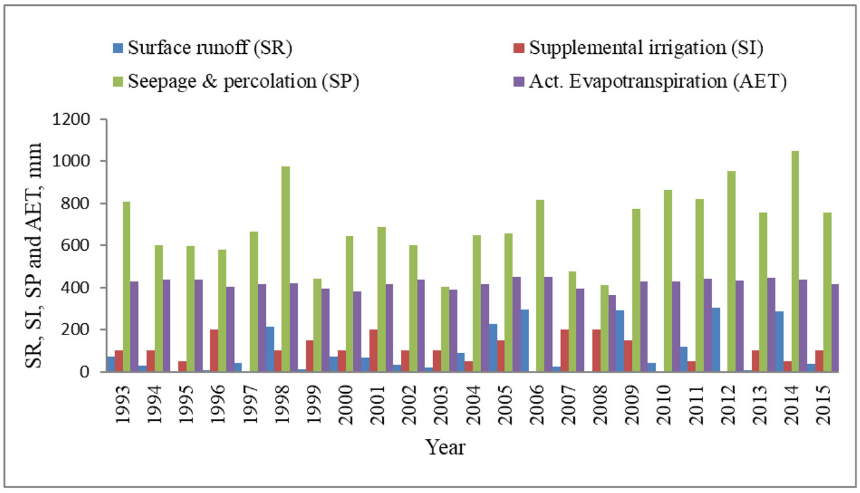

Fig. 6. Simulation of seasonal values of water balance parameters for 100 mm ponding water level.

on average. It was reduced that due to more ponding depth in the rice field there is less requirement of SI. Due to an increase in the depth of ponding, WHP at 50% PE level, was reduced from 1.31 in 50 mm PWL to 1.01 in 100 mm PWL. Where, WHP is above 1.0 which also indicates that, a research area has water harvesting potential.

The 23-year interval's seasonal values of SR, SP and AET for 100 mm PWL were varied in range of 0 to 305 mm, 401.14 to 1046.61 mm and 365.26 to 452.28 mm, respectively, with CV values of 1.06, 0.24 and 0.053, respectively. As compared to 50 mm PWL, the mean of SR reduces from 153.51 to 99.62 mm, whereas, SP and AET increased from 647.06 to 694.12 mm and 419.36 to 420.44 mm, respectively. The SD for SR, SP and AET has been found to be 106.44, 171.74 and 22.41, respectively. However, the coefficient of skewness for SR, SP and AET. It was determined to be 1.03, 0.14 and -0.79, respectively. The seasonal WHP varied from 0 to 5.72, while their mean, SD, CV, and skewness to 0.81, 1.29, 1.58 and 2.61, respectively.

The probability of above mentioned seasonal values was computed for different PDFs from 10 to 90% PE and shown in Fig. 5. The computed RMSE and ME values of Gamma, Log-pearson and Log-normal distributions confirmed to be (0.001, 0.028), (0.051, 0.041) and (0.073, 0.061), for SR, WHP and SI, respectively. Seasonal values at the 50% PE level of SR, WHP and SI were computed as 66.23 mm, 1.1 and 79.03 mm, respectively.

All simulated result of seasonal values of water balance parameters at 100 mm ponding of water level were shown in Fig. 6.

Water balance parameters at 150 mm PWL

Stage wise variation at different PE levels for 150 mm PWL for rainfall, SR, SI WHP were shown in Fig. 7. At 150 mm PWL, Log-normal, EV Type III was best fitted to rainfall and SR, respectively for RMSE and ME values of 0.048, 0.038 and 0.081, 0.068 for stage 1, respectively. While, EV Type III and Pearson were best fitted to rainfall and SR with RMSE and ME values of (0.061, 0.049) and (0.039, 0.032) for stage 2, respectively. Further, SI and WHP were best fitted to Log-normal (3 P) and EV Type III with RMSE and ME values of (0.0714, 0.0593) and (0.093, 0.073), respectively for stage 1 alone. Surface runoff that occurred in stage 1 was 4.45% of total rainfall in stage 1. Similarly, SR in stage 2 was 8.9% of total rainfall in stage 2. As compared to 100 mm PWL, SR in stage 1 of 150 mm PWL, was seen to be decreased by 40.17%, while in stage 2, it was decreased by 4.7%. Best fitted values of rainfall and SR at 50% PE, for stage 1 and stage 2 were observed to be (972.6 mm, 236.50) mm) and (15.3 mm, 12.32 mm), respectively. Likewise, WHP and SI at 50% PE were observed to be 1 and 67.72 mm, respectively.

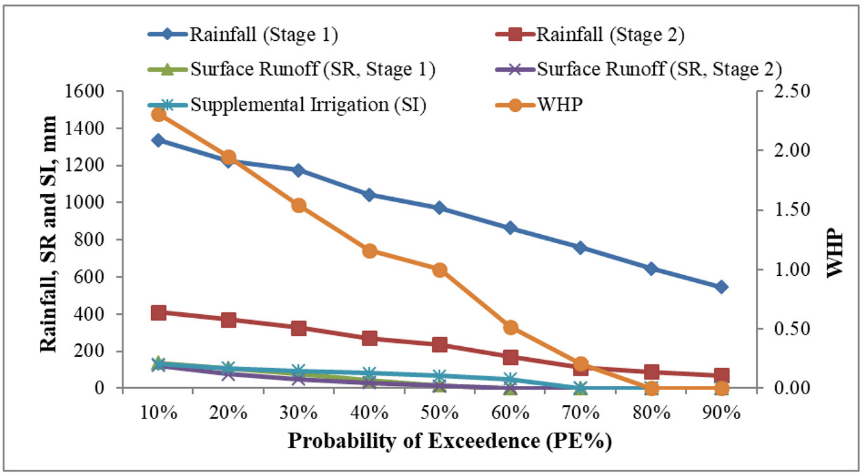

Fig. 7. Stage wise variation of rainfall, SR, SI and WHP at different PE levels for 150 mm PWL.

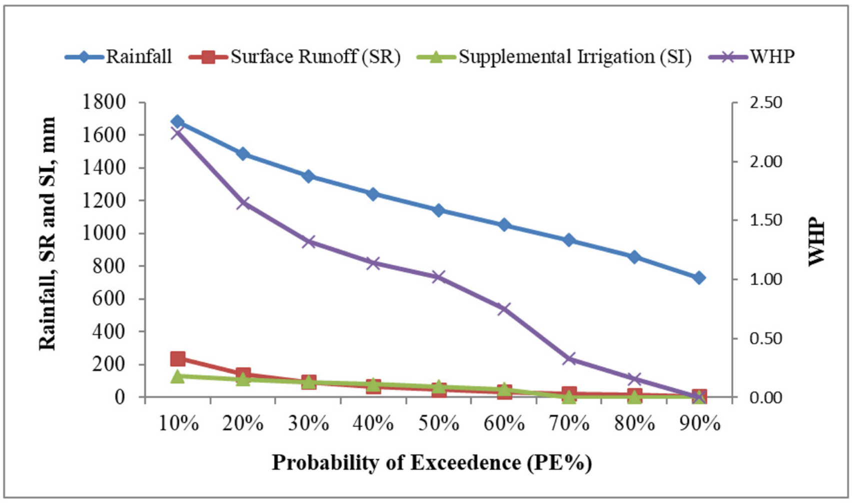

Fig. 8. Seasonal variation of rainfall, surface runoff, supplemental irrigation and water harvesting potential at different PE levels for 150 mm PWL.

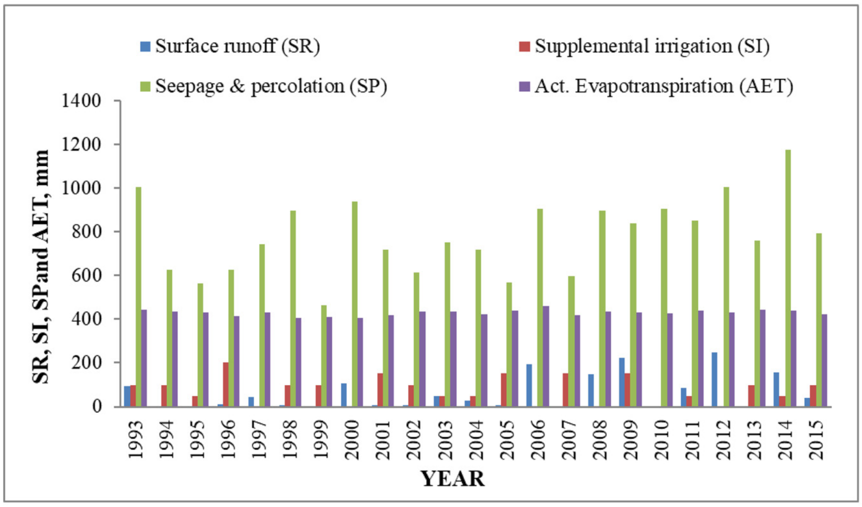

Fig. 9. Simulation of seasonal values of water balance parameters at 150 mm PWL.

Seasonal simulated WBM parameters such as SR, SP and AET were shown in Fig. 8 which varied from 0 to 249.57 mm, 462.86 to 1175.64 mm and 406.21 to 461.03 mm, respectively. Hence, due to variation, different PE were calculated from 10 to 90% by different PDFs and their best fit was presented in Fig. 8. The coefficient of variation for SR, SP and AET were observed as 1.23, 0.21 and 0.03, respectively. Comparing the mean of WBM parameters of 150 mm PWL to 100 mm PWL, it was noted that SR was decreased by 37.07% from 99.61 to 62.55 mm, while SP and AET were found to increase by 12.58 and 2.17% at 100 mm PWL. Their performance was also studied by SD and Skewness from observed values of 77.51, 1.19 for SR, 169.91, 0.22 for SP and 13.13, -0.03 for AET. Log-pearson, EV Type III and Log-normal (3-P) PDFs were best fitted to SR, WHP and SI seasonally. They were best fitted by RMSE and ME at 0.065, 0.053 for SR, 0.07, 0.056 for WHP and 0.071, 0.059 for SI. At 50% PE, SR, WHP and

SI value lies at 65.94 mm, 1.02, 67.72 mm. As WHP was still above 1, which indicates that there is water harvesting potential.

All simulated result of seasonal values of water balance parameters at 150 mm ponding of water level were shown in Fig. 9.

CONCLUSION

Seasonal variation of WHP, SR, SI and rainfall for 50 mm PWL at different PE level were best fitted by pareto, pareto, EV Type III and Log-pearson. At 50% PE, for 50 mm PWL, SI, rainfall, SR, and WHP were best fitted at 91.96 mm, 1144.1 mm, 120.13 mm and 1.52, respectively. A value of WHP greater than 1 indicates the rainfall were adequate in area to harvest, so that it can meet crop water need when require.

Stage wise WBM parameters for 50 mm PWL, at 50% PE, rainfall in both stages were observed as 985.30 and 213.50 mm, which indicate that rainfall in stage 1 is more than four times of rainfall in stage 2. However, SR also more in stage 1 than stage 2 at quantity of 66.54 and 7.55 mm, respectively and there WHP were calculate to be 1.31, which proves to be there is scope of potential of water harvesting.

At 50% PE, seasonal values of SR, WHP and SI recorded at 66.23 mm, 1.1 and 79.03 mm, for 100 mm PWL, respectively. They were best fitted by Gamma, Log-pearson and Log normal, respectively. A value of WHP greater than 1 indicates the rainfall were adequate in area to harvest, so that it can meet crop water need when require.

At 50% PE, for 100 mm PWL, values of rainfall at stage 1 and stage 2 were revealed to be 976.4 and 210.5 mm, respectively. While, SR at 50% PE were found to be 32.57 to 16.99 mm for stage 1 and stage 2 and WHP at 50% PE, found to be 1.01 in 100 mm PWL. As WHP above 1 which also indicate that, study area has water harvesting potential.

Log-pearson, EV Type III and Log-normal (3-P) PDF were best fitted to SR, WHP and SI at seasonally for 150 mm PWL. At 50% PE, SR, WHP and SI value lies at 65.94 mm, 1.02, 67.72 mm. As WHP was still above 1, which indicate there is water harvesting potential.

For 150 mm PWL, best fitted values of rainfall and SR at 50% PE, for stage 1 and stage 2 were observed to be 972.6 mm, 236.50 mm and 15.3 mm, 12.32 mm, respectively. Likewise, SI and WHP at 50% PE were observed to be 67.72 mm and 1, respectively.

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