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Sensitivity analysis of water footprint in paddy

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ABSTRACT

Water is an incredibly important aspect of our daily lives. Water footprint assessment is a fast growing field of research, but as yet little attention has been paid to the uncertainties involved. The study investigates the sensitivity analysis of water footprint conducted in Samrakalwana village near Allahabad, UP, India. Water footprint was calculated for Paddy crop and factors that influencing the water footprint is identified. Sensitivity analysis was done for the parameters influencing on water footprint with One-at-a-time method (OAT), for parameters like reference evapotranspiration (ET_0), Crop Coefficients (Kc), Precipitation (PR), Crop planting date, Field capacity of soil moisture (Smax) and Yield(Y).The results shows that the water footprint of Paddy is 3384.701l/kg. The parameters like ETo, Kc, PR and Smax are changed within the range of ±90% and Crop Planting Date changes within range of ±30% and yield is changed within range of ±50%. The water footprint is most sensitive in ET_0, Kc, PR followed by yield. Sensitivity Index Parameters have calculated and for increasing the yield of Paddy crop certain recommendations have been explained.

Keywords: *Water Footprint, Sensitivity Analysis, Crop Water Use and Yield*

1. INTRODUCTION

Water is an incredibly important aspect of our daily lives. Every day we drink water, cook with water, bathe in water, and participate in many other activities like agricultural and industrial purpose. Unfortunately, water is increasingly becoming scarce in many parts of the world. Water scarcity can be the result of both human and natural causes. Changes in climate and weather patterns can cause the availability of water to drop. This has led to scientific approach to water resources planning, development and management. Continuous repetitive observations in space and time are needed to provide the necessary input data for water balance models too. It will help to better understand the complex processes and interactions that are involved in modeling (*Kampman,2007*).

The concept of the water footprint has been introduced to create a consumption-based indicator of water use (*Falkenmark,2004*). This in contrast to the traditional production-sector-based indicators of water use, that are useful in water management but do not indicate the water that is actually needed by the inhabitants of a country in relation to their consumption pattern (*Falkenmark,2004*). The water footprint is defined as the volume of water needed for the production of the goods and services consumed by the inhabitants of a country (*Hoekstra*). The water footprint can be divided into an internal and an external water footprint. The internal component covers the use of domestic water resources and the external component covers the use of water resources elsewhere. Water footprints within the agricultural sector have been extensively studied, mainly focusing on the water footprint of crop production. Finally, the water footprint can be divided into a blue, a green and a gray water footprint. The blue component covers the use of groundwater and surface water during the production of a commodity, the green component covers the use of rain water for crop growth, and the gray component covers the water required to dilute the water that is polluted during the production of the commodity (*Mesfin,2014*).

The factors that influencing the crop water footprint are precipitation, reference evapotranspiration, crop coefficient, crop planting date, water stress factor, soil moisture and yield. The changes in these parameters are effects the crop water footprint.

Sensitivity Analysis is a technique used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions. This technique is used within specific boundaries that will depend on one or more input variables *(Zhuo, 2014)*. Sensitivity analysis is very useful when attempting to determine the impact the actual outcome of a particular variable will have if it differs from what was previously assumed. By creating a given set of scenarios, the analyst can determine how changes in one variable(s) will impact the target variable. It has been observed that the global water footprint of paddy varies drastically (*Zhuo, 2014*).To understand the sensitivity of water footprint to input parameters will help us to recommend practices as and when a particular parameter influences the water footprint adversely. In the view of above, a study was conducted on "Sensitivity analysis in crop water footprint" for paddy grown in Samrakalwana village with the following objectives: To investigate the sensitivity of parameters influencing crop water footprint. To recommend agricultural practices beyond the acceptable parameter range.

2. STUDY AREA

Allahabad is situated in Southern Eastern part of the state Uttar Pradesh. The study area in Allahabad is the Samrakalwana village a part of trans. Yamuna and lies within the Latitude 25.17N, Longitude 81.49E. This village is rich in water resources and has paddy and wheat as the main cropping pattern. It is irrigated by a canal as well as around fourteen ponds. The annual mean temperature is 26.1°C, monthly mean temperatures are 18–29°C. Allahabad experiences three seasons: hot dry summer, cool dry winter and warm humid monsoon.

3. MATERIALS AND METHODS

Crop water footprint

Water consumption in agriculture can be measured or estimated with a set of empirical formulas or with a crop model suitable for estimating evapotranspiration based on input data on climate, soil and crop characteristics. The distinction between the blue and green water footprint is important because the hydrological, environmental and social impacts, as well as the economic opportunity costs of surface and groundwater use for production.

$$\text{WF} = \frac{CWU}{Y}$$

Where CWU=Crop water use, Y= Yield

The CWU over the crop-growing period (in l/ha) were calculated from the accumulated corresponding ET (mm/day). The calculation was done over the growing period from the day of planting (d = 1) to the day of harvest (lgp, the length of growing period in days). The factor 10 (m^3/ mm/ha) is applied to convert the mm to m3/ha. The daily ET (mm/day) was calculated according to (*Zhuo.,2014*)

$$ET = Ks \times Kc \times ET_0$$

Where Ks=Water stress coefficient, Kc=Crop Coefficient and ET_0=reference evapo-transpiration.

The crop coefficient Kc values paddy crop is taken as 1.0 (FAO56). Where the water stress coefficient Ks is calculated based on a daily function of the maximum and actual available soil moisture in the root zone (*FAO56., allen)*

$$Ks = \frac{TAW - Dr}{(1-P)TAW}$$

Where TAW is total available soil water in the root zone [mm], P is the atmospheric pressure and Dr is root zone depletion in mm calculated by(*FAO56.,allen*)

$$Dr = Dr_i - (P - RO) - I - Etc + DP$$

Dr_i is the water content in the root zone at the end of the previous day (mm), P is the precipitation on day (mm),RO is runoff from the soil surface on day (mm),I is the net irrigation depth on day that infiltrates the soil (mm),ETc is crop evapotranspiration on day (mm) and DP is the amount of water loss out of the root zone by deep percolation on day (mm).

4. RESULTS AND DISCUSSIONS

Crop Water Footprint

Quantification of crop water footprint is dependent on ETc, Kc, rainfall, soil moisture, crop planting date, and yield .in this chapter, water footprint of Paddy crop is calculated and its sensitivity to various parameters obtained. The average water footprint of Paddy crop is 3384.701 l/kg.

Sensitivity to the changes in input parameters:

Sensitivity of water foot print to changes in Reference Evapotranspiration (ET_0)

The sensitivity of water footprint to changes in reference evapotranspiration (ET_0) within a range of -90% to +90%, is shown in fig.1. As ET_0 increases the CWU increases as a result the water footprint increases. Due to the combined effect of increasing ET_0 and CWU, at constant Yield, the water footprint increases. The sensitivity of water footprint is the combined effect of the CWU and

Yield. The values of water footprint of for -90% and +90% are -338.47 l/kg and 6430.932 l/kg. As the ET_0 decreases the WFP decreases and tends to be negative. The negative results may be ignored as in real world water foot prints cannot be negative. The result is same for the Crop coefficient parameter also.

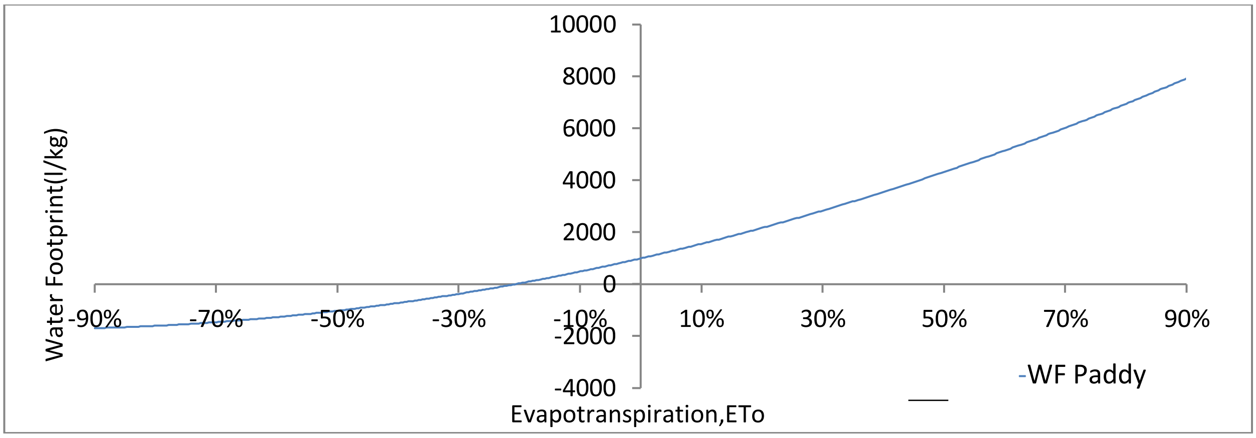

Fig. 1: Sensitivity of WF to changes in reference evapotranspiration (ET_0)

Sensitivity of water foot print to change in Precipitation (PR)

The sensitivity of WF to the changes in precipitation, the trend line was drawn by varying from -90% to +90% of precipitation as shown in Fig.2. It is known that, if we increase in precipitation there will be high decrease in the evapotranspiration and that leads to low water footprint, if we decrease the precipitation, high increase in water footprint. The sensitivity of water footprint is the combined effect of CWU and Yield. The result shows that evapotranspiration may decrease in certain climate conditions in practice although the water footprint decreases. The values of water footprint of for -90% and +90% are 4907.816 l/kg and -1861.59 l/kg.

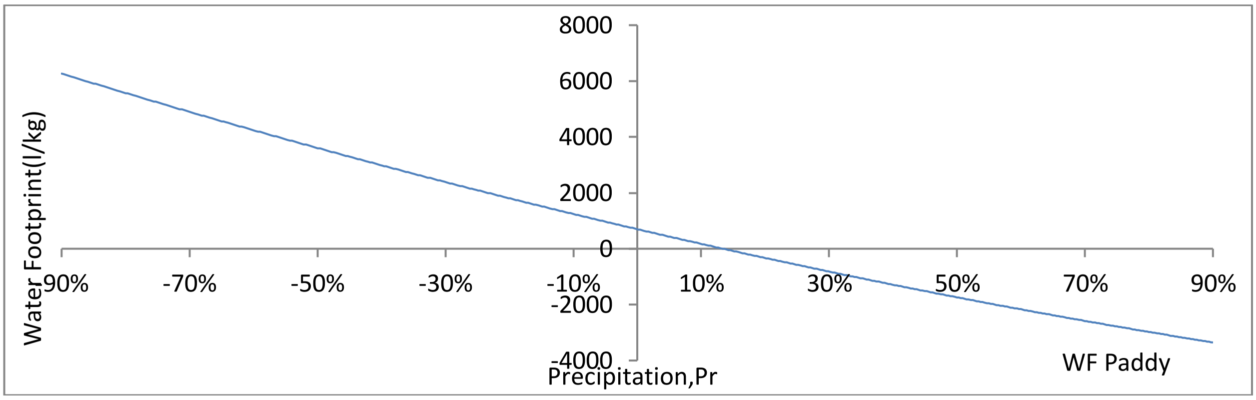

Fig. 2: Sensitivity of WF to changes in precipitation (PR)

Sensitivity of water foot print to change in Crop planting date (D)

The sensitivity of WF to the change of the crop planting date is given in fig.3. There is no linear relationship between the crop planting date and WF. WF was smaller with late planting date, which is mainly due to the decrease in the CWU for paddy. Meanwhile, we found a reduced ET_0 over the growing period with delayed planting of the paddy which leads to decrease in crop water use. Late planting particularly for paddy crop, could save water, while increases the yield. The difference in water footprint is due to change in sowing date of paddy and a different response curve was observed for paddy with earlier planting. Therefore from perspective of the agricultural practice, the response of crop production and crop water use with change in the planting date should be considered in agricultural water saving projects. The values of water footprint for the range of -30 days and +30 days are 3909.072 l/kg and 3041.602 l/kg.

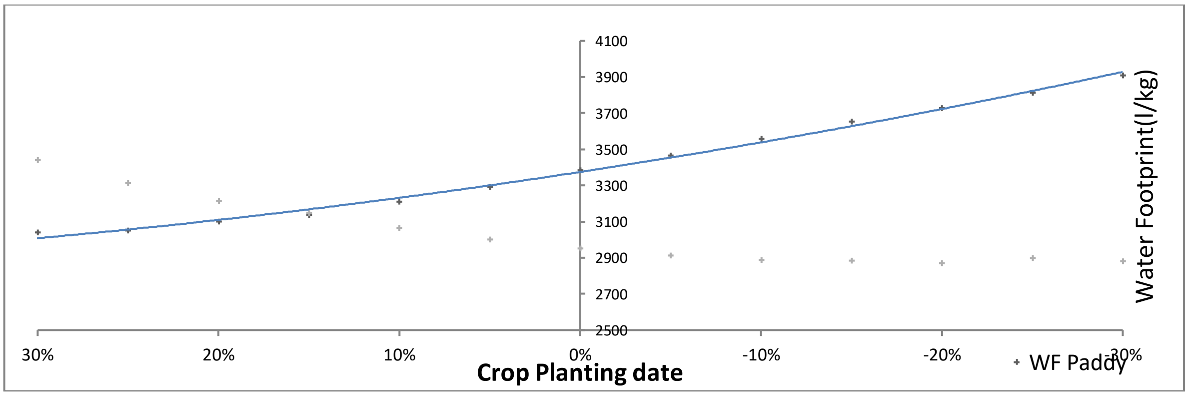

Fig. 3: Sensitivity of WF to changes in Crop Planting Date

Sensitivity of water foot print to change in Field capacity of the soil water (Smax)

The sensitivity curves of WF to the changes of the Smax within -90%to +90%,the trend line is shown in Fig.4.As the decrease in Smax there is large decrease in water footprint in crop, if the Smax increases it is increasing upto to certain limit and then decreases respectively. Due to increase in soil moisture the evapotranspiration increases upto certain limit and then decreases. The values of water footprint for the range of -90% and +90% are -33847 l/kg and 1781.422 l/kg.

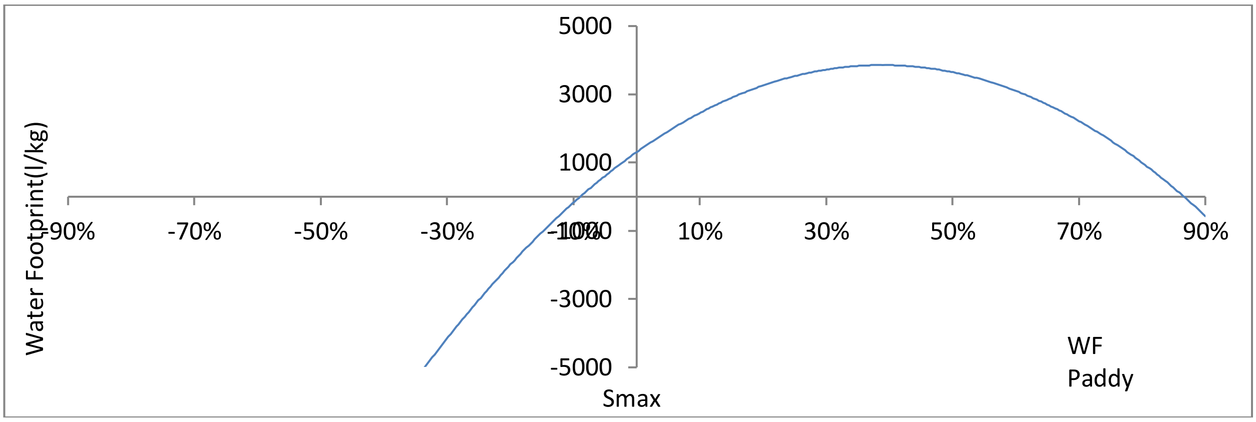

Fig. 4: Sensitivity of WF to changes in Field capacity of the soil water (S_{max})

Sensitivity of water foot print to change in Yield(Y)

The yield is the important parameters defining the Water Footprint. It is clear that as we increase in yield there is gradually decrease in water footprint. Fig.5.shows the trend lines of the sensitivity of Y and WF of each crop -50% to +50%. Due to the difference in the sensitivity of crop to water stress that leads to different levels of sensitivity in Y and WF. The values of water footprint for the range of -50% and +50% are 6769.402 and 2256.467 l/kg.

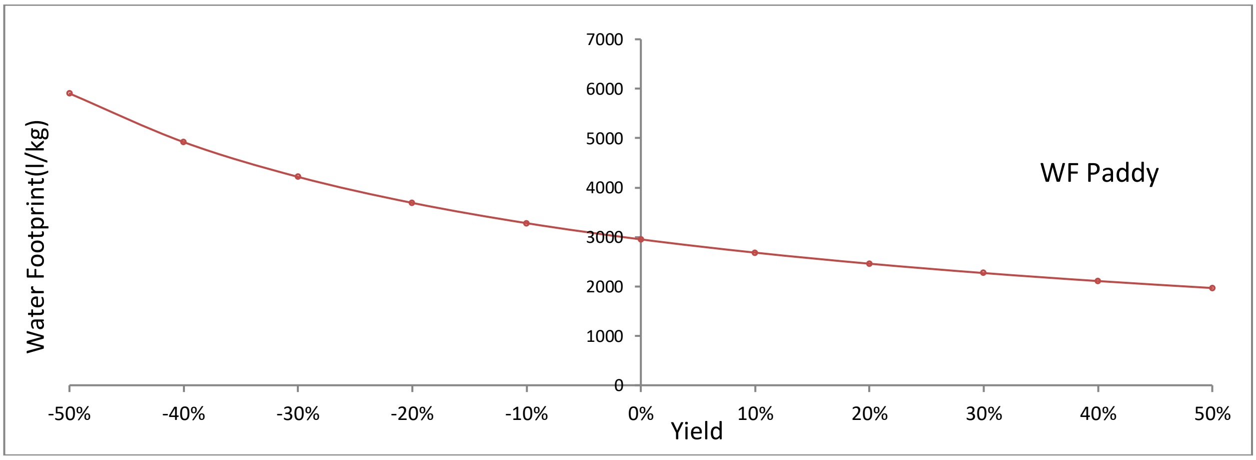

Fig. 5: Sensitivity of WF to changes in Yield(Y)

Sensitivity Index of parameters

Sensitivity analysis concerns the mathematical model representation of a physical system and attempts to assess the sensitivity of the model output to variation of model input given by variables or parameters and variations of model assumptions Fasso and Perri (1982).

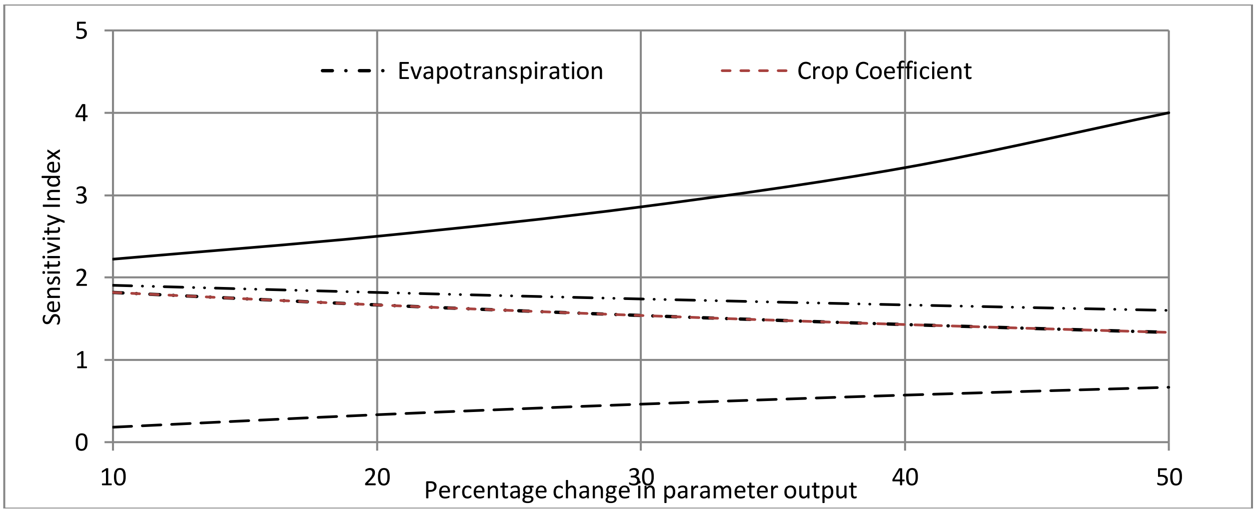

Fig. 6: Sensitivity index of output of the parameters

A sensitivity index is a number calculated by a defined procedure which gives information about the relative sensitivity of results to different parameters of the model, Pannell. D. J (1997). The sensitivity index for all the parameters influencing the WFP has been derived and shown in Figure.6. The slope of ET_0 and Kc show sensitive can be seen in water footprint as the parameters are highly sensitive. It is seen that ET_0 and Kc are equally sensitive to water footprint, there is a change in sensitivity as we increase 20-30%, 30-40% and 40-50%.The sensitivity index reduces throughout the range but it classified as highly sensitive. In soil moisture an increase in the parameter leads to sensitivity increase. The precipitation shows least sensitivity to water footprint because increase in the precipitation will leads to the decrease in water footprint. In the parameter crop planting date shows late sensitivity index, it doesn't have much influence upon the water footprint, Ultimately evapotranspiration is determining if the increase in crop planting date. If we increase yield water footprint decreases, it shows that it is sensitive to yield. An increase in yield will lead to decrease in WFP. Most sensitive parameter is soil moisture followed by precipitation, ETo, Kc, Yield and crop planting date.

5. RECOMMENDATIONS FOR IMPROVING PADDY YIELD

Sensitivity Index helps in recommendation of management practices as and when any parameter influences the yield adversely. From these results we have recommend certain agricultural practices, which helps to improve the Yield.

- Soil moisture is the most sensitive parameter influencing WFP. From figure.6 it can be observed that with the rise in change the sensitivity index for WFP rises drastically. Any change beyond 20% needs attention. In case of less soil moisture immediate irrigation is required. However the Crop available water, wilting point and readily available water has to be taken into consideration while considering irrigation or adding moisture into the field. More moisture means more water and hence higher WFP. Less moisture will induce stress in the plants and influence yield.
- Precipitation is the sensitive parameter second in effectiveness influencing WFP. From figure.6 it can be observed that with the change in input WFP decreases. Any change beyond 20% needs attention. In case of less precipitation immediate irrigation is required. However the crop available water and readily available water has to be taken into consideration while considering irrigation.
- Reference evapotranspiration is the sensitive parameter third in effectiveness influencing WFP. From figure.6 it can be observed that with the change in input WFP decreases. Any change beyond 20% needs attention. In case of less reference evapotranspiration immediate irrigation is required. However the crop available water is taken into consideration while considering irrigation, so the yield will be increased.
- Crop Coefficient is the sensitive parameter influencing WFP. From figure.6 it can be observed that with the change in input WFP decreases. Any change beyond 20% needs attention. In case of less crop coefficient immediately we recommend to grow more crop canopy.
- Yield is the sensitive parameter influencing WFP. From figure.6 it can be observed that with the change in input WFP increases. Any change beyond 20% needs attention. In case of less yield immediately the agronomic practices like time of sowing, Irrigation, weed control etc, should be done. So for improving the yield of Paddy crop timely sowing, irrigation at critical growth stages and control of weeds are essential.
- Crop Planting Date is the sensitive parameter influencing WFP. From figure.6 it can be observed that with the change in input WFP increases. Any change beyond 10% needs attention. The time of planting should be last week of October to first week of December so that the crop will grow in required conditions and the will get good yield (*rajesh et al.,2011*). If the time of planting is late the yield of crop will be reduces.

6. CONCLUSION

Sensitivity Analysis of Water Footprint, the study provides the estimation of sensitivity of parameters effecting water footprint in Samarakalwana village. The parameters effecting the water footprint are reference evapo-transpiration (ETo), crop coefficient(Kc), Precipitation(PR), Crop planting date(D),Field capacity at soil moisture(Smax) and yield(Y) .the changes in these parameters are effecting the water footprint.

The sensitivity analysis was obtained for the parameters influencing the water footprint, the results shows that parameters ETo, Kc, PR and Yield are most sensitive towards water footprint and change in parameters like Smax and Crop Planting Date are not sensitive towards change in the values. The Coefficient of Variation was obtained for the parameters and results shows that parameters such as ETo, Kc, PR have high mean when WFP increased from 10% to 20% and from 30% to 50% there is very small change in the mean. The other parameters like Crop planting date and yield have no change in mean when WFP is increased from 10% to 20% and there is increase in the mean when WFP increases from 30% to 50%.

The Sensitivity Index was obtained to know the relative sensitivity of the output of WFP of each parameter. From the result it is concluded that the most sensitive parameter is soil moisture followed by precipitation, ETo, Kc, yield and crop planting date. Sensitivity Index helps in recommending the best management practices as and when any parameter influences the yield adversely. Soil moisture being the most sensitive parameter among all parameters, we recommend the irrigation in case of less soil moisture. The current study shows possible ways to assess the sensitivity in water footprint of Paddy crop in relation to change in input variables and parameters. The outcome of this study can be used as a reference in future sensitivity studies on crop water footprint.

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