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An assessment of sustainability of agriculture and water resources in the state of Haryana

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ABSTRACT

Overexploitation of groundwater resources for agricultural purpose has caused serious groundwater depletion in the majority of states in north–western India. In states of Punjab, Haryana, Rajasthan, Delhi and Western Uttar Pradesh, the depletion of groundwater resources has lowered the groundwater level, increased the cost of pumping and has raised questions about the sustainability of groundwater resources. In the present study, an effort has been made to develop composite water sustainability index (CWSI) for the state of Haryana to quantify the status of sustainability of water resources in the state. Seventeen indicators crucial for the sustainability of agriculture and water resources were identified for the analysis. The CWSI for the state of Haryana was calculated as 0.534, with the district–wise value varying from a minimum of 0.444 in Panipat to a maximum of 0.681 in Panchkula district. The reason for such low to moderate water sustainability in the state of Haryana was attributed to improper cropping system and overexploitation of groundwater resources.

1. INTRODUCTION

Water is the most critical input for crop production. Irrigated agriculture plays a crucial role in meeting the food requirement of ever–increasing worldwide population. At the same time, it is also the largest exploiter of water resources, since about 70% of the freshwater is withdrawn to produce food (FAO, 2012). The water footprint of a nation is the total volume of freshwater that is used to produce the goods and services consumed by the people of the nation. In an open economy, goods and services produced may be consumed in the country as well as exported to the rest of the world. In case of the latter, water footprint has an export connotation. A geographical entity, a province or a nation, which exports a large percentage of agricultural produce to outside its geographical boundaries, as the case with Punjab and Haryana, is said to be exporting precious water resources embodied in the agricultural produce.

The total freshwater available in India is estimated at 4000 billion cubic meter (BCM), out of which, only 1123 BCM is utilized and remainder is lost. Out of the annual 393 BCM replenishable groundwater available for use, country withdraws 249 BCM for irrigation and other purposes (CGWB, 2019). It means, the groundwater development (GWD) is the ratio of groundwater draft to net deposit; 249/393 is 63.3%. As a whole, India, thus, stands in the so called 'safe' category of GWD; a region is classified 'safe', if the GWD is <70% or contrarily unsafe/exploited, if this limit is exceeded. But in case of Punjab and Haryana, this percentage go up to 168% and 137%, respectively, falling under the category of over–exploited (CGWB, 2019). This unprecedented development on groundwater dependence became the leading cause of aquifer drying in north–western Indian states of Punjab and Haryana (fall in groundwater table 60% to 70%). Rodell *et al*. (2009) reported that groundwater reserves in north–western Indian states is depleting at an alarming rate.

When the rate of extraction exceeds the rate of recharge by natural processes, groundwater is said to be in a state of overdraft, and water levels drop. Under prolonged overdraft conditions, the water level of an aquifer can fall to a depth where it is no longer economically feasible to pump and the resource become exhausted. The resource in this case is non–renewable. Depleting groundwater resources not only disrupt ecological balance, but also put heavy financial burden on farmers and give rise to socio–economic inequality in its distribution (Srivastava *et al.*, 2017). Few studies have identified reasons for emerging groundwater crisis and have elucidated hydrological, institutional and policy related measures to improve groundwater sustainability. Among many approaches, regulation of energy supply and its pricing is debated as an effective way to manage groundwater resources in the country. The water–food–energy nexus exists in these states and there is a need to find solution for sustainable agriculture and water management.

Considerable work has been done by crop and soil scientists to define and measure indicators as a basis for tracking the sustainability of agricultural systems (Barnett *et al*., 1995; Pieri *et al*., 1995). Several agricultural sustainability assessment methods have been developed over the last decades (Binder *et al*., 2010). Assessment methodologies are being developed for the purpose of research and policy advising, farm monitoring, certification, self–assessment, landscape planning and consumer information (Schader *et al*., 2014). Talukder *et al.* (2017) have summarised eight such methodologies which attempt to capture the holistic nature of agricultural sustainability. Notable of them are (i) Response Inducing Sustainability Evaluation (RISE) model (Hani *et al*., 2003), (ii) Monitoring Tool for Integrated Farm Sustainability (MOTIFS) (Meul *et al*., 2008), (iii) Multi–Criteria Decision Analysis (MCDA) (Dantsis *et al*., 2010) etc. All the above methods of sustainability frameworks have focused on the farm level sustainability, which may or may not be applicable to the larger spatial domains like agro–ecological regions, provinces and national states.

To overcome such problem and to get better idea about sustainability, researchers have devoted efforts to construct composite agricultural sustainable indices or composite indicators combining individual indicators. Such composite indicators or indices are a prerequisite for the adequate design, implementation and monitoring of agricultural policies aimed at a more sustainable farming sector. As Schader *et al.* (2014) have pointed out, there is need for broader consensus on a common framework for agricultural sustainability assessments to make a step towards comparability and quality of assessments. Holistic approaches that address different dimensions and objectives of sustainability are important (Gafsi *et al.,* 2006; Van de Fliert and Braun, 2002). Sustainable management of water resources is one of the sub goals of sustainable agriculture every society should thrive for. In the present study, an attempt has been made to develop composite water sustainability index (CWSI) for the state of Haryana considering different indicators crucial for sustainability of agriculture and water resources.

2. MATERIALS AND METHODS

The study was carried out for the state of Haryana which covers an area of 44,212 sq km, which is 1.4% of India's total geographical area (Fig. 1). It is the 22nd largest Indian state by area comprising 22 districts. Despite recent industrial development, Haryana is primarily an agricultural state with 70% of residents engaged in agriculture. Haryana is the second largest contributor to India's central pool of food grains. The main crops of the state are wheat, rice, sugarcane, cotton, oilseeds, gram, barley, corn, millet etc. However, excessive use of fertilisers and indiscriminate

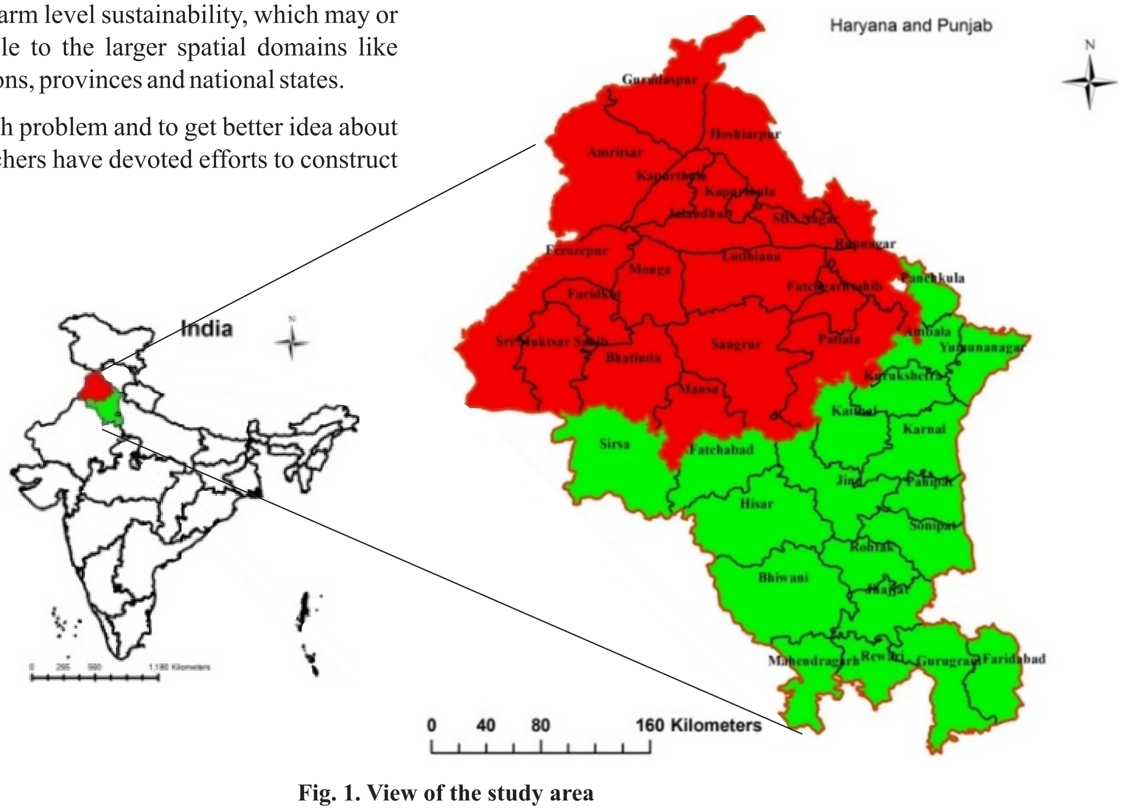

Fig. 1. View of the study area

withdrawal of groundwater for agriculture has caused sharp groundwater table decline.

The CWSI for the state of Haryana was computed following the stepwise procedure prescribed by OECD Handbook (OECD, 2008). The steps for construction of composite indicators are developing framework for selection of indicators, identification of data source, data collection, multivariate analysis, normalisation, weighting and aggregation, sensitivity analysis and validation of results.

Selection of Indicators

From the available scientific literature and discussion with experts in a National Workshop organized by the ICAR–National Institute of Agricultural Economics and Policy Research held in October, 2018, seventeen indicators belonging to (1) climate and weather related indicators, (2) water stress indicators, and (3) water management related indicators were identified for computation of CWSI for the state of Haryana.

Climate and Weather Related Indicators

1. DAR (Deviation from long–term average rainfall): This indicator furnishes the drought and heavy precipitation frequency. It is the number of years in which the deviation from normal rainfall is more than 25%. A total of 41 years rainfall data from 1971 to 2011 was considered (Data source: IMD).
2. HCW (Heat and cold waves): Number of episodes of extreme weather conditions (heat and could waves). The heat wave events are defined as the number of days with maximum temperature above 32°C and cold wave events are number of days with minimum temperature below 4°C. This is taking into consideration the major wheat crop sown in the region. A total of 41 years temperature data from 1971 to 2011 was considered (Data source: IMD).
3. CDD (Consecutive dry days): Number of dry spells of consecutive 14 dry days (June to Oct) were considered. Consecutive dry days can serve as an effective measure of seasonal drought. Consecutive dry days is defined as number of episodes with rainfall below 2.5 mm for consecutively 14 days during the monsoon days (June to September).
4. GDD (Growing degree days): Growing degree days is a weather–based indicator for assessing crop development. It is defined as the mean daily temperature (average of daily maximum and minimum) above a certain threshold temperature. GDD is calculated using the formula, $cdd = (T_{max} + T_{min}) / 2 - \text{base temperature}$ (5°C). In the present study, GDD was computed for wheat crop considering duration from 16th November to 15th March.
5. SPI (Standardized precipitation index): The SPI, in simple words, measures meteorological drought or abnormal precipitation phenomenon over a period of time and it corresponds with the time availability of different water resources *e.g.* soil moisture, snowpack, groundwater, river discharge and reservoir storage etc. (McKee *et al.,* 1993). It is the probability index that gives a representation of abnormal wetness and dryness. SPI < -0.99 is considered as undesirable for agricultural sustainability.

Water Stress Indicators

1. GDI (Groundwater development index): GDI represents the degree of ground water withdrawal. GDI index is as per the estimation by the Central Ground Water Board.
2. GWTD (Groundwater table depletion): GWTD is change in groundwater level in meters during the period 1996–2018 based on the data accessed from the Central Ground Water Board (CGWB, 2019).
3. GWTD 7 (Groundwater table depth below 7 m): Number of tube wells having water table at a depth of more than 7 m. This is based on data accessed from Central Ground Water Board.
4. WQI (Water quality index): It is calculated based on pH and EC values of the water quality data accessed from the Central Ground Water Board.
5. TWD (Tubewell density): It is the number of tube wells per 100 ha of net sown area.
6. ROF (Runoff potential): It is defined as runoff potential as percentage of water demand in agriculture measures. Runoff potential is taken from the ICAR–Indian Institute of Soil and Water Conservation, Dehradun (unpublished report, 2019) and crop wise area (ha) from the Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers Welfare, GoI for the year 2015–16. Crop water requirement is estimated by the method suggested by Chand *et al.* (2019).
7. RWS (Relative water supply): Water supply as percent of demand. This is calculated based on water availability (MCM), crop wise area (ha) and crop water requirement estimated as suggested by Chand *et al.* (2019).

Water Management Related Indicators

1. WUE (Water use efficiency): This is calculated by taking irrigated area by sources (ha) and assuming irrigation efficiency of 35% from surface irrigation and 70% from groundwater irrigation for the state of Haryana.
2. PUC (Percentage utilisation of potential irrigation): This is based on district–wise irrigated area and irrigation potential utilized as per information accessed from the Directorate of Economics and Statistics, and Ministry of Water Resources, GoI.

3. IDS (Investment on drainage system): This is calculated as investment on drainage system for degraded land based on the data accessed from the ICAR–Central Soil Salinity Research Institute, Karnal and the State Irrigation Departments of Haryana.
4. IWS (Investment on watershed): Investment on watershed / rainwater management based on area under degraded lands (Source: ICAR–CSSRI) and investment in watershed management during the period 2009–15 accessed from the Department of Land Resources, Ministry of Rural Development, GoI.
5. MI (Micro–irrigation): This is the area under MI based on the proxy indicator of groundwater utilisation.

Normalization

Aggregation of data of different indicators into a composite index without normalization can be done if all the variables are measured with the same unit. But in most situations, the variables to be aggregated have different units. Therefore, normalization is a crucial process in developing sustainability indices as it makes indicators comparable with each other on a common basis. Normalization is therefore the process of reducing the measurements to a standard scale which helps to avoid the dominance of extreme values in a data set and partially corrects data quality problems. Normalization of indicators is required to make the indicators mathematically operational in aggregation (Talukder *et al.,* 2017). In this study, the benchmark method of normalization has been followed. Benchmarking function assigns a normalized value to each indicator based on its level of sustainability, determined by reliable and authentic literature and international legislation sources. The benchmarking normalization function is not an internal normalization function, as it depends on indicator values each being mapped to some value based on a qualitative valuation of their level of sustainability.

Assigning Weights to Indicators

Assigning weights to individual indicators is an important step in construction of composite indicators. There are three standard possible ways of assigning weights to individual indicators. These are equal weights, expert opinion and principal component analysis (PCA). Each system of assigning weights has its own advantages and disadvantages. Equal weights may undermine some variables which largely influences the index; expert opinion will be subjective and limited to availability of experts, number of variables and research time to get the response; and PCA works with the assumption that linear relationship exist among variables. In the present study, a comparison has been made among the three approaches.

3. RESULTS AND DISCUSSION

Table 1 shows the district–wise weather and climate related indicators in the state of Haryana. The DAR index values shows that highest drought years is observed in the district of Fatehbad (39%) followed by Jind and Katihal districts (34%). Lowest drought years is observed in Faridabad and Kurukshetra districts (17%). The average frequency of drought years in the state of Haryana is observed 27%. The HCW index values suggest that the frequency of extreme weather events are maximum in Mahendragarh (61) and Rewari districts (60). On the other hand, the districts like Panchkual (24), Ambala (34) and Yamunanagar (34) have the least frequencies of such extreme episodes. The average number of such episodes in the state of Haryana is 50. It is observed from the CDD index values that, events of consecutive 14–days dry spell has occurred maximum times in the Fatehbad (93) district followed by Sirsa (81) district. The least frequency is observed in Ambala (27) followed by Yamunanagar district (28). The average value for the state of Haryana is 56. The parameter GDD in wheat is crucial as the wheat growing state of Haryana depend on favorable weather conditions for healthy growth of the wheat crop. The state average GDD (from November 15 to March) is observed as 1508 (Table 1). Highest GDD is observed in Mahendragarh district (1783) closely followed by Rewari (1761) district. The least GDD during this period is observed in Ambala (1162) followed by Fatehbad district. Standardized precipitation index quantifies observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data. From Table 1, it is observed that probability of occurrence of standardized precipitation index (SPI) < -0.99, is 17 in the state. The highest probability of occurrence of such events (27%) is in

Table: 1
District–wise weather and climate related indicators

District	DAR	HCW	CDD	GDD	SPI
Ambala	20	34	27	1162	17
Bhiwani	29	55	63	1347	22
Faridabad	17	59	46	1368	10
Fatehbad	39	50	93	1268	15
Gurugram	22	59	46	1378	12
Hissar	29	53	78	1320	27
Jhajjar	29	58	67	1349	15
Jind	34	56	76	1699	15
Kaithal	34	44	66	1584	17
Karnal	27	39	49	1537	20
Kurukshetra	17	39	37	1537	12
Mahendragarh	24	61	62	1783	20
Panchkula	20	24	33	1338	17
Panipat	24	53	46	1693	20
Rewari	29	60	65	1761	15
Rohtak	29	57	60	1730	15
Sirsa	29	57	81	1618	17
Sonipat	27	53	40	1693	22
Yamunanagar	29	34	28	1486	12
State average	27	50	56	1508	17

Hissar district. The lowest probability of occurrence (10%) is observed in Faridabad district followed by Gurugram, Kurukshetra and Yamunanagar districts.

Table 2 shows the district−wise water stress indicators in the state of Haryana. The runoff potential as percentage of water demand in agriculture (ROF) is highest in Panchkula (23.78%) followed by Gurugram district (9.14%). It is as low as 0.58% in Fatehbad district and 0.65% in Kaithal and Sirsa districts. The average value for the state is only 1.57%. The average GDI index for the state is very high at 135% which is a matter of concern. The value is very high (>200%) for the districts of Kurukshetra and Kaithal, whereas it is somewhat reasonable (<100%) in the districts of Jhajjar, Mahendragarh, Panchkula, Rewari and Rohtak districts. The GWTD index values show that average groundwater depletion in the state during the period 1996−2018 is 8 m. Highest depletion of groundwater level during the period has occurred the Faridabad district (34 m) followed by Kurukshetra district (20 m). There was a rise in groundwater level in Panchkula district (4 m) followed by Bhiwani and Jhajjar district (1 m each). The GWTD7 index values suggest that in 60% tubewells in the state, groundwater level is below 7 m. In Kurukshetra, Mahendragarh and Rewari districts, 100% of tubewells have groundwater level below 7 m, whereas in Faridabad, Kaithal, Karnal, Panipat and Yamunanagar districts, it is for more than 80% of the tubewells. The average WQI index value for the state is 0.33. The districts Yamunanagar, Jhajjar and Ambala have better groundwater quality with higher WQI index. The TWD index shows that on an average, there are 24 tubewells per 100 ha area in the state. The tubewell density is highest in the Sonipat district (TWD = 42) followed by Karnal district (TWD = 35). The average water supply in the state as percentage of demand (represented by RWS index) is 48%. The RWS index is highest in Rohtak district (90) followed by Sonipat district (83), whereas it is lowest in Bhiwani (23) followed by Mahendragarh district (33).

Table 3 shows the district wise water management related indicators for the state. The average water use efficiency (WUE) for the state is 60%. It is highest for the districts of Faridabad, Gurugram, Panchkula and Rewari (70%). It is lowest in the district of Hissar (41%) followed

Table: 3
District−wise water management related indicators

District	WUE	PUC	IDS	IWS	MI
Ambala	69	90	0.00	267989	4.71
Bhiwani	55	90	0.33	33810	75.53
Faridabad	70	90	0.00	33426	1.36
Fatehbad	60	90	0.50	33426	13.02
Gurugram	70	90	0.00	32865	20.70
Hissar	41	90	1.76	31784	17.43
Jhajjar	55	90	0.50	7694	1.71
Jind	43	90	0.55	33426	1.51
Kaithal	57	90	0.30	33426	0.47
Karnal	63	90	0.00	33426	3.79
Kurukshetra	69	90	0.00	33426	1.87
Mahendragarh	69	90	0.00	33426	84.26
Panchkula	70	90	0.00	33426	0.47
Panipat	58	90	0.00	33426	8.49
Rewari	70	90	0.00	57864	24.92
Rohtak	48	90	0.50	6764	1.64
Sirsa	43	90	0.50	33426	9.65
Sonipat	64	90	0.50	16406	0.62
Yamunanagar	69	90	0.00	33426	1.63
State average	60	90	0.50	33426	26.94

Table: 2
District−wise water stress indicators

District	ROF	GDI	GWTD	GWTD7	WQI	TWD	RWS
Ambala	6.18	102	7	48	0.48	20	55
Bhiwani	1.03	169	−1	59	0.34	15	23
Faridabad	7.07	99	34	80	0.38	30	78
Fatehbad	0.58	184	4	40	0.28	19	46
Gurugram	9.14	133	16	63	0.27	20	71
Hissar	0.74	112	2	60	0.20	23	47
Jhajjar	1.71	83	−1	8	0.53	27	51
Jind	0.77	113	9	74	0.41	32	58
Kaithal	0.65	226	2	88	0.27	28	35
Karnal	1.63	121	9	97	0.38	35	47
Kurukshetra	2.10	281	20	100	0.36	26	49
Mahendragarh	1.16	86	1	100	0.24	15	33
Panchkula	23.78	80	−4	71	0.42	16	77
Panipat	1.47	163	9	80	0.29	32	64
Rewari	0.83	92	13	100	0.31	22	44
Rohtak	1.05	70	0	6	0.34	24	90
Sirsa	0.65	175	3	75	0.05	18	34
Sonipat	1.42	111	7	39	0.23	42	83
Yamunanagar	4.57	135	6	87	0.59	30	40
State average	1.57	135	8	60	0.33	24.23	48

Table: 4
Normalized water indicators using benchmark method

District	DAR	HCW	CDD	GDD	ROF	SPI	WUE	PUC	RWS	IDS	IWS	MI	GDI	GWTD	GWTD7	TWD	WQI
Ambala	0.80	0.72	0.93	1.00	0.00	0.83	0.75	0.90	0.55	0.00	1.00	0.00	0.00	0.80	0.52	0.52	0.48
Bhiwani	0.71	0.55	0.85	1.00	0.00	0.78	0.44	0.90	0.23	0.44	1.00	0.01	0.00	1.00	0.41	0.64	0.34
Faridabad	0.83	0.51	0.89	1.00	0.00	0.90	0.78	0.90	0.78	0.00	1.00	0.00	0.03	0.00	0.20	0.25	0.38
Fatehbad	0.61	0.59	0.77	1.00	0.00	0.85	0.56	0.90	0.46	0.67	1.00	0.00	0.00	0.89	0.60	0.54	0.28
Gurugram	0.78	0.51	0.89	1.00	0.00	0.88	0.78	0.90	0.71	0.00	1.00	0.01	0.00	0.53	0.38	0.52	0.27
Hissar	0.71	0.56	0.81	1.00	0.00	0.73	0.14	0.90	0.47	1.00	1.00	0.00	0.00	0.95	0.40	0.43	0.20
Jhajjar	0.71	0.52	0.84	1.00	0.00	0.85	0.44	0.90	0.51	0.67	0.31	0.00	0.57	1.00	0.92	0.33	0.53
Jind	0.66	0.54	0.81	0.51	0.00	0.85	0.18	0.90	0.58	0.73	1.00	0.00	0.00	0.72	0.26	0.20	0.41
Kaithal	0.66	0.64	0.84	1.00	0.00	0.83	0.48	0.90	0.35	0.40	1.00	0.00	0.00	0.39	0.12	0.31	0.27
Karnal	0.73	0.68	0.88	1.00	0.00	0.80	0.62	0.90	0.47	0.00	1.00	0.00	0.00	0.73	0.03	0.12	0.38
Kurukshetra	0.83	0.68	0.91	1.00	0.00	0.88	0.76	0.90	0.49	0.00	1.00	0.00	0.00	0.42	0.00	0.35	0.36
Mahendragarh	0.76	0.50	0.85	0.08	0.00	0.80	0.76	0.90	0.33	0.00	1.00	0.01	0.47	0.96	0.00	0.63	0.24
Panchkula	0.80	0.81	0.92	1.00	0.00	0.83	0.78	0.90	0.77	0.00	1.00	0.00	0.67	1.00	0.29	0.60	0.42
Panipat	0.76	0.56	0.89	0.54	0.00	0.80	0.52	0.90	0.64	0.00	1.00	0.00	0.00	0.73	0.20	0.21	0.29
Rewari	0.71	0.51	0.84	0.19	0.00	0.85	0.78	0.90	0.44	0.00	1.00	0.00	0.27	0.60	0.00	0.46	0.31
Rohtak	0.71	0.53	0.85	0.35	0.00	0.85	0.28	0.90	0.90	0.67	0.27	0.00	1.00	0.99	0.94	0.42	0.34
Sirsa	0.71	0.53	0.80	0.91	0.00	0.83	0.17	0.90	0.34	0.67	1.00	0.00	0.00	0.91	0.25	0.56	0.05
Sonipat	0.73	0.56	0.90	0.54	0.00	0.78	0.66	0.90	0.83	0.67	0.66	0.00	0.00	0.80	0.61	0.00	0.23
Yamunanagar	0.71	0.72	0.93	1.00	0.00	0.88	0.75	0.90	0.40	0.00	1.00	0.00	0.00	0.81	0.13	0.27	0.59
State average	0.73	0.59	0.86	1.00	0.05	0.83	0.56	0.90	0.48	0.67	1.00	0.27	0.00	0.00	0.40	0.40	0.33

by Jind and Sirsa districts (43% each). The PUC index values show that the percentage of irrigation water utilised in the state of Haryana for all the districts is more or less uniform at 90%. The average investment in drainage system (IDS) for the state of Haryana is 0.50 lakh ha^{-1}. This is highest in the district of Hissar (1.76 lakh ha^{-1}), whereas it is nil in about 10 districts. The IWS index values show that the investment in watershed management programmes in the state is ₹ 33426 ha^{-1}. The value is highest in the district of Ambala. The average value of MI indicator representing the area under micro−irrigation for the state is 26.94%. The value is highest in the districts of Mahendragarh (84.26%) and Bhiwani (75.53%). The value is lowest in the districts of Panchkula and Kaithal (0.47% each).

Table 4 shows the normalized water indicators for all the districts of the state using benchmark method of normalization. Some of the indices like DAR, HCW, CDD, GDI, GWTD, GWTD7 having higher index value for a particular district have been assigned lower values after normalization. This is due to the fact that the higher value of the indices imply lower sustainability. Table 5 shows the assigned relative weights to different indicators by the equal weight, PCA weight and expert weight method. The summation of the weights of all the indicators is equal to unity.

Table 6 presents the CWSIs for all districts of Haryana using the equal weight, PCA weight and expert weight approach along with ranking of the districts. In case of equal weights, Panchkula has highest CWSI (0.681) followed by Jhajjar (0.598) and Bhiwani (0.593). Panipat has the lowest CWSI (0.438) followed by Rewari (0.443) district. In case of PCA weights, the first position is again occupied by Panchkula (0.676) followed by Bhiwani district (0. 587). Panipat (0.449), Karnal (0.457) and Rewari district (0.459) occupy the last three positions. CWSIs with expert weights

Table: 5
Assigned relative weights for water indicators using different methods

Variable	Equal weight	PCA weight	Expert weight
DAR	0.063	0.066	0.060
HCW	0.063	0.067	0.048
CDD	0.063	0.064	0.063
GDD	0.063	0.046	0.063
ROF	0.063	0.067	0.056
SPI	0.063	0.064	0.055
WUE	0.063	0.069	0.085
RWS	0.063	0.072	0.088
IDS	0.063	0.064	0.052
IWS	0.063	0.065	0.065
MI	0.063	0.068	0.057
GDI	0.063	0.054	0.065
GWTD	0.063	0.052	0.063
GWTAB7	0.063	0.059	0.058
TWD	0.063	0.066	0.055
WQI	0.063	0.054	0.062
Total weights	1	1	1

Table: 6
Combined water sustainability indices (CWSI) for the state of Haryana

District	Equal weights	Rank	PCA weight	Rank	Expert weight	Rank
Ambala	0.545	5	0.549	5	0.548	5
Bhiwani	0.593	3	0.587	2	0.578	4
Faridabad	0.501	10	0.506	10	0.516	10
Fatehbad	0.533	7	0.536	6	0.526	6
Gurugram	0.516	9	0.522	9	0.522	7
Hissar	0.538	6	0.535	7	0.521	8
Jhajjar	0.598	2	0.581	3	0.591	2
Jind	0.452	17	0.460	16	0.444	19
Kaithal	0.460	15	0.462	15	0.455	16
Karnal	0.454	16	0.457	18	0.459	15
Kurukshetra	0.485	12	0.490	12	0.491	12
Mahendragarh	0.521	8	0.534	8	0.521	9
Panchkula	0.681	1	0.676	1	0.687	1
Panipat	0.438	19	0.449	19	0.445	18
Rewari	0.443	18	0.459	17	0.450	17
Rohtak	0.587	4	0.581	4	0.585	3
Sirsa	0.476	14	0.478	14	0.460	14
Sonipat	0.478	13	0.490	13	0.485	13
Yamunanagar	0.496	11	0.498	11	0.500	11
Haryana	0.534		0.539		0.528	

Table: 7
Difference between CWSI values among different weighting methodologies

Haryana	Equal weight	PCA weight	Expert weight
Equal weight	0		
PCA weight	0.005 (t −0.144, P 0.442)	0	
Expert weight	0.006 (t 0.026, P 0.489)	0.011 (t 0.173, P 0.431)	0

also gave nearly similar results. Panchkula (0.687) occupies the highest rank followed by Jhajjar district (0.591). The last two positions are occupied by Jind (0.444) and Panipat districts (0.445). The average CWSI for the state is 0.534, 0.539 and 0.528 in equal weight, PCA weight and expert weight method, respectively.

Fig. 2 shows the CWSIs of different districts in graphical form. Table 7 presents the t−statistics for different CWSIs calculated based on the three weighting methods. It is evident that the t−ratios are not significant at any level of significance. Hence, it can be safely concluded that the weighting methodologies are not making significant difference in the calculation of CWSIs for various districts as well for the entire state of Haryana.

As the methodological variations do not have significant impact on the outcome (estimated value of CWSIs), it would not be inappropriate to take the average of the estimated CSWIs by three different approaches, to arrive at a single measure of water sustainability. Table 8 presents such average CWSIs for all districts for the state of Haryana. From Table 8, it is evident that the state has a lower moderate water sustainability at 0.534, just marginally above the 0.500 benchmark. The reasons for such moderate water sustainability can be attributed to two reasons. They are (a) low sustainability of sub−spatial CWSIs (district CWSIs) add up to low aggregate CWSI for the state; and (b) low values of individual indicators pertaining to the larger spatial dimension.

Low Values of District CWSIs

As Table 8 shows, the state's CWSI at 0.534 is reflective of the district CWSIs which vary between 0.444 in Panipat to 0.681 in Panchkula district. There are nine districts out of 19 which has CWSIs lower than 0.500. The low performing districts of Panipat (0.444), Rewari (0.451), Jind (0.452), Karnal (0.457), Kaithal (0.459), Sirsa (0.457) etc. have significant influence in dragging down the state average. In addition to the specific agro−ecological factors, management of water resources are much to be desired.

Low Values of Individual Parameters for the States

The normalised data for the state has been presented in Table 4. From Table 4, it can be seen that the normalised values with respect to 8 out of 17 indicators are pretty low which have dragged down the overall CWSI of Haryana. For instance, the normalised values of indicators like for micro−irrigation, GDI index, groundwater table depletion, tubewell density, groundwater table at more than 7 m depth, groundwater quality, runoff potential and relative water supply have dragged down the overall CWSI for the state.

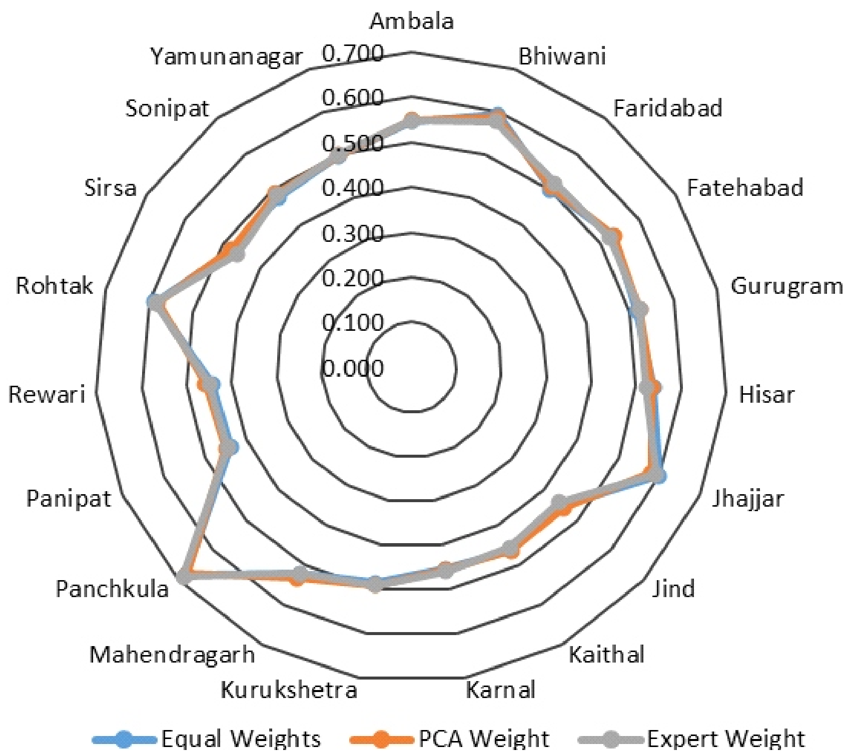

Fig. 2. CSWIs for different districts of Haryana

Table: 8
Reconstructed CWSI value for the state

District	CWSI	District rank
Ambala	0.547	5
Bhiwani	0.586	3
Faridabad	0.508	10
Fatehbad	0.532	6
Gurugram	0.520	9
Hissar	0.531	7
Jhajjar	0.590	2
Jind	0.452	17
Kaithal	0.459	15
Karnal	0.457	16
Kurukshetra	0.489	12
Mahendragarh	0.525	8
Panchkula	0.681	1
Panipat	0.444	19
Rewari	0.451	18
Rohtak	0.584	4
Sirsa	0.471	14
Sonipat	0.484	13
Yamunanagar	0.498	11
Haryana	0.534	

The natural factors (indicators) have performed better than the manmade factors. Hence, it warrants better management practices in the state. Overexploitation of groundwater in the state has also contributed to the low to moderate CWSI. The GDI index for the state is 135%. Central Ground Water Board puts a benchmark of 70% as most sustainable exploitation of groundwater. Such huge deviation from the benchmark GDI impacts the ultimate CWSI of the state. Improper cropping systems in Haryana contributes to low CSWI. Rice cultivation requires a minimum annual rainfall of 650 mm to demand less irrigation. Many districts in the state of Haryana have annual rainfall of less than 650 mm. The cropping pattern in groundwater overexploited regions of the state requires to be diversified to low duty crops like maize, pulses and oilseeds etc. However, the present marketing (MSP and public procurement), comparative yield and per hectare income from these crops, the risk of getting better quality seed and managing disease and pests in these alternative crops need to be established to lure away farmers from water guzzling rice crop.

4. CONCLUSIONS

In view of the extensive cultivation of water–guzzling crops and overexploitation of groundwater for this purpose in the state of Haryana, a CWSI for the state has been developed. The indicators crucial for the sustainability of agriculture and water resources for the state were identified. In total, there were 17 indicators under the weather and climate related indicators, water stress indicators, and water management related indicators. Normalisation and weight assignment to the indicators were done in order to develop the CWSI. The average CWSI for the state was calculated as 0.534 with a minimum value of 0.444 in the Panipat district and a maximum value of 0.681 in the Panchkula district.

The improper cropping system and overexploitation of groundwater are the main reason for the low to moderate sustainability of agriculture and water resources in the Haryana state. There is a need to diversify to low duty crops like maize, pulses and oilseeds in place of high water consuming crops like rice in order to have better sustainability of water resources.

REFERENCES

Barnett, V., Payne, R. and Steiner, R. 1995. *Agricultural Sustainability: Economic, Environment and Statistical Considerations*. John Wiley and Sons, UK.

Binder, C., Feola, G. and Steinberger, J. 2010. Considering the normative, systemic and procedural dimensions in indicator−based sustainability assessments in agriculture. *Environ. Impact Assess. Rev.*, 30(2): 71−81.

CGWB. 2019. *Dynamic Groundwater Resources of India 2017*. Central Ground Water Board (CGWB), Ministry of Water Resources, New Delhi, India.

Chand, P., Jain, R., Chand, S., Kishore, P., Malangmeih, L. and Rao, S. 2019. Estimating water balance and identifying crops for sustainable water resources in Bundelkhand region of India. *Trans. of the ASABE*, 63(1): 117−124.

Dantsis, T., Douma, C., Giourga, C., Loumou, A. and Eleni A.P. 2010. A methodological approach to assess and compare the sustainability level of agricultural plant production systems. *Ecol. Indic.*, 10(2): 256−263.

FAO, 2012. *Coping with Water Scarcity an Action Framework for Agriculture and Food Security.* Food and Agriculture Organization of the United Nations. http://www.fao. org/docrep/016/i3015e/i3015e.pdf.

Gafsi, M., Legagneux, B., Nguyen, G. and Robin, P. 2006. Towards sustainable farming systems: effectiveness and deficiency of the French procedure of sustainable agriculture, *Agric. Syst.*, 90: 226–242.

Hani, F., Braga, F., Stampfli, A., Keller, T., Fisher, M. and Porsche, H. 2003. RISE, a tool for holistic sustainability assessment at farm level. *Int. Food Agribus. Manage. Rev.*, 6: 78−90.

OECD. 2008. *Handbook on constructing composite indicators, methodology and user guide*. OECD, Paris.

McKee, T.B., Doesken, N.J. and Kleist, J. 1993. *The relationship of drought frequency and duration of time scales*. Eighth Conference on Applied Climatology, American Meteorological Society, Jan17−23, 1993, Anaheim CA, pp179−186.

Meul, M., Passel, S.V., Nevens, F., Dessein, J., Rogge, E., Mulier, A. and Hauwermeiren, V. 2008. MOTIFS: a monitoring tool for integrated farm sustainability. *Agron. Sustain. Dev.*, 28: 321−332.

Pieri, C., Dumanski, J., Hamblin, A. and Young, A. 1995. *Land Quality Indicators*. World Bank Discussion Paper no. 315, World Bank, Washington, DC.

Rodell, M., Velicogna, I. and Famiglietti, J.S. 2009. Satellite based estimates of groundwater depletion in India. *Nature,* 460: 999−1002.

Schader, C., Grenz, J., Meier, M.S. and Stolze, M. 2014. Scope and precision of sustainability assessment approaches to food systems. *Ecol. Soc.,* 19(3): 42.

Srivastava, S.K., Chand, R., Singh, J., Kaur, A.P., Jain, R., Kingsly, I. and Raju, S.S. 2017. Revisiting groundwater depletion and its implications on farm economics in Punjab, India. *Curr. Sci.,* 111(3): 422−429.

Talukder, B. and Alison, B. 2017. Comparison of methods to assess agricultural sustainability. *Sustain. Agric. Rev.*, 13: 149−168.

Van de Fliert, P. and Braun, A. 2002. Conceptualizing integrative, farmer participatory research for sustainable agriculture: From opportunities to impact. *Agr. Hum. Values,* 19(1): 25−38.