Chapter 14
Measurement of Water Scarcity

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Abstract When the balance between availability and demand of water is disturbed, problems of water scarcity begin. In this chapter an attempt is made to explain the methods of measuring water scarcity based on secondary and primary data for which Thornthwaite's water balance method and Sullivan's water scarcity index method have been taken, respectively. The paper explains how water scarcity can be calculated by using different data sets by different methods, and their positive and negative aspects have also been evaluated with respect to the outcome.

Keywords   Scarcity • Water balance • Deficit • Water scarcity index

14.1   Introduction

Water scarcity is a most serious hindrance to agricultural development and a major threat to the environment in dry areas (Oweis 2005, p. 192). Once considered an abundant resource, now water is increasingly seen as a 'scarce' resource, one that needs to be managed judiciously. Before going into the details of this problem, it is necessary to understand what water scarcity really is. The etymological roots of the word 'scarcity' go back to the Old Northern French word '*escartre*,' which meant insufficiency of supply (Mehta 2003, p. 5067). Actually, the term scarcity of water refers to situations in which water resources available for producing output are insufficient to satisfy human wants. According to the European Environment Agency, "*water scarcity occurs where there are insufficient water resources to satisfy long-term average requirements. It refers to long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system.*" As used by water engineers, if the annual

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availability of renewable freshwater is 1,000 m^3 or less per person in the population, this is a situation of water scarcity.

Water scarcity is, thus, inevitably and also incorrectly assumed to be caused only by deviations from normal in rainfall. However, the most alarming and exponential increases in water scarcity during the past few years cannot be linked exclusively to the abnormalities in rainfall because there is no long-term change in rainfall, although there have been some variations in annual rainfall. Further, water scarcity and drought are no longer restricted to arid regions with scanty rainfall. Areas receiving high rainfall, such as Kerala and Goa, are also experiencing acute water scarcity and have been demanding drought relief. There are, however, many other intangible and ambiguous aspects of the problem, leading to different types of scarcities experienced by a wide range of actors. Hence, the responses to 'scarcity' are also varied, and there is a need to understand their relational aspects.

Water scarcity is closely linked with the availability and demands of water in a particular area. Availability of water depends upon the surface water and groundwater resources. The water requirement now and in the future will also increase, not only because of increasing population but also because of changing lifestyles in both rural and urban areas. The utilization patterns of water are also changing. On the basis of present-day utilization patterns, future water requirements can be projected. The water requirement would be higher in urban areas because of the high concentration of population. Of the water required in urban areas, the maximum would be utilized to maintain cleanliness in public and private places. Hence, the water requirement will increase on a large scale. On the other hand, water available per capita decreases very sharply with an increase in population density.

When the balance between availability and demand of water is disrupted, problems emerge. Water scarcity is also the result of this imbalance. Not only does this imbalance create water scarcity, but mismanagement of available water resources also exacerbates the situation. For example, in the northeastern states of India, where there is enough rainfall and water is available in the rainy season, the physiography of the area as well as lack of proper management techniques creates a water scarcity situation during the summer season.

In popular usage, "scarcity" is a situation in which there is insufficient water to satisfy normal requirements. There are degrees of scarcity—absolute, life threatening, seasonal, temporary, and cyclical. Populations with normally high levels of consumption may experience temporary scarcity more keenly than other societies who are accustomed to using much less water. Scarcity often arises because of socioeconomic trends that have little to do with basic needs. Defining scarcity for policy-making purposes is very difficult. Terms such as water scarcity, shortage, and stress are commonly used interchangeably, although each term has different specific meanings. *Water shortage* is a dearth, or absolute shortage; low levels of water supply relative to minimum levels necessary for basic needs can be measured by annual renewable flows (in cubic meters) per head of population, or its reciprocal, that is, the number of people dependent on each unit of water, such as millions of persons per cubic kilometer. *Water scarcity* is an imbalance of supply and demand under prevailing institutional arrangements and demand in excess of available supply; a

high rate of utilization compared to available supply, especially if the remaining supply potentials are difficult or costly to tap. Because water scarcity is a relative concept, it is difficult to capture in a single index.

The symptoms of water scarcity or shortage are growing conflict between users and competition for water, declining standards of reliability and service, harvest failures, and food insecurity. The term water stress was coined in 1992 by a Swedish hydrologist, Malin Falkenmark. To understand 'water scarcity' and 'water stress,' Falkenmark concluded that countries are characterized as water stressed and water scarce depending on the amount of renewable water available. Water stress is a situation when a region faces acute water crises to such an extent that the basic water requirement is not met (Falkenmark 1983). The circumstances may range from supply hindrances to distance factors or economic constraints. Water stress, thus, represents widespread and chronic lack of access to safe and affordable water. Water scarcity, on the other hand, indicates that there is an insufficiency of the resource to meet the demands. Water-scarce regions are those where water resource availability is less; hence, the means of water availability and accessibility to the concerned population become restrained (Sahay 2003).

The discussion concludes that water scarcity is a relative concept, depends on local conditions, and is difficult to measure. Thus, in this study an attempt is made to explain the methods for measuring water scarcity in arid and semiarid parts of Rajasthan, that is, Sikar and its five surrounding districts: Jaipur, Churu, Pilani, Nagaur, and Ajmer.

14.2   Review of the Literature

In recent years natural resources have been studied from various aspects such as physical, economic, political, and social. Water scarcity as a major threat to water resources has been studied by many researchers. They have used different methods to measure the intensity and magnitude of the problem, but neglected the suitability of the technique without knowing its merits and limitations. Some of the important studies have been reviewed in this context.

Subramaniam and Vinayak (1982) stated that water balance studies in relationship to climatic studies are one of the important disciplines of applied climatology. They have studied the climatic features of Trivandrum and its vicinity. The water balance methods of Thornthwaite (1948) and Thornthwaite and Mather (1955) were adopted. On the basis of humidity, aridity, moisture indices, and moisture adequacy calculation, they found that the study area reveals a stable humid climate, and currently a shift toward dry climate was evidenced by the researchers in the study area. Joshi (2004) analyzed the relationship between requirements and availability of water in Port Blair town. The availability of groundwater and its changing nature with seasons was discussed with the variations in the consumption pattern of water for domestic use depending upon season and the beliefs, customs, and habits of the users. It is concluded that water crisis is a permanent feature in Port Blair town.

Soundaravalli (1992) identified surplus and deficit areas in Dindigul city of Anna district, Tamil Nadu and explained the causes of nonavailability of water over the years. Bandyopadhyay (1987) suggested analysis of interaction among environmental and political forces in finding a solution to the problem of water scarcity. Drought and water scarcity are positively related to each other. The political ecology approach has been emphasized to cope with water scarcity. Oweis (2005) stated that in dry areas, water is most scarce, land is fragile, and drought inflicts severe hardship on already poor populations. The efficient use of water can help to alleviate the problems of water scarcity and drought.

Among the numerous techniques for improving water use efficiency, the most effective are water harvesting and supplemental irrigation. Water harvesting stores the water by different methods and effectively combats desertification and enhances the resilience of the communities and ecosystem under drought. Khurana (2003) found that the problem of scarcity of water can be solved by adopting the rainwater harvesting system. Rainwater harvesting is not just the starting point for meeting drinking water needs, but also the starting point of an effort to eradicate rural poverty itself. It can generate massive rural employment and reduces distress-based migration from rural to urban areas. The harvesting system also generates community spirit within the village, and builds up what economists call 'the social capital.'

The foregoing discussion explains that the problem has been discussed and analyzed from various points of view. Thornthwaite's water balance method remained quite popular to identify the water-scarce areas. However, the method is quite old, using natural climatic conditions (mainly temperature and rainfall) to determine the deficit conditions in an area, but now the modern conditions have become so complex that water scarcity is no more a natural phenomenon. It depends more on human aspects such as accessibility, availability, and the quality of water as deteriorated by humans. At present, it is a man-made problem. Water has been made scarce by humans misusing and mismanaging it. This study highlights the importance of measuring water scarcity in arid areas of India in particular and in the world in general.

14.3   The Study Area

Rajasthan State is the largest in India, at present, in terms of areal coverage. The study area lies in the northeastern part of the State (Fig. 14.1). Mainly six districts, Sikar, Jaipur, Churu, Ajmer, Nagaur, and Pilani, have been selected to study Thornthwaite's method of water balance, and only Sikar district was selected to test Sullivan's water scarcity index. The Sikar district is located in the Shekhawati region of the State, the second most developed district after Jaipur (capital of Rajasthan). This administrative headquarters of Sikar District is located in the northeastern part of Rajasthan between 27°21′ and 28°12′N and 74°44′ and 75°25′E at an average elevation of 432 m above mean sea level, with an area of 7,732 km^2. Sikar is the most important town in the Shekhawati region. Sikar, besides being the
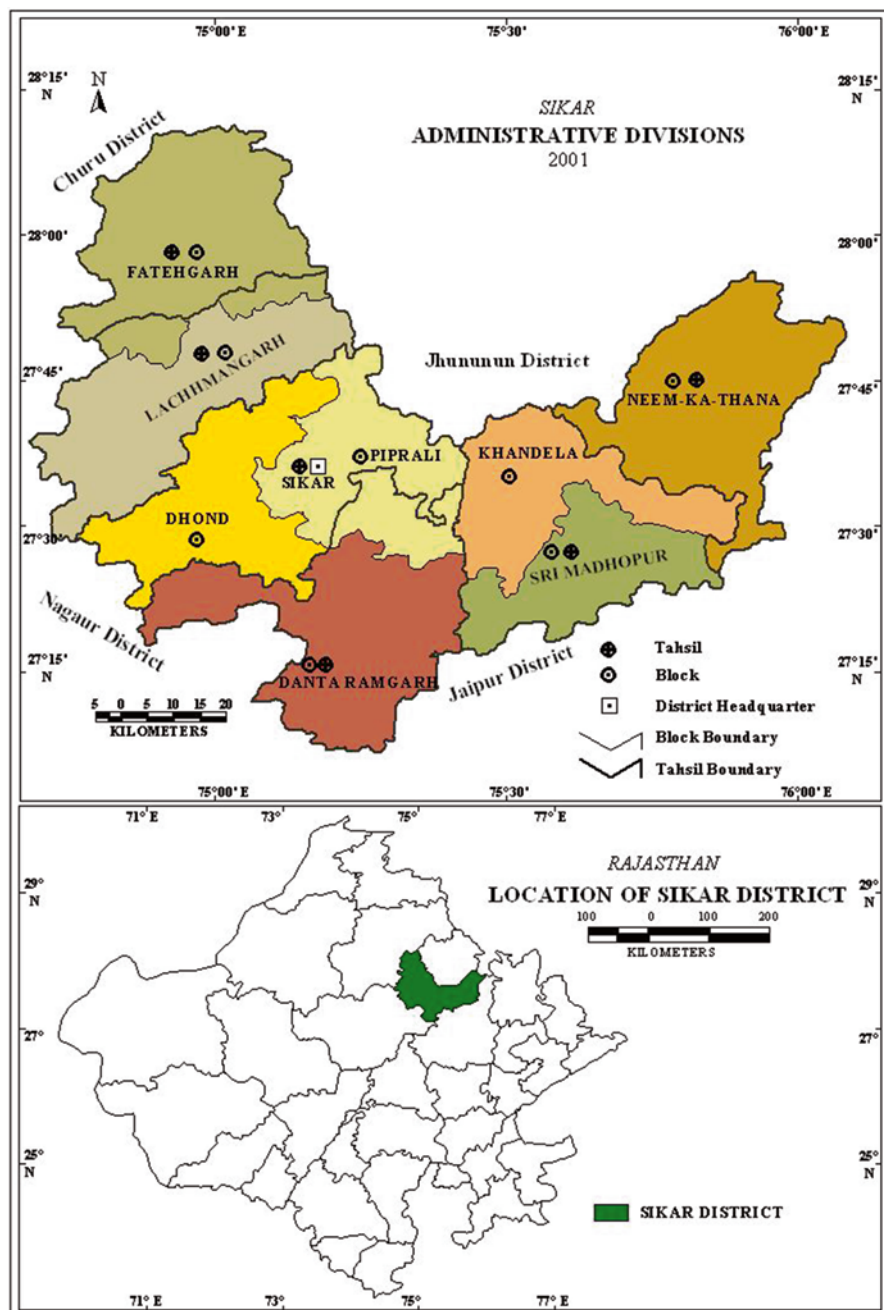
Fig. 14.1 Rajasthan: location of study area, 2001

district headquarters administratively, constitutes six tahsils, namely, Fatehpur, Lachhmangarh, Sikar, Danta Ramgarh, Neem Ka Thana, and Sri Madhopur, and eight blocks, namely Fatehpur, Lachhmangarh, Dhond, Piprali, Danta Ramgarh, Khandela, Neem Ka Thana, and Sri Madhopur.

The Aravalli ranges divide the district into two main topographic areas. The western region is characterized by sand dunes and the eastern by hill ranges. There are no perennial rivers in the district. Sikar district occupies a part of the eastern limit of the desert tract. The climate of the study area is characterized by hot summers, scanty rainfall, a chilly winter season, and general dryness of the air except during the monsoon season. The average maximum temperature was 46 °C, the minimum temperature 0.0 °C, and the mean temperature 23 °C during 2001. Normal annual rainfall is 466 mm; the average annual rainfall for the year 2001 was recorded as 250 mm. Rainfall is very low, highly indefinite, and variable in the district. The total population of the district is 22.8 lakhs (2,287,788) (Census of India 2001), with a density of 296 persons/km^2.

The Sikar district and its surrounding districts have been selected for study because of the acute water scarcity in the whole state and particularly in the study area. The climatic conditions increase the magnitude of the problem in the study area. The gap between water requirements and the total utilizable supply is increasing day by day. Sikar and its surrounding districts, therefore, have been selected as a case for the measurement of water scarcity.

14.4   Data and Methods

The study is based on both primary and secondary sources of data. The secondary data have been collected from the Public Health and Engineering Department (PHED), Census of India Publications, and data related to temperature and rainfall to calculate water balance were collected from the Indian Meteorological Department (IMD). In addition, books, theses, journal articles, newspapers, and Internet websites were also consulted.

The secondary data for temperature and rainfall were available at the district level; water balance was calculated at district level. Water balance has been calculated for Sikar and its five surrounding districts in the State. To calculate water deficit, the Thornthwaite (1948) method and the Thornthwaite and Mather (1955) water balance method have been used. Here, it has been assumed that high deficit means higher water scarcity and lower deficit means a lower level of water scarcity.

The magnitude of water scarcity, the Water Scarcity Index (WSI) developed by Caroline Sullivan (2002a), has been used, and primary data were collected and analyzed to determine the WSI scores. In this method, a higher WSI score means a lower magnitude of water scarcity and a lower WSI score means a higher scarcity. On the basis of WSI scores, *iso-scarcity* lines have been drawn and spatial variations in the water scarcity have been determined.

The *stratified proportionate random sampling* technique was adopted for selecting the village and household for primary data collection. Villages were selected proportionately from deficit zones, that is, 2.5 % of villages from each deficit zone. The deficit zones were identified on the basis of Thornthwaite's (1948) and Thornthwaite and Mather's (1955) water balance method. Based on the level of deficit, water-scarce areas have been delimited. Of 992 villages, 25 villages in eight blocks and four towns (total, nine towns in the district), 1 from each deficit zone, were selected for primary survey. The sampling frame was chosen in a manner that would provide an even spatially distributed sample. A total of 261 households (225 rural and 36 urban) were covered, 9 households from each selected unit of analysis.

14.5 Discussion

14.5.1 Thornthwaite's Water Balance

It is assumed that high deficit means a higher magnitude of water scarcity and vice versa. To identify the deficit in the district, the water balance method has been used. For the climatological water balance for any period and place, Thornthwaite's formula as a useful tool is best known. He had actually arrived at a complex exponential formula for evaluating daily or monthly potential evapotranspiration (PET) from more generally available data of mean air temperature, rainfall, length of day, and latitude. The whole computational procedure carried out on the water balance of a place is expressed by the equation given below:

$$PET = 1.6 \left(10 \times \frac{Ti}{I} \right) a$$

where

PET = potential evapotranspiration
Ti = mean monthly or daily temperature
I = monthly heat index
and **a** is a constant (*where* $a = 6.75E^{-7} I^3 - 7.71E^{-5} I^2 + 1.79E^{-2} I + 0.49239$).

The spatial distribution of annual estimated PET reveals an interesting pattern (Table 14.1). Because data were available to the district level, six districts were taken into consideration to determine the pattern of deficit.

Figure 14.2 exhibits a decreasing tendency of PET values toward the center, that is, Sikar District, reflecting the temperature of the study area, which is comparatively low. The annual PET calculated for Sikar is 1,398 mm. It increases as we move in all directions from the center, although its increasing trend is different. It increases rapidly in the north and northeastern directions from the center, but in the

Table 14.1 Mean monthly potential evapotranspiration by the Thornthwaite method, 2000

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. Sikar	$I=119.11$		$a=2.6712$									
T (°C)	13.10	14.65	22.05	27.85	30.10	33.45	27.55	27.80	29.10	10.55	17.80	10.05
PET (mm)	20.63	27.81	82.91	154.70	190.38	252.37	150.29	153.96	173.95	11.57	46.79	10.16
C.F.	0.92	0.88	1.03	1.07	1.16	1.16	1.18	1.13	1.02	0.99	0.90	0.90
Adj. PET	18.88	24.48	85.39	165.53	220.84	**291.48**	177.34	173.97	177.43	11.40	42.12	9.15
2. Jaipur	$I=150.89$		$a=3.75709$									
T (°C)	16.30	16.95	23.75	32.35	33.95	34.10	29.5	29.30	29.25	28.65	22.70	17.40
PET (mm)	21.38	24.76	87.95	280.84	336.68	342.31	210.22	193.59	192.35	177.94	74.20	27.33
C.F.	0.92	0.88	1.03	1.07	1.16	1.15	1.18	1.13	1.02	0.99	0.90	0.90
Adj. PET	19.67	21.79	90.58	300.50	390.55	393.65	248.06	218.75	192.35	177.94	74.20	27.33
3. Pilani	$I=145.55$		$a=3.5458$									
T (°C)	13.60	15.25	21.45	30.45	34.35	33.80	31.20	30.85	29.35	28.0	21.40	15.70
PET (mm)	12.58	18.88	63.28	219.18	336.03	317.34	238.92	229.56	192.37	162.79	62.76	20.93
C.F.	0.91	0.88	1.03	1.07	1.16	1.16	1.18	1.13	1.02	0.98	0.90	0.90
Adj. PET	11.45	16.61	65.18	234.52	389.79	368.11	281.93	259.40	196.22	159.53	56.48	18.83
4. Churu	$I=152.82$		$a=3.8364$									
T (°C)	14.60	16.0	22.7	31.7	35.7	35.35	32.35	32.05	30.25	27.85	21.05	15.70
PET (mm)	13.43	19.08	73.01	262.89	414.73	399.34	284.18	274.20	219.67	159.97	54.66	17.74
C.F.	0.91	0.88	1.03	1.07	1.17	1.16	1.19	1.13	1.03	0.98	0.90	0.90
Adj. PET	12.22	16.79	75.20	281.29	485.23	463.24	338.17	309.85	226.26	156.77	49.19	15.97

5. Nagaur	I=156.84		a=4.008									
T (°C)	15.00	18.50	24.50	30.00	34.50	36.00	33.00	32.00	31.50	28.00	22.50	16.50
PET (mm)	13.38	31.01	95.59	215.22	376.82	446.89	315.33	278.74	261.70	163.23	67.95	19.61
C.F.	0.92	0 88	1.03	1.07	1.16	1.15	1.18	1.13	1.02	0.99	0.90	0.90
Adj. PET	12.31	27.29	98.45	230.28	437.11	**513.93**	372.09	314.98	266.93	161.60	61.15	17.64
6. Ajmer	I=158.49		a=4.0800									
T (°C)	18.45	18.60	25.00	32.65	33.35	33.40	29.60	29.55	30.00	30.75	24.85	20.45
PET (mm)	29.74	30.74	102.73	305.31	332.91	334.95	204.63	203.22	216.15	239.06	100.24	45.26
C.F.	0.92	0.88	1.03	1.07	1.16	1.15	1.18	1.13	1.02	0.99	0.91	0.91
Adj. PET	27.36	27.05	105.81	326.68	386.18	385.20	241.46	229.64	220.47	236.67	91.22	41.19

Source: Calculated by the author

T temperature, *PET* potential evapotranspiration, *Adj. PET* adjusted PET, *C.F.* correction factor
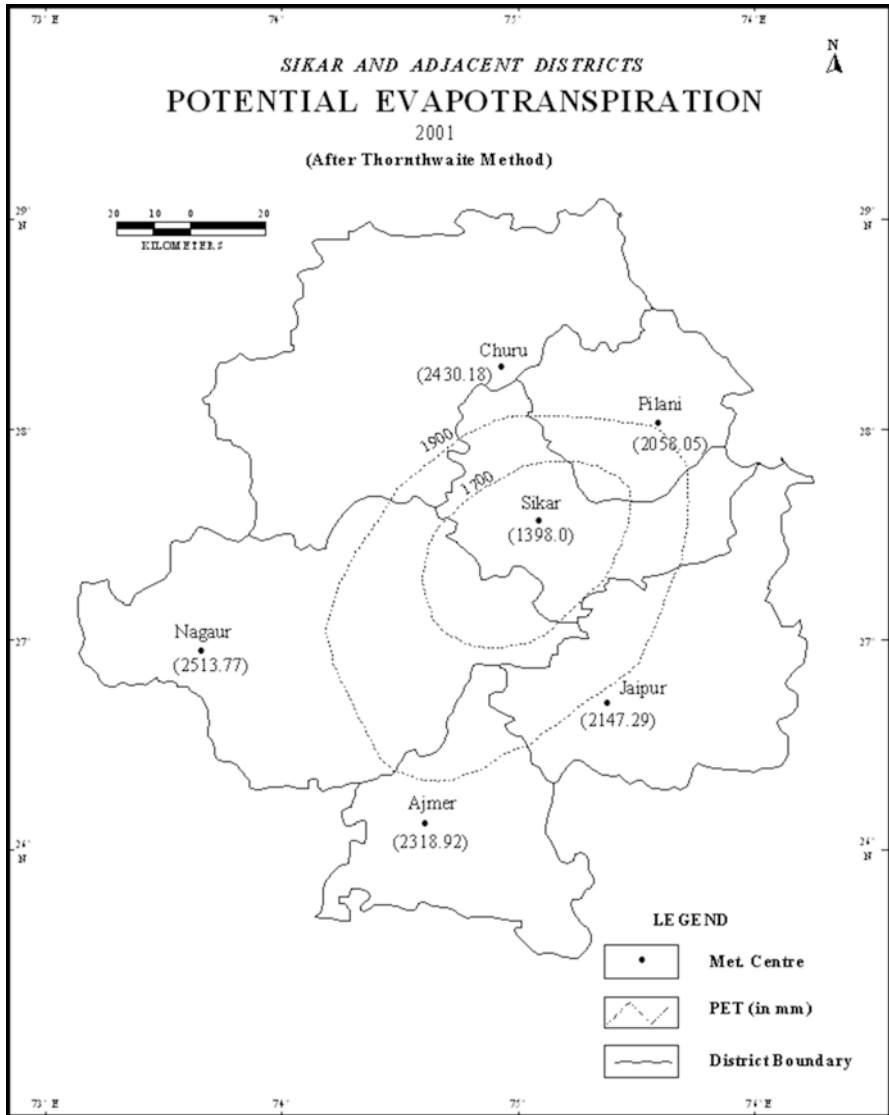
Fig. 14.2 Sikar and adjacent districts: potential evapotranspiration, 2001

southwest, south, and southeast, PET increases slowly because of distance between
district headquarters, the point where temperature is recorded, and thus the iso-PET
lines become wider. The highest PET value, 2,513.77 mm, was obtained at Nagaur,
the southwestern margin, followed by Ajmer (2,318.92 mm) in the south and Jaipur
(2,147.29 mm) in the southeast.

14.5.1.1   Surplus and Deficit

The amount of water that cannot be stored is termed the soil moisture (SM) surplus and is calculated by subtracting recharge from excess precipitation during wet months:

$$\text{Thus, surplus} = (P - PET)\ \ (+\Delta SM) \qquad \text{when } P > PET$$

Because all months have no soil moisture, there is no surplus of water at all the stations. Thus, all the stations face deficits that vary in magnitude. The amount by which actual evapotranspiration (AET) and potential evapotranspiration (PET) rates differ in any month is called the soil moisture deficit:

$$\text{Deficit} = PET - AET$$

Deficit is the difference between PET and AET, respectively. Once a soil moisture deficit develops, it can be reduced when excess precipitation is stored in the soil at the beginning of the wet season. Thus, on the basis of *iso-deficit* lines, spatial variations in deficit are identified. The water balance is been shown (Fig. 14.3a–f) for all six stations.

Deficit varies from 1,380 mm at Sikar to 2,325.7 mm at Nagaur (Fig. 14.4). Deficit increases in all directions from the center at Sikar. In the northwestern direction, *iso-deficit* lines are closer to each other, signifying the rapid increase in the deficit level. It can also be calculated that scarcity of water increases toward the northwestern side. Finally, the deficit area has been extracted for the Sikar district and the deficit zones are demarcated.

14.5.1.2   Deficit Zones

On the basis of intensity of deficit, the district is divided into four deficits zones: very high, high, medium, and low (Fig. 14.5). Temperature and rainfall were low in the central part of the study area. A low difference between PET and AET has resulted in a low deficit in the center in comparison to surrounding areas; this is a low-deficit zone, and the deficit range is less than 1,500 mm. As we move toward the northwest and eastern directions, the deficit increases. Very high deficit zones have a deficit level of more than 1,900 mm, located in the northwestern part of the district. Thus, the Thornthwaite's water balance method provides deep insight into water scarcity based on collected meteorological data. The higher deficit indicates a higher level of water scarcity and vice versa. The figure also explains increase in level of water scarcity from the center. Thus, in the study area deficit and water scarcity are positively correlated. The method provides a regional pattern of water scarcity at the district level or the point where the climate data is collected.
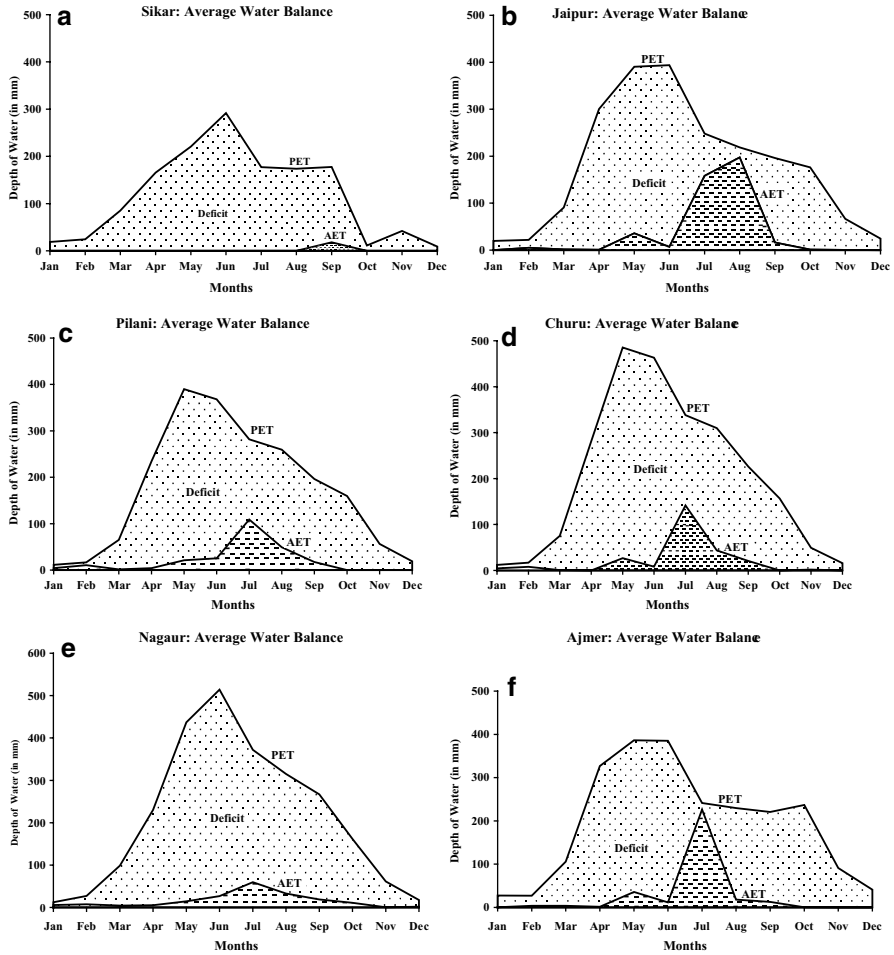
Fig. 14.3 Water balance, 2001 (Based on Thornthwaite method): (**a**) Sikar, average water balance; (**b**) Jaipur, average water balance; (**c**) Pilani, average water balance; (**d**) Churu, average water balance; (**e**) Nagaur, average water balance; (**f**) Ajmer, average water balance

14.5.2   Water Scarcity Index

Another widely known assessment of global water resource scarcity is the work published by Caroline Sullivan (2002a). Sullivan is an environmental economist specializing in water management and policy. She and her team of researchers of the Centre for Ecology and Hydrology (CEH), Wallingford, discussed various indicators that could be used in the water scarcity index (WSI). The water scarcity index is designed as a composite, interdisciplinary tool, linking indicators of water and human welfare to indicate the degree to which water scarcity impacts on human populations.
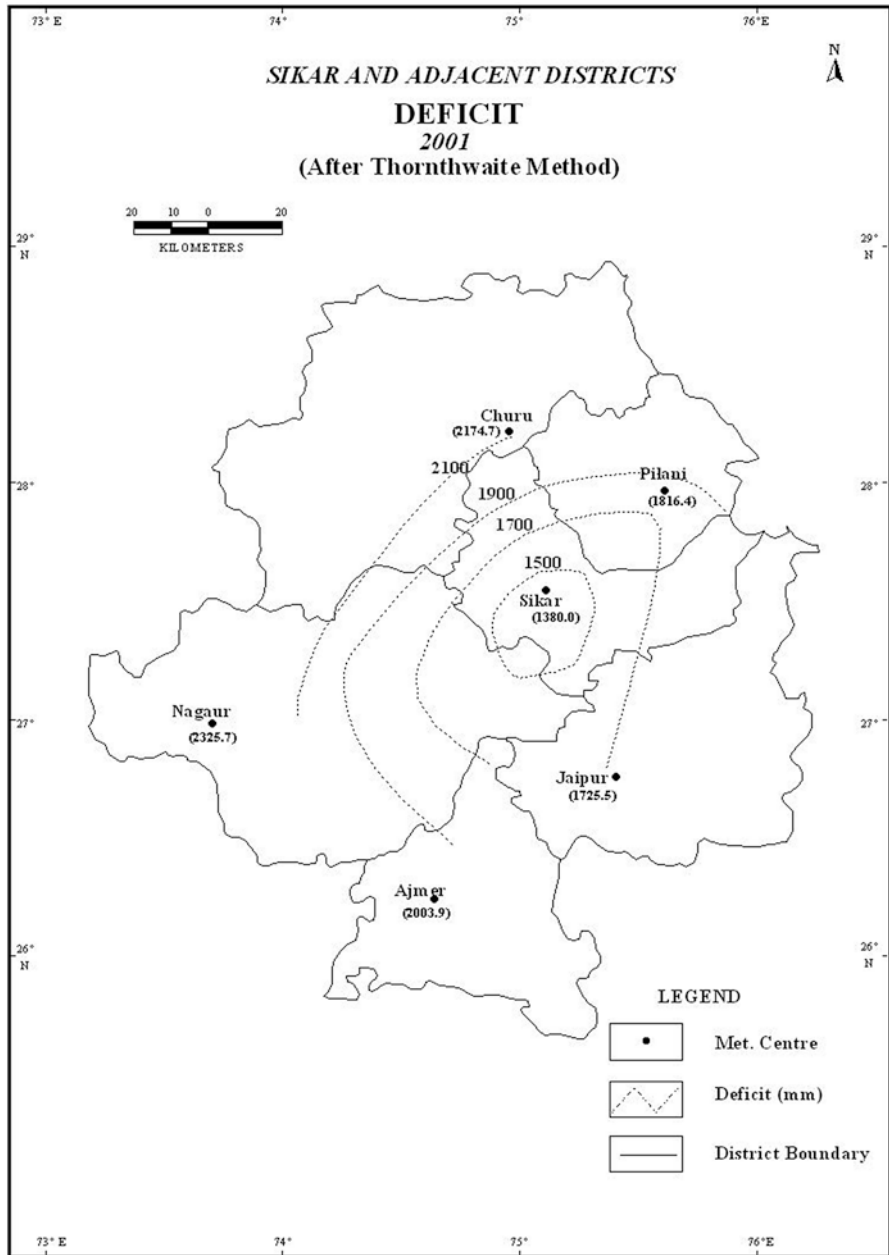
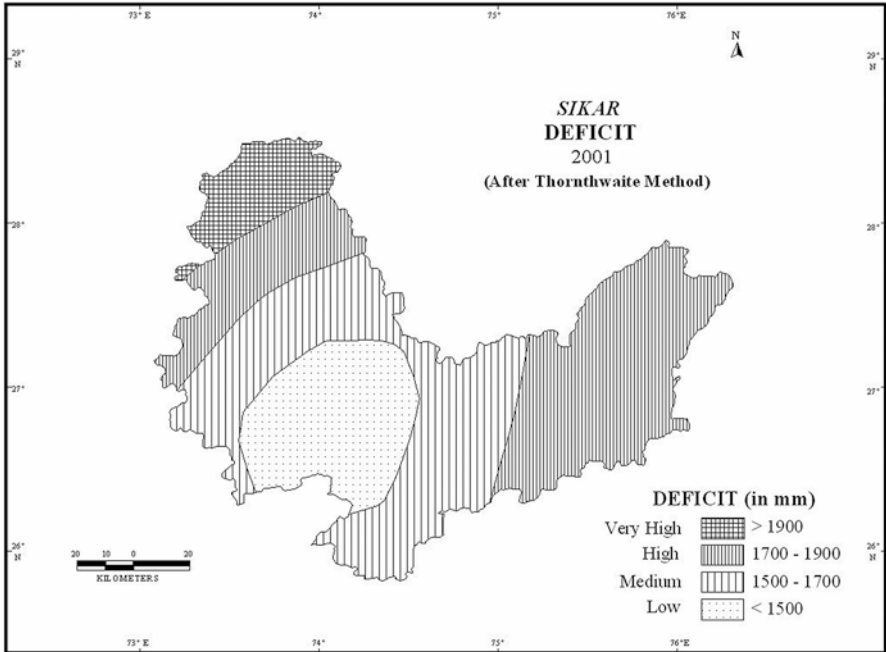**Fig. 14.4** Sikar and adjacent districts: deficit, 2001

Fig. 14.5 Sikar: deficit, 2001

The primary focus of the index is on poor people, who suffer most from inadequate access to water. The WSI combines physical, social, economic, and environmental information associated with water scarcity, access to water, and ability to use water for productive purposes. The identified components are, first, water availability, which refers to water resources. The actual physical availability of surface water and groundwater make up this factor. Various aspects of this component, such as types of water demand—domestic, agricultural, and time taken in collecting water— are included in assessing this element. In the present case, the resource component was represented by availability of water in number of hours. Because this single aspect inherently includes seasonal variability and collection time, duration of water availability in hours was considered for the water scarcity index.

The chief component is water quality. Safe water quality is considered as a true representative of community environmental concern: it is taken as an environmental indicator. The population with access to safe water has been taken into consideration. Here, it is considered only from the respondent standpoint of water's fitness for drinking, cooking, washing, and bathing, and fitness for other purposes is not included. The last component is time taken to collect domestic water. With variations in rainfall and groundwater availability, difference in access to water is inevitable. Access to water for human use, including time and effort required to collect water for the household, is another major component of the water scarcity index.

The heterogeneity of water's physical availability is generally compounded by unequal access to water resources in a district or even within a community. This variability in one's access to water, spread over a region or a community, is perhaps the essence of water scarcity. In the proposed index, access to the resource is represented by ownership of a water source. Private ownership of a water source (as taps, hand pumps, wells, or tube wells) converts into rights of access to water, whereas non-ownership or use of a common water source denotes difficulty in accessing water.

14.5.2.1 Estimation of WSI

In this method, the index is constructed from a series of variables that capture the essence of being used to measure scarcity, which is done using national level data, or at a local level using locally determined values and parameters. Using the composite index approach, the following elements are included in calculating the water scarcity index:

1. Water availability
2. Access to safe water
3. Time taken to collect domestic water

These data result in the WSI formula as follows:

$$\text{WSI} = w_a A + w_s S + w_t \left(100 - T\right) \left(\text{Sullivan 2002b, p.1203}\right)$$

where

- A is adjusted water availability (AWA) assessment as percentage. Calculated on the basis of groundwater and surface water availability related to ecological water requirement, plus all other domestic demands, as well as the demand from agriculture and industry. The resource component is represented by availability of water in number of hours, which includes seasonal variability and collection time for water.
- S is a population with access to safe water and sanitation in percentage.
- T is an index to represent time and effort taken to collect water for the households, for example, from proportion of population having access in or near the home (common or private ownership), etc. $100 - T$ is the structure used to take account of the negative relationship between the time taken to get water and the final level of the WSI.
- w_a, w_s, and w_t are the weights given to each indicator of the index, and their total should be 1 to produce a WSI between 0 and 100.
- Because A, S, and T are all defined to be between 0 and 100, and w_a, w_s, and w_t are between 0 and 1, to develop a water scarcity index value between 0 and 100, the formula needs to be modified as follows:

$$\text{WSI} = 1/3\left(w_a A + w_a S + w_t \left(100 - T\right)\right)\left(\text{Sullivan 2002b, p.1203}\right)$$

The method is important to identify those areas where water scarcity conditions are severe. With the help of water scarcity index values, information about the magnitude of scarcity in the area can be derived. Figure 14.6 shows the spatial variation in the magnitude of water scarcity in the Sikar district. On the map, *iso-scarcity lines* are plotted that join equal scarcity level based on WSI values. The study has identified very high, high, and medium levels of water-scarce regions; their WSI values are given here:

1. Very high (less than 20):   *Villages*: Ramgarh (6.5), Hathideh (8.3), Dhandhela (9.3), Piprali (13.9), Kuli (14.8), Gurara (16.7), Kalyanpura (16.7), Gaonri (18.5), Hirna (18.5), Bheekamsara (18.5), Mundru (19.5)
Towns: Neem Ka Thana (11.1), Khandela (13.0), Sikar (13.9), Fatehpur (16.7)

2. High (20–30):   *Villages*: Dhod (20.4), Hetamsar (22.2), Doodwa (24.1), Garh Bhopji (24.1), Kachhwa (25.9), Palsana (25.9), Sanwali (26.9), Lapuwa (26.9), Khanri (27.8), Hukumpura, Maganpura (28.7)

3. Medium (more than 30):   *Villages*: Peethampuri (31.5), Napawali (32.4), Goriyan (33.3)
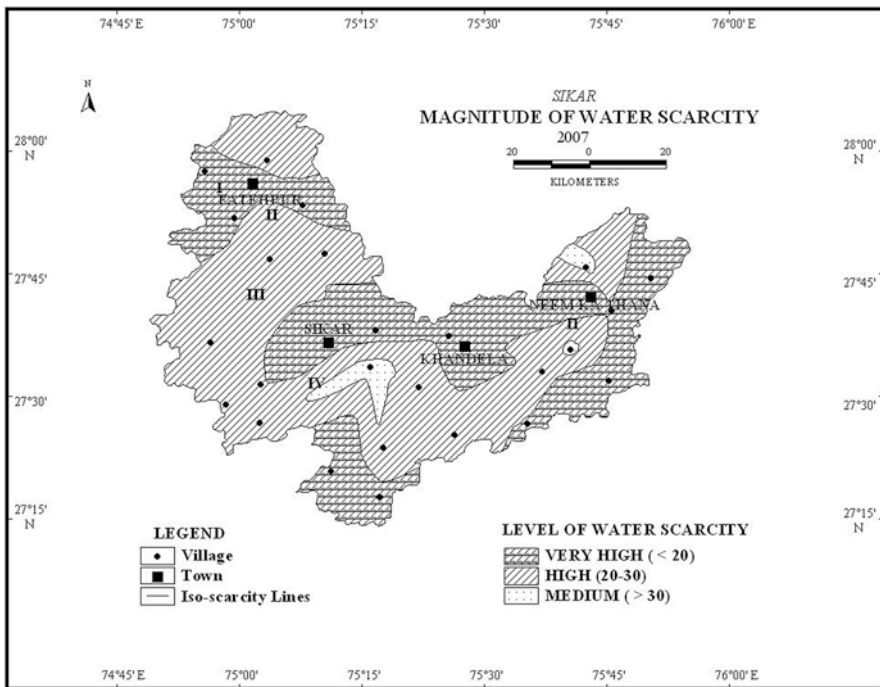

Fig. 14.6 Sikar: magnitude of water scarcity, 2007

The WSI scores of all 25 sampled villages and four towns indicate that 11 villages and four towns fall in the first category, that is, very high scarcity category with less than 20 in WSI values (Table 14.2). Eleven villages are found in the second category, that is, high scarcity of water (20–30), and 3 villages are moderately scarce with WSI scores of 30 and above.

Table 14.2 reveals that the WSI scores of rural and urban areas differ. As mentioned earlier, the higher the WSI score, the lower the degree of water scarcity, whereas a lower WSI score means high. Thus, the highest water scarcity and the lowest rural WSI score of Ramgarh village is 6.5, followed by Hathideh (8.3) and Dhandhela (9.3), while Neem Ka Thana town (11.1) is highly scarce, first in all urban examples. Surprisingly, all towns fall in the very high scarcity category with scores less than 20. With the maximum score, Fatehpur (16.7) is comparatively less scarce. On the other hand, in rural areas the maximum WSI scores are for Goriyan village, displaying a 33.3 score, which means moderately scarce.

14.6 Comparison of the Methods

Based on the foregoing analysis, it is pertinent to evaluate and compare the characteristics of both methods. Both methods are equally important to judge the availability and amount of water available to a particular area. The different types of data used by both secondary and primary methods by Thornthwaite and Sullivan give different patterns of water scarcity at different hierarchical levels. The availability of data for the Thornthwaite method is easier than for the Sullivan method, which uses primary data, often hard to collect. Secondary data (temperature and rainfall) were available up to district level, whereas primary data were collected up to individual level. Thus, the results of secondary data will provide district level patterns; conversely, the local level pattern can be extracted with the help of primary data. Secondary data are considered authentic and reliable because they are collected and published by the concerned government departments from time to time. Thus, the temporal analysis becomes easy in this method. On the other hand, primary data are raw data collected by an individual surveyor and may have errors because of manipulation. Thus, the actual picture may remain out of sight, although not entirely.

The water balance method requires data such as temperature, rainfall computational tables, and the moisture-holding capacity of the soil to calculate the water balance of an area. This method has difficult concepts with difficult calculations that require efficiency to calculate water balance. The WSI method requires first-hand information regarding accessibility, availability, and quality of water, which is easily available by talking to the people and spending time with them. Thus, the data cost is less, but it is a time-consuming process. Therefore, temporal analysis based on primary data becomes very difficult to use. This method has simple concepts that can be handled.

Table 14.2 Sikar: water scarcity index scores for villages

Rank	Village (block)	Availability	Safe water	Time taken	Wgt I	Wgt II	Wgt III	wA	wS	100−T	wt (100−T)	Total	WSI
1	Ramgarh (DRG)	33.3	0	88.9	0.5	0.25	0.25	16.7	0.0	11.1	2.8	19.4	6.5
2	Hathideh (KHN)	11.1	44.4	66.7	0.5	0.25	0.25	5.6	11.1	33.3	8.3	25.0	8.3
3	Dhandhela (NKT)	0	100	88.9	0.5	0.25	0.25	0.0	25.0	11.1	2.8	27.8	9.3
4	Piprali (PPR)	33.4	100	100	0.5	0.25	0.25	16.7	25.0	0.0	0.0	41.7	13.9
5	Kuli (DRG)	55.6	66.7	100	0.5	0.25	0.25	27.8	16.7	0.0	0.0	44.5	14.8
6	Gurara (KHN)	44.4	88.9	77.8	0.5	0.25	0.25	22.2	22.2	22.2	5.6	50.0	16.7
7	Kalyanpura (FPR)	100	0	100	0.5	0.25	0.25	50.0	0.0	0.0	0.0	50.0	16.7
10	Gaonri (NKT)	22.2	77.8	0	0.5	0.25	0.25	11.1	19.5	100.0	25.0	55.6	18.5
8	Hirna (FPR)	100	0	77.8	0.5	0.25	0.25	50.0	0.0	22.2	5.6	55.6	18.5
9	Bheekamsara (FPR)	100	0	77.8	0.5	0.25	0.25	50.0	0.0	22.2	5.6	55.6	18.5
11	Mundru (SMP)	88.9	55.6	100	0.5	0.25	0.25	44.5	13.9	0.0	0.0	58.4	19.5
12	Dhod (DHD)	66.7	55.6	44.4	0.5	0.25	0.25	33.4	13.9	55.6	13.9	61.2	20.4
13	Hetamsar (FPR)	100	55.6	88.9	0.5	0.25	0.25	50.0	13.9	11.1	2.8	66.7	22.2
14	Doodwa (LMG)	100	77.8	88.9	0.5	0.25	0.25	50.0	19.5	11.1	2.8	72.2	24.1
15	Garh Bhopji (KHN)	100	77.8	88.9	0.5	0.25	0.25	50.0	19.5	11.1	2.8	72.2	24.1
16	Kachhwa (LMG)	100	77.8	66.7	0.5	0.25	0.25	50.0	19.5	33.3	8.3	77.8	25.9
17	Palsana (PPR)	77.8	100	44.4	0.5	0.25	0.25	38.9	25.0	55.6	13.9	77.8	25.9
18	Sanwali (LMG)	100	100	77.8	0.5	0.25	0.25	50.0	25.0	22.2	5.6	80.6	26.9
19	Lapuwa (SMP)	88.9	77.8	33.3	0.5	0.25	0.25	44.5	19.5	66.7	16.7	80.6	26.9
20	Khanri (DRG)	77.8	88.9	11.1	0.5	0.25	0.25	38.9	22.2	88.9	22.2	83.4	27.8
21	Hukumpura (DHD)	88.9	100	33.3	0.5	0.25	0.25	44.5	25.0	66.7	16.7	86.1	28.7
22	Maganpura (DRG)	100	66.7	22.2	0.5	0.25	0.25	50.0	16.7	77.8	19.5	86.1	28.7
23	Peethampuri (NKT)	100	100	22.2	0.5	0.25	0.25	50.0	25.0	77.8	19.5	94.5	31.5
24	Napawali (NKT)	100	100	11.1	0.5	0.25	0.25	50.0	25.0	88.9	22.2	97.2	32.4
25	Goriya (PPR)	100	100	0	0.5	0.25	0.25	50.0	25.0	100.0	25.0	100.0	33.3

Source: Calculated by the author

DRG Danta Ramgarh, *FPR* Fatehpur, *DHD* Dhond, *NKT* Neem Ka Thana, *KHN* Khandela, *PPR* Piprali, *SMP* Sri Madhopur, *LMG* Lachhmangarh

Thornthwaite's method is a nonempirical estimation of water balance because it uses secondary data. The results do not represent ground reality because of the large areal coverage and one point of data collection, as up to district level. On the other hand, Sullivan's water scarcity index method is more practical, contains easy concepts, and represents ground reality as a result of the units of data collection. In both methods, graphical representation is done by plotting *iso-scarcity lines* on the map. The Thornthwaite method depends on secondary data, and the Sullivan method, which is quite new, represents more ground reality. Thus, it is necessary that researchers should deeply evaluate the nature of the problem and the availability of data for the study area. Both methods have their own implications and limitations depending upon the local conditions.

14.7 Findings

The results of both methods are quite noticeable from Figs. 14.5 and 14.6. The most important finding, after discussing the methods and their outcome, is that the results of Thornthwaite's water balance method are important if the study is to be conducted for a large region. The reason can be the unit of analysis, which can be a district or group of districts for which secondary data can be easily collected and analyzed. In this method, the variation will not be clearly visible beyond the district level because of data limitation. But if the study is conducted at the local or village level, then, being primary data based, a water scarcity index method will be very effective to obtain the local level spatial variations in water scarcity. In the WSI method, the variations are more evidently detected than the water balance method. As we know, a microregion has also local-level variations, thus, it is difficult to suggest any water management strategies for a wide area that has been identified as water deficit based on the water balance method. On the other hand, WSI is mostly based on face-to-face interviews and data collection, and it is quite easy to suggest management strategies that could be taken up for water management at the microlevel.

14.8 Conclusions

The study has prepared the ground for a systematic evaluation of water scarcity with the help of Thornthwaite's water balance and Sullivan's water scarcity index method. The results by both methods cast useful light on the problem of water scarcity measurement. Both methods present their own merits and demerits related to data availability, processing and analysis, and provided results. It can be concluded that both methods provide good insight into the patterns of water scarcity in a region at different regional levels according to the nature of the data used.

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