CHAPTER 7

Water accounting for Luni river basin, Western Rajasthan

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7.1 Introduction

Rajasthan is one of the most water-scarce regions in India, with very limited renewable freshwater resources and high aridity. Renewable water availability is least in the western parts of the state, which receives extremely low rainfall and experiences hyperarid climate. Part of the region is Thar desert. Yet, this part of the state has significant agricultural activities, supported by large-scale import of water through IGNP (Indira Gandhi Nehar project) canals irrigating large areas in six districts in the desert, viz., Hanumangarh, Bikaner, Churu, Ganganagar, Jaisalmer, and Barmer. The demand for water for agriculture has been growing with expansion of irrigated crop production, putting pressure on the limited freshwater resources. As surface water resources are very scarce in the river basins of this region and are already overappropriated, groundwater is intensively used in for irrigated crop production and livestock farming. Aquifer mining is a major environmental threat in western Rajasthan.

A project implemented by the government of Rajasthan with the support of the European Union during 2006–13 sought integrated water management solutions for this region, to address the growing demand-supply gap in water resources and protect the integrity of the hydrological system. The project area encompassed 10 districts of the region. Luni river basin is one of the river basins of the region, which covers seven districts viz., Ajmer, Barmer, Jalore, Jodhpur, Nagaur, Pali, and Rajsamand, some partly and some fully. A study was undertaken in Luni river basin to identify the range of IWRM solutions for the region on the supply and demand side and to evaluate the extent to which each one of these solutions would help address the water management challenges.

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Basin-level water accounting was an important component of the study aimed at understanding the nature of water management challenges and opportunities for the basin. The chapter presents the findings of the water accounting study. It assesses the amount of renewable water resources generated in the basin annually, and then quantifies how much of this water gets used up consumptively for beneficial and nonbeneficial uses in various competitive uses and estimates how much of it goes uncaptured.

7.2 Luni river basin: A bird's eye view

Luni is one of the largest river basins in Rajasthan, which falls fully within the geographical boundaries of the state. The drainage map of the basin is given in Plate 7.1. The basin has a total geographical area of 69,302 km^2.[a] The basin covers the districts of Ajmer, Jodhpur, Nagaur, Barmer, Jalore, and Sirohi in part and Pali in full. The river originates from the western slopes of the Aravalli ranges at an elevation of 550 m above MSL, and after traversing a distance of 495 km in the south westerly direction, it disappears into the marshy land of Rann of Kachchh (Bhuiyan and Kogan, 2009). The rainfall in the basin ranges from as high as 1048 mm in the eastern slopes to a lowest of 221.50 mm in the South western side. The rainfall is highly erratic, and the mean annual rainy days varies from a highest of 38 days in the high rainfall areas to a lowest of 12 days in the low rainfall areas (Tahal Consultants, 2014).

The mean value of maximum daily temperature in the basin ranges from 26.8° to 35° and the highest value of maximum daily temperature ranges from 37.2° to 46.7°. The mean value of minimum daily temperature in the basin ranges from 12.81° to 20.9° centigrade. The lowest value of minimum daily temperature ranges from −2.05° centigrade to 6° centigrade. The annual mean value of daily wind speed ranges from 1.9 to 7.16 km/h. The annual mean of daily relative humidity is 49.2%, with the values ranging from 43.5% to 60.4%. With very low rainfall, high temperature, and low relative humidity, most parts of the basin have arid to hyperarid climatic conditions. The watershed elevation ranges from 1619 to 0 m above mean sea level (Tahal Consultants, 2014).

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[a] Past studies and old official records of the government of Rajasthan report a basin area of 37,000 km^2. The report study by Tahal consultants, however, has considered a modified area of 69,302 km^2 based on terrestrial modeling. In our study, we have considered the modified basin area of 69,302 km^2, which includes large areas in the northern side.

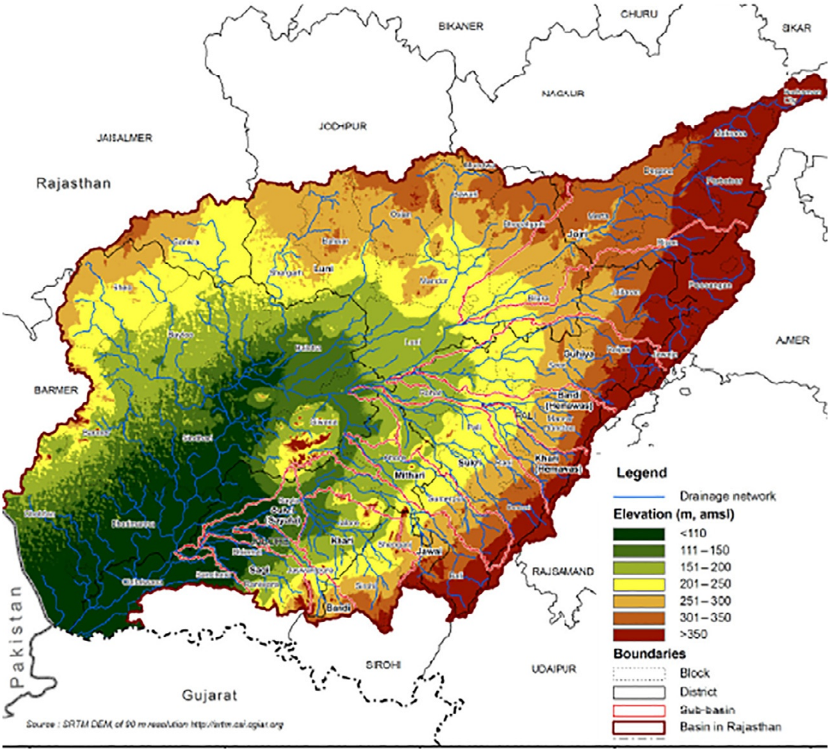

Plate 7.1 Drainage Map of Luni basin, Western Rajasthan (Area: 69,000 km^2). *Source: Study on Planning of Water Resources of Rajasthan, Draft Final report submitted to SWRPD, GoR, Tahal Consultants, December 2013.*

The basin has heterogeneous geohydrology, with recent alluvium to older alluvium, tertiary, Jurassic and Vindhyan sandstone to Phyllites and Schist. The premonsoon depth to water table in the basin varies drastically. The average premonsoon depth to water table is in the range of 20–40 m below ground level in large parts, while many parts have water table in the range of 10–20 m. In certain pockets of Jalore, Nagaur, Barmer, and Jodhpur, the water table depth is in the range of 60–80 m and 80–100 m (Tahal Consultants, 2014).

The soil in the basin is predominantly loamy sand occupying 48% of the geographical area of the basin, and the other soil types are sandy loam, silt loam, sandy clay loam, sand, loam, and clay loam. The annual potential evaporation in the basin ranges from a lowest of 1500 mm near Jawai dam to a maximum of 2600 mm in the northern and north western parts. Luni river basin as 13 sub-basins, the largest one being Luni sub-basin and the smallest is Pali sub-basin. The basin has 2 major and 11 medium reservoir schemes built for irrigation and drinking water supplies (Tahal Consultants, 2014).

7.3 The basin hydrology and groundwater resources

7.3.1 Rainfall in the basin

Topography is a very important factor influencing the occurrence of monsoon rains in Luni river basin. The Aravalli mountain range is higher than the surrounding land and so the moisture-enriched air goes up the slope, showering mostly in the eastern part and the land west of the Aravalli Range receives less amount of rainfall. More than 90% of the annual rainfall occurs during the monsoon season (June–September) alone and, in certain years, monsoon-rainfall accounts for the total annual rainfall (Das, 1996).

Analysis of point rainfall data for 13 locations in the basin for the period 1957–2012 was carried out and the outputs are presented in Table 7.1 for mean and coefficient of variation. The lowest mean annual rainfall was in Barmer (267 mm) and highest in Desuri (638.5 mm) in the South East of Pali. The coefficient of variation in rainfall, which reflects the interannual variability, ranges from a lowest of 39.1% in Ajmer to a highest of 60.4% in Barmer.

The arrival and/or retreat of the monsoon also get delayed in some years, whereas in other years one or both of the events occur early. As a result,

Table 7.1 Min, max, mean, SD, and CV of annual rainfall in Luni river basin (from 1957 to 2012).

Rain gauge station	Location in Luni river basin	Mean (mm)	CV
Ajmer	Northeast	534.9	39.1
Nagaur	Northeast	381.5	52.8
Pali	East	409.1	53.3
Jaitaran	Northeast of Pali	413.1	44.1
Desuri	Southeast of Pali	638.5	45.0
Bali	South of Pali	566.7	49.5
Sojat	Northeast of Pali	405.7	45.3
Raipur	Northeast of Pali	483.4	44.1
Marwar Jn.	East of Pali	494.6	44.7
Jodhpur	North	362.1	46.9
Sirohi	South	616.9	51.0
Jalore	Southwest	407.6	52.3
Barmer	West	267.0	60.4

Source: Authors' own analysis based on data from IMD, 1957–2012.

there is high interannual variability in monsoon in terms of amount and intensity of precipitation, distribution and pattern of precipitation, wind speed, and onset and withdrawal of the monsoon (Singh, 1994). Similarly, the number of rainy days varies from year to year and place to place in the region. On average, there are 21 rainy days in the region; in most years, the bulk of the rainfall occurs in the month of July but in certain years it shifts even to September.

The monsoon rainfall in the Luni Basin[b] follows some patterns with variations in spatial distribution. During the years of low rainfall and drought, the amount of rainfall is found to decrease gradually from east to west or from northeast to southwest (Fig. 7.1A and B). During the years in which the entire country experienced droughts (1985, 1986, 1987, 1999, 2000, and 2002), Luni basin received very low rainfall, ranging from 0.0 to 200 mm). In 1987 and 2002, the entire basin was in the grip of extreme drought (Bhuiyan and Kogan, 2009).

7.3.2 Hydrology and geohydrology

Due to low rainfall and high aridity, the basin produces very low runoff. The Luni river is an ephemeral stream and flows last for 2–3 months in a year, even in a good rainfall year. Due to large-scale water resources development in the relatively better catchments available in the south eastern parts, through small, medium, and large reservoirs, in most years, the basin does

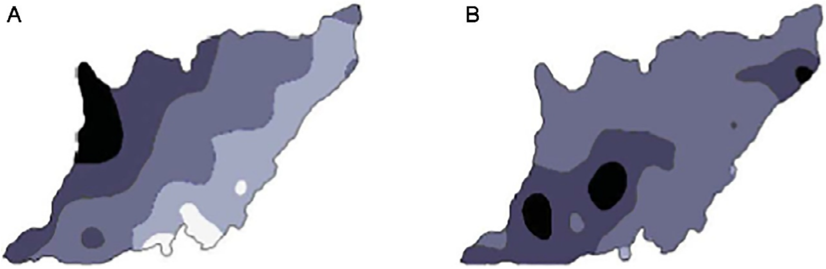

Fig. 7.1 Spatial variation in monsoonal (A) and nonmonsoon (B) rainfall in Luni river basin. *Source: Bhuiyan, C., Kogan, F.N., 2009. Monsoon variation and vegetative drought patterns in the Luni basin in the rain-shadow zone,* Int. J. Remote Sens. *31 (12), 3223–3242.*

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[b] The analysis carried out by Bhuiyan and Kogan (2009) of droughts in the basin considered the drainage area, as per the old official records of Rajasthan government, i.e., 37,000 km^2.

not have outflows. The gross storage capacity of all the 13 (11 medium and 2 major) reservoirs built in the basin is estimated to be 560.37 MCM, with a total live storage capacity of 539.17 MCM. The flow of the basin (virgin flow) with 75% dependability estimated for the basin (Draft Final Report of Tahal Consultants, Vol. 3.2), is 196 MCM per annum.

But, the observed flows at Gandhav gauging station for the period from 1970–71 to 2009–10 are provided in a semilogarithmic graph in Fig. 7.2. The highest recorded flow was during 1999–91, with a total annual flow of 2200 MCM. In 14 out of 39 years for which data are available, the stream flow was zero. One important hydrological feature of Luni river basin is that the stream channels are very shallow and infiltration of the soils in the stream beds is very high. Due to this reason, the flow rates (discharge) for the streams reduce toward downstream in the river course.

Plate 7.2 shows the extent of different types of soils in the basin (source: based on Tahal Consultants report, Vol. 3.2, 2c). Loamy sand, sand and sandy loam soils account for 70% of the basin area. These soils have very high infiltration rates. Such a soil cover ensures moderately good recharge to groundwater in the foothills of Aravalli ranges, which receive high rainfall of more than 1000 mm. The average annual renewable groundwater resource in the basin is estimated to be 3.65 cm. This is quite considerable when compared to the fact that the basin is arid to hyperarid.

Groundwater abstraction in the basin has seen significant increase over the past 15 years since 1995. The estimated groundwater draft in the basin in 1995 was 2460 MCM, which went up to 2824.11 MCM in 2007 and then reduced marginally to 2717.5 MCM in 2009 (source: report of Tahal Consultants, 2013, Vol. 3.2, 2c). This is against a renewable groundwater

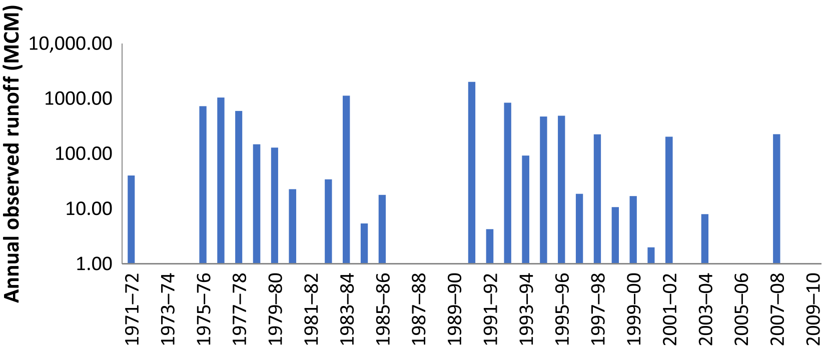

Fig. 7.2 Observed streamflows at Gandhav, Luni river basin (1970–71 to 2009–10).

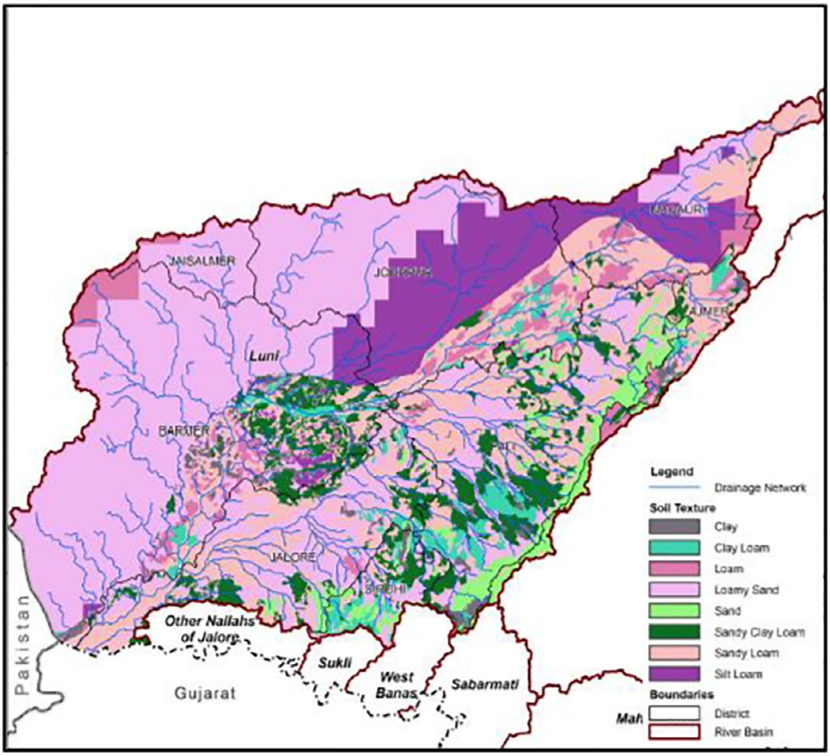

Plate 7.2 Soil cover in Luni river basin. *Source: Study on Planning of Water Resources of Rajasthan, Draft Final report submitted to SWRPD, GoR, Tahal Consultants, December, 2013.*

resource of 2203 MCM per annum. The excessively high draft in 2007 could be because the 5 consecutive years preceding 2007, i.e., 2002–03 to 2006–07 were bad years, with no surface runoff, increasing the pressure on groundwater to meet growing water demands in the basin. The basin is able to sustain such a high level of abstraction by virtue of the groundwater stock available, which is now getting mined very fast.

From the data on stream flows, and groundwater availability, it can be inferred that groundwater is the major source of water in the basin.

But, several of the groundwater bearing formations in the basin also suffer from water quality problems, such as high levels of salinity, nitrate, and fluoride. Large parts of the aquifers in the basin have EC levels ranging from 2250 to 5000 micro mhos/cm. Groundwater in only around 28% of the basin area have EC levels below, 2250 micro mhos/cm, and 72% of the area have EC levels >2250 micro mhos/cm. Only around 22% of the basin area has groundwater with EC levels <45 ppm. Further, only 30% of the groundwater underlying the basin has fluoride levels below 1.5 ppm. This essentially means that only very small areas in the basin have groundwater, which is potable.

As regards suitability of groundwater for irrigation, around 28% of the groundwater underlying the basin area has salinity below the permissible levels for irrigation, i.e., <2250 micro mhos (i.e., <1500 ppm). In around 46% of the area, groundwater has salinity in the range of 2250–5000 micro mhos (i.e., a TDS in the range of 1500–3350 ppm). Draft final report, Vol. 3.2, Tahal Consultants: 103–112). This also means that the return flows from irrigation cannot be recovered in many areas for reuse.

7.4 Socioeconomic drivers of water use in the basin

Luni river basin has a total population of 74.86 lac people, with a population density of 108 persons per km^2 (source: author's own estimates based on data on rural and urban populations in the blocks/districts falling in the basin and the proportion of the geographical area of these administrative units falling inside the basin). Urban population constitutes 36.7% of the total basin population. The economy of the districts falling in the basin is largely agrarian, with crops and livestock farming. Livestock farming is one of the most important economic activities of the region. The total livestock population of the basin is 67.66 lac animal units, nearly 68.6% of which are small ruminants (sheep and goat) (Table 7.3). Some of the districts in the basin also have industries, with dyeing, chemicals, and cement manufacturing.

Crop production in the region is mostly rain-fed, with large area under crop production during the monsoon season. However, with access to wells, irrigated crops are also grown in the region. The total irrigated area in the basin including those which are irrigated during the rainy season is only 24.7% of the total cropped area (Table 7.2). But, in lieu of the fact that rainfall variability is very high in the region, in years of monsoon failure, the crops that are grown in the monsoon season, also have to be provided supplementary irrigation. This situation also upsets the region's water balance, as the recharge and stream flows during such years would also be drastically low. The water accounts for the basin would therefore depend heavily on which hydrological year is considered for the analysis.

As regards industrial production, Pali and Jodhpur are the two most industrialized of all districts located in the basin. The other districts are Jalore, Barmer, and Nagaur. Jodhpur has a total of 24,374 industrial units, of which

Table 7.2 Groundwater resources in Luni river basin.

Name of the sub-basin	Renewable groundwater resources (MCM per annum)	Groundwater draft (MCM per annum)	Stage of groundwater development (%)	Total groundwater stock (MCM)
Bandi	39.46	52.72	133.6	137.2
Bandi (Hemawas)	34.51	51.74	149.9	16.27
Guhiya	84.18	120.06	142.6	81.97
Jawai	129.17	157.73	122.1	272.1
Jojri	116.44	137.61	118.2	522.51
Khari	142.73	140.43	98.4	273.24
Khari (Hemawas)	36.64	38.98	106.4	2.49
Luni	571.7	633.26	110.8	3464.76
Luni WRIS	797.82	726.54	91.1	5084.04
Mithari	64.62	58.98	91.3	80.7
Sagi	80.83	148.74	184.0	342.13
Sukri	55.5	60.77	109.5	29.26
Sukri (Sayala)	50.26	83.85	166.8	399.2
Total for Luni river basin	2203.86	2411.41	109.4	10,705.87

Source: Study on Planning of Water Resources of Rajasthan, Draft Final report submitted to SWRPD, GoR, Tahal Consultants, Vol. 3.2, 2c, December 2013.

Table 7.3 Socioeconomic features of Luni river basin: A quick glance.

Particulars	Rural	Urban	Total
Human population in the basin (2011)	4,739,624	2,747,058	7,486,682
Population density (persons/km^2)			108
Livestock population in the basin (2007)			67,66,726
Total cattle (indigenous, cross bred, bullocks)			11,01,670
Buffaloes			9,52,571
Sheep/goat			46,43,850
Donkeys			12,783
Camels			37,370
Pigs			14,965
Horses/pony			3517
Total rain-fed area (2011–12): lac ha			18.52
Total irrigated area (2011–12): lac ha			6.09

Source: Authors' own analysis based on Census 2011 and livestock census 2007.

15 are large industrial units. There are also 15 medium-scale industries, all located close to Jodhpur. Pali has a total of 13,834 registered industries, of which only 5 are large industries. They consist of two cement industries, one fabric yarn industry, one agro implements industry, and one industrial unit for manufacturing bitumen. Jalore has a total of 4510 industrial units, of which only 2 falls under large and medium category. The industries in the district fall under the following categories: mineral-based industries; agro-based industries; engineering and metal industries; forest-based industries; leather industries; and handloom industries. Barmer has three large and medium industries. In total, it has 2925 industrial units, which include small-scale industrial units. Most of them are textile industries. The other types of industries are agro-based industries, paper industries, and rubber/plastic industries (Table 7.4).

Table 7.4 Details of large, medium, and small industries in five districts of Rajasthan, falling in Luni river basin.

Name of district	Total no. of industrial units	Total no. of large and medium industries	Micro and small enterprises (types)
Jodhpur	24,374	30 (15 + 15)	Engg; agro industries; chemical; Livestock based; building material
Pali	13,834	5	Agro industries; beverages and tobacco; paper; plastics/rubber; metals and engg.; leather industries; textile; mineral and metal based; wood industries
Jalore	4510	5	Mineral-based industries; agro industries; engg. and metal; forest based; leather industries; handloom
Barmer	2925	3	Textile; agro industries; paper; rubber/plastic
Nagaur	8165	3	Agro industries; forest-based industries; mineral-based industries; textile; chemical; engineering; animal product

Source: Brief industrial profile of Jodhpur, Pali, Barmer, Jalore and Nagaur, Micro, Small and Medium Enterprises, Ministry of MSME, Government of India.

7.5 Methodology and analytical procedure

In water accounting for blue water, we can look at: (a) the renewable water resources (annual surface water flows and groundwater replenishment) as the "total inflow" into the basin during a hydrological year; (b) the amount of water that is being used up in various consumptive uses during the same year (various outflow); and (c) the "balance," which is in the form of unutilized water at the drainage outlet of the sub-basin and the changes in groundwater and surface storage occurring during the hydrological year.

The amount of water that is being used up in various consumptive uses during the year consists of evaporation from open water bodies, swamps and ET from crop land, nonrecoverable deep percolation, and the "net" of water used by cities and rural areas for domestic and industrial uses minus the "return flows" to the natural system in the form of wastewater. Here, the outflows from cropland would NOT consider the water directly used by the cropland from rainfall (effective precipitation or the green water use by the crop) and would only consider the consumptive use from irrigation of the crops grown during the three seasons.

The runoff as part of the total inflow (virgin flows) can be estimated by adding up the "observed flows" and the "effective diversion" by the major reservoirs, other storages and diversion points in the basin. The effective diversion would be the total water diverted from the rivers and tributaries for various purposes minus the estimated return flows to the stream. The return flows can be from irrigation commands and urban centers. The "total water diverted from rivers and tributaries" can be estimated using data on reservoir releases, river lifting, reservoir evaporation, and the net storage change during the hydrological year. There are 13 major and medium reservoirs in Luni river basin.

The water accounts for the basin can be estimated as:

$$\begin{aligned}\mathrm{INFLOW_{TOTAL}} = {} & \mathrm{CU_{IRRIGATION}} + \mathrm{CU_{RURAL-DOMESTIC}} \\ & + \mathrm{CU_{URBAN}} + \mathrm{CU_{LIVESTOCK}} \\ & + \mathrm{CU_{INDUSTRY}} + \mathrm{EVAP_{RESERVOIR}} \\ & + \mathrm{OUTFLOW_{STREAM}} + \mathrm{GWS_{CHANGE}} \\ & + \mathrm{SC_{RESERVOIR}} \end{aligned} \tag{7.1}$$

$$\mathrm{INFLOW_{TOTAL}} = \mathrm{VFLOW_{STREAM}} + \mathrm{GWR_{RENEW}} + \mathrm{WATER_{IMPORT}} \tag{7.2}$$

But, virgin flow ($\mathrm{VFLOW_{STREAM}}$) can be estimated as:

$$\mathrm{VFLOW_{STREAM}} = \mathrm{OUTFLOW_{STREAM}} + \mathrm{EWD} \tag{7.3}$$

If we assume that the urban wastewater is reused in agriculture and the return flows from irrigated fields only contribute to groundwater recharge in the command area, return flows from irrigation schemes and urban areas into the streams can be treated as zero. This is normally the case in arid and semiarid regions.

In such situations, the sum of total water released from reservoirs, water lifted from diversion points along the stream/river, evaporation from these water bodies and their annual (+ive) storage change can be treated as EWD. But, in this case, the estimation of renewable recharge should not consider the recharge from command area, as this would lead to double counting.

The consumptive use of water in urban area ($\mathrm{CU_{URBAN}}$) can be treated as 80% of the total water supplied to meet the municipal water needs, whereas all the water supplied to meet the rural domestic water needs can be considered as the $\mathrm{CU_{RURAL-DOMESTIC}}$.

Irrigation includes four components, viz., beneficial evapotranspiration by crops (ET); nonbeneficial evaporation from the soil (both from the soil not covered by canopy and the barren soil in the field after crop harvest); nonrecoverable deep percolation (also the water flows into saline formations); and return flows to streams or groundwater system, which can be recovered for reuse. How much of the water applied in the field would be available for these components would be determined by the technical efficiency with which water is applied (Allen et al., 1998; Kumar and van Dam, 2013). Therefore, consumptive water use from irrigation includes three major components, ET, nonbeneficial evaporation, and nonrecoverable deep percolation.

$$\begin{aligned}&\text{Irrigation water consumed in crop production } (\mathrm{CU_{IRRIGATION}})\\&\quad = \mathrm{A} \times [\mathit{\Delta}_{\mathrm{IRRIGATION}} - \{(\mathit{\Delta}_{\mathrm{APPLIED}} - \mathrm{ET}) \times F\}]\end{aligned} \tag{7.4}$$

Here, $\mathit{\Delta}_{\mathrm{APPLIED}}$ is the sum of irrigation dosage ($\mathit{\Delta}_{\mathrm{IRRIGATION}}$) and total soil moisture available from rainfall (also known as effective rainfall). For purely irrigated crops of winter and summer, the effective rainfall (P_{EFF}) can be assumed to be zero. A is the cropped area. The factor "F" is introduced to take account for the fraction of the total water applied in excess of crop water requirement, which is available for reuse.

In regions with hyperarid, arid, and semiarid climatic conditions, nonbeneficial soil evaporation, as explained earlier, can be significant.

Again, if the area has deep water table conditions (depth to water table exceeding 100 ft), the deep percolation from the irrigated field might not be recoverable, meaning no return flows to groundwater.

Hence, in the case of deep groundwater table conditions, in semiarid and arid climates, the value of F can be assumed as zero, and in case of very shallow groundwater, the value can be assumed as 1 (one). In the latter case, real water saving from the use of microirrigation systems will be negligible. Given the fact that a large part of the basin has arid climatic conditions, and groundwater table is deep, the value of F can be considered as zero, which means the excess water applied in the field would not contribute to groundwater recharge. In other words, the irrigation in excess of the irrigation requirements would be lost in soil evaporation and nonrecoverable deep percolation. For using this procedure, the value of depth of irrigation should be known from primary survey.

Alternatively, the irrigation application $\Delta_{\mathrm{IRRIGATION}}$ can be estimated as the difference between ET and effective rainfall of the crop (using FAO CROPWAT model), plus the extra water required to take care of field application efficiency.

$$\Delta_{\mathrm{IRRIGATION}} = (\mathrm{ET} - P_{\mathrm{EFF}})/\mathrm{IE}_{\mathrm{APPLICATION}} \tag{7.5}$$

7.6 Presentation of results

7.6.1 Estimation of virgin flows

The time series data on outflows at the last gauging point in the basin, which has a catchment area of 62,228 km^2, are available from the integrated hydrological data book of Central Water Commission (2012). First, the virgin flows were estimated for the basin by adding up the outflows from the basin (at Gandhav gauging station), and the total amount of water stored in the eight major and medium reservoirs spread over the basin, during the monsoon period, and not on the basis of the volumetric water releases, the storage changes over the year. This is because the data on the water release from these reservoirs were not available. Hence, in this case, the reservoir evaporation rates are not required to be considered for inflow estimates on the left-hand side of the water accounting formula. But at the same time, such an approach warrants that the estimates of outflow separately consider the evaporation from the reservoir. Also, as per this approach, the change in storage should consider the water remaining in the reservoirs.

The estimated virgin flows vary from 26.33 MCM (during 1972–73, 1987–88, and 2002–03) to 2144.68 MCM (1990–91). The virgin flow with a dependability of 75% is 133.48 MCM and that with 50% dependability is 179.64 MCM. Fig. 7.3 shows the dependability curve for estimated virgin flows of the basin for the period.

7.6.2 Estimating rainfall-runoff relationships

Data on annual rainfall were available for 13 gauging stations in Luni river basin for the period from 1954 to 2012. The weighted average of the rainfall was estimated for these stations for all the years of observation (Fig. 7.4). The mean annual rainfall was estimated to be 414.5 mm. In volumetric terms, this is 25,762 MCM of water. Since the rainfall varies across space in the Luni basin, ideally Theisen polygon method has to be used. But, this is a time-consuming process. Due to time constraints, we have made some approximations. For gauging stations, which are located close to the basin boundary (three of them), a weightage of 0.25 was given whereas for all the remaining 12 stations, which were interior, a weightage of 1.0 was given.

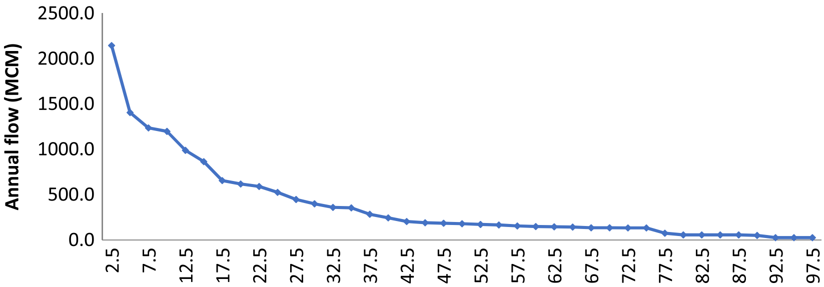

Fig. 7.3 Probability of occurence of flows in Luni river basin.

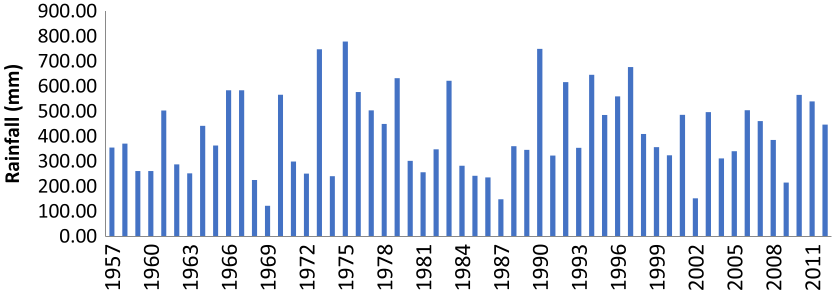

Fig. 7.4 (Weighted) average annual rainfall: Luni river basin (1957–2012).

The virgin flows were estimated for the period from 1971–72 to 2009–10 (as discussed in Section 7.6.1). The mean annual virgin flow is estimated to be 383.7 MCM. This works out to be 13.5 mm, or 3.26% of the total rainfall in the basin. In order to estimate the rainfall-runoff relationship, which can in turn be used to estimate the runoff or future years and also for smaller catchments in the basin, it is essential to estimate the average annual rainfall for the entire basin for the corresponding period.

The rainfall-runoff relationship was estimated to be a power function, indicating higher runoff coefficient for higher rainfall values, or disproportionately higher runoff values for higher values of average annual rainfall. The estimated R square value was 0.54, meaning a reasonably good fit. The rainfall-runoff relationship for the basin is graphically presented in Fig. 7.5. It shows that "X" mm of rainfall generates a runoff equal to $0.0016 \times X^{1.977}$ MCM of runoff.

These runoff rates are extremely low. There are many reasons for this. *First*: Nearly 48.5% of the basin is covered by loamy sand and sand. The topography is flat, with <1% catchment slope.

Second: the climate is hyperarid to arid and the daily temperature is very high in the basin even during the rainy season and humidity low, which keeps the soil moisture depletion rate high, due to which the infiltration rates remains high even after the first few showers. The infiltrating water eventually gets evaporated due to high temperature, rather than percolating down into the deep strata, as 49,485 km^2 of the drainage area (i.e., 71.4%) is barren.

Third: the stream channels (fluvial deposits) are important sources of recharge of shallow aquifers (Sinha and Navada, 2008), with the result that there is a huge transmission loss reducing the runoff volume (Sharma and Murthy, 1998).

Now, the total average annual rainfall of the entire Luni river basin for the year 2011–12 was estimated to be 539.6 mm on the basis of rainfall data

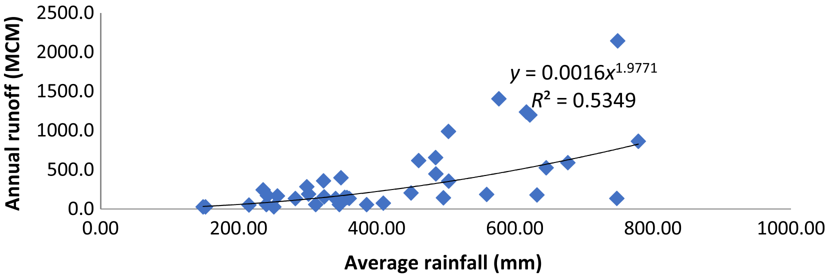

Fig. 7.5 Rainfall–runoff relationship for Luni river basin (1971–2010).

for 13 gauging stations spread over the basin. The corresponding value for runoff was estimated to be 403 MCM using the above rainfall-runoff model. This is the total amount of renewable surface water resources in Luni basin. While a lot of this water would get captured in the reservoirs built in the upper catchment, some might go uncaptured as outflows. However, neither the data on storage nor the data on outflows are available for crossverification.

What is unique about the basin's surface flows is that the entire surface hydrology must have been affected by the large number of water impounding structures. In the absence of these structures, the outflows would not have been higher than what is observed today. This is because of the high transmission loss, which can occur in the stream channels. But, this also means that under such situations (of no surface water-impounding structures), the groundwater recharge happening in the basin would have been much higher than what the estimates show.

7.6.3 Estimating replenishable groundwater

The estimates of annual replenishable groundwater in Luni basin are directly obtained from the report of Tahal Consultants, Vol. 3.2. The assessment was done sub-basin wise. The figures are presented in Table 7.5. The last column of the table also provides estimates of static groundwater resources in the basin. The estimates of groundwater replenishment and draft are average figures, and the actual groundwater replenishment of the basin can change drastically from year to year depending on the rainfall. The total replenishable groundwater in the basin is 2203 MCM per annum. This works out to be around 23% of the static groundwater resources available in the basin.

7.6.4 Imported water

Luni river basin receives water from the adjoining regions. The amounts of imported water with different degrees of dependability are given in Table 7.6. The major sources of water import are Indira Gandhi Nehar Project (IGNP), which supplies water to four districts falling in Luni basin, viz., Jaisalmer, Ganganagar, Churu and Barmer, and Sardar Sarovar Project of Gujarat, which supplies water to Jhalore.

7.6.5 Evaporation from reservoirs

In arid areas, significant amount of water can be lost in evaporation from reservoirs due to excessive evaporation. There are two major and seven medium reservoirs located in the basin. The evaporation from these

Table 7.5 Dynamic and static groundwater resources in Luni river basin.

Name of district	Renewable groundwater resources (MCM per annum)	Existing groundwater draft (MCM per annum)	Stage of groundwater development (%)	Static ground water resources in different sub-basins (MCM)
Bandi	39.46	52.72	133.6	137.2
Bandi (Hemawas)	34.51	51.74	149.9	16.27
Guhiya	84.18	120.06	142.6	81.97
Jawai	129.17	157.73	122.1	272.1
Jojri	116.44	37.61	118.2	522.51
Khari	142.73	140.43	98.4	273.24
Khari (Hemawas)	36.64	38.98	106.4	2.49
Luni	571.7	633.26	110.8	3464.76
Luni WRIS	797.82	726.54	91.1	5084.04
Mithari	64.62	58.98	91.3	80.7
Sagi	80.83	148.74	184.0	342.13
Sukri	55.5	60.77	109.5	29.26
Sukri (Sayala)	50.26	83.85	166.8	399.2
Total for Luni River Basin	2203.86	2411.41	109.4	10,705.87

Source: Study on Planning of Water Resources of Rajasthan, Draft Final report submitted to SWRPD, GoR, Tahal Consultants, Vol. 3.2, 2c, December 2013.

Table 7.6 Imported water in Luni river basin.

Dependability (%)	Volume of water imported (MCM)
25	569.36
50	404.31
75	331.33
90	240.61
Mean	476.61

Source: Study on Planning of Water Resources of Rajasthan, Draft Final report submitted to SWRPD, GoR, Tahal Consultants, Vol. 3.2, 2c, December 2013.

reservoirs depends on the number of days for which water remains in the reservoir, and the potential evaporation in the locality concerned during those days and the reservoir water spread area.

It can be estimated as:

$$\mathrm{EVAP}_{\mathrm{RESERVOIR}} = \sum_{i=1}^{m} \mathrm{RA}_i \times \mathrm{CU} - \mathrm{EVAP}_i \tag{7.6}$$

Where CUE_i is the cumulative evaporation rate for reservoir, i for the time period for which water remains in it; RA_i is the average water spread area of the reservoir, "i." It is to be kept in mind that the water spread area of the reservoir would keep declining as time progresses and more water is drawn from it, and hence some approximation would be required if this equation is used.

The mean potential evaporation (PE) values for Pali varies gradually from 1700 mm in the southern parts of the district to a highest of 2300 mm in the northern parts (source: Water Resource Atlas of Rajasthan), with a mean value of 2000 mm. The mean potential evaporation for Jaisalmer is around 2600 mm. The reference evapotranspiration (Penman) (ET_0) values for different months for two locations in the basin are given in Fig. 7.6. It shows that ET_0 can be as high as 10 mm in the hottest month of May. The total annual ET_0 for Pali is 2066 mm, while the corresponding value for Jaisalmer is 1967 mm. Hence, the estimated values of the ratio of PE/ET_0 for the two locations are 0.96 and 1.32, respectively.

Using these fractions, the monthly PE values for the two locations can be estimated. The estimated monthly PE values for the two locations are given in Table 7.7. It is evident from the table that evaporation rate would be highest during the month of June in Jaisalmer and May in Pali.

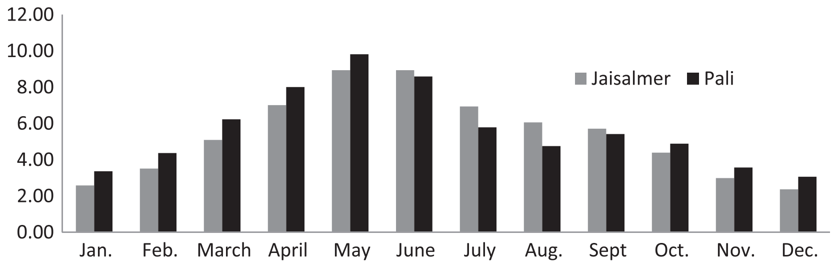

Fig. 7.6 Reference evapotranspiration for two locations in Luni river basin.

Table 7.7 Estimated monthly potential evaporation values for two locations in Luni river basin.

Location/ month	Month											
	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Jaisalmer	3.41	4.64	6.73	9.26	11.7	11.80	9.17	8.00	7.54	5.80	3.95	3.13
Pali	3.25	4.22	6.01	7.73	9.48	8.3	5.52	4.59	5.23	4.72	3.45	2.95

Source: Rajasthan Water Resources Atlas and IMD data on ET_0.

Based on the inflow data available for the period from 1995 to 2010, the study by Tahal consultants had estimated reservoir evaporation from 13 reservoir projects in Luni river basin. The estimates are given in Table 7.8.

The total evaporation, as estimated by Tahal Consultants from major, medium, and minor irrigation reservoirs, is 35.61 MCM. This is against a total reservoir area of 5930 ha, i.e., 59.3 km^2. This constitutes 0.086% of the total basin area. The average evaporation works out to be 0.60 m. The potential evaporation rate during August to January, the time period during which water is generally available in these reservoirs, for Pali and neighboring districts situated on the eastern part of the basin, where all these reservoirs are located, is around 600 mm. Hence, these values seem to be reliable.

7.6.6 Consumptive water use through irrigation

Since depth of irrigation water applied to the crops is not available for any of the crops grown in the region, we have used the FAO CROPWAT to estimate irrigation water requirement and assumed a factor of 1.25 to arrive at irrigation water application, which is to provide allowance for consumptive uses, which are nonbeneficial—nonbeneficial evaporation and nonrecoverable deep percolation (Allen et al., 1998). This should not be confused with field application efficiency in irrigation, which can be much

Table 7.8 Estimates of evaporation from 13 major/medium reservoirs in Luni river basin.

Name of the major/medium/ minor project	Reservoir water spread area (ha)	Total volume of evaporation (MCM)
Angore dam project	130	1.41
Bandi Sendra project	200	2.36
Bankli bund	500.0	3.34
Bisalpura bund project	0.0	0.12
Giroliya tank	360.0	0.033
Hemawas bund project	30.0	7.14
Jaswant Sagar	410.0	0.62
Jawai bund	1250.0	11.46
Kharda bund	950.0	1.67
Ora bund	10.0	1.68
Phool Sagar Jaliya	10.0	0.037
Raipur Luni project	80.0	0.167
Sardar Samand project	2000.0	5.58
Total	5930.0	35.61

Source: Study on Planning of Water Resources of Rajasthan, Draft Final report submitted to SWRPD, GoR, Tahal Consultants, Vol. 3.2, 2c, December 2013.

lower for surface irrigation in the basin, but can be accepted as a working methodology, as we are ultimately concerned with estimating consumptive water use, and we treat the irrigation water application ($\Delta_{\mathrm{IRRIGATION}}$) as the consumptive use (meaning zero return flows from the irrigated field). For this reason, while doing the estimation, the return flow fraction (F) is assumed as zero, irrespective of the method of irrigation. The total consumptive water use in irrigation is estimated by multiplying the depth of irrigation with the area under the crop concerned, for the year 2011–12.

The areas under irrigated kharif and winter crops in the basin are provided in Tables 7.9 and 7.10, respectively.

The estimates of crop wise consumptive water use for irrigation are presented in Table 7.11 for kharif and winter crops.

The total water consumption in agriculture is estimated to be 2404.4 MCM during the year 2011–12. Fig. 7.7 presents the graphical representation of volumetric water use by different irrigated crops in the basin. Castor is the largest consumer of irrigation water in the basin (733 MCM), followed by wheat, which consumes around 497 MCM. Castor, while sown during the kharif season, lasts for most parts of the winter season.

7.6.7 Domestic water use in Luni basin

Luni is an absolutely water-scarce basin. There is very little imported water in the basin, except in Jodhpur city, which receives water from IGNP for its municipal water supply. The rural areas depend on groundwater sources, mostly open wells. During drought years, these wells go dry and only the tube wells function. The rural communities face water shortage for domestic uses. We have therefore assumed a per-capita daily water use of 50 lpcd for domestic uses in the region. After Gleick (1996), this is also the basic minimum required for survival. For nonmetros with planned sewage, we have assumed 135 lpcd (like Jodhpur). For small towns without planned sewage (such as Barmer, Nagaur, Pali), we have assumed a per-capita water consumption of 70 lpcd. This is as per the recommendation in the 12th Plan document for small towns without a centralized sewerage system. From water accounting point of view, though a large share (80%–90%) of this water would be available as domestic effluent (wastewater return flow), it may get depleted in the local sinks (ponds, natural depressions, etc.), and hence is not accounted for separately. However, in the case of Jodhpur, a wastewater return flow of 80% is assumed. This means the actual consumptive water use would be only 20% of the total of 135 lpcd. The remaining

Table 7.9 Irrigated area during kharif season.

	Irrigated area during kharif (2011–12)							
Crops	**Ajmer**	**Barmer**	**Jalore**	**Jodhpur**	**Nagaur**	**Pali**	**Rajsamand**	**Sirohi**
Rice	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jowar	0.0	6.3	25.7	25.6	32.0	0.0	0.0	0.0
Bajra	0.4	2501.0	1302.4	5782.5	2397.1	2.0	0.0	8.5
Maize	45.0	0.2	24.0	0.9	4.5	462.0	2.3	49.7
Green gram	0.0	1.2	46.4	240.8	94.4	0.0	0.0	0.0
Moth	0.0	37.5	7.5	115.8	2.2	0.0	0.0	0.0
Chaula	0.0	0.0	3.3	1.8	1.3	0.0	0.1	0.0
Sesame	0.0	1.4	7.5	141.7	13.2	0.0	0.0	0.0
Groundnut	274.8	239.5	4088.6	9447.1	1343.5	0.0	0.0	1976.0
Soybean	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Castor	61.2	8654.1	62,853.1	6089.2	84.6	1307.0	0.0	13,850.7
Cotton	2135.8	1.2	566.2	2922.5	3928.9	6261.0	484.3	710.2
Sanhemp	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sugarcane	3.8	0.0	0.0	0.0	0.1	0.0	20.2	0.0
Cluster bean	2.5	5.6	5.8	518.2	30.5	5.0	0.0	2.0
Chillies	117.4	6.8	321.7	296.4	9.7	464.0	10.6	80.0
Overall	2647.9	11,454.7	69,252.2	25,582.5	7942.1	8501.0	517.4	16,677.1

Table 7.10 Irrigated area under winter (2011–12).

Irrigated area during winter (2011–12)								
Crops	**Ajmer**	**Barmer**	**Jalore**	**Jodhpur**	**Nagaur**	**Pali**	**Rajsamand**	**Sirohi**
Wheat	9931.3	2584.7	24,135.5	7587.0	6045.4	47,922.0	2840.7	14,849.0
Barley	3419.1	4.7	354.8	32.4	1201.4	4163.0	663.6	484.8
S. Millets	0.0	0.0	422.8	0.3	0.0	0.0	0.0	261.4
Gram	248.0	0.9	0.0	138.9	1151.4	6419.0	23.8	603.2
Green peas	0.0	0.0	0.0	0.0	129.1	0.0	0.0	0.0
Masur	3.1	0.0	1.7	0.0	0.0	0.0	0.0	0.0
Other rabi pulses	36.1	0.0	0.0	0.0	0.0	0.0	0.1	15.4
Rapeseed and mustard	4440.4	1751.2	36,511.6	9456.2	3117.2	34,880.0	214.7	6800.1
Taramira	17.0	25.2	29.8	21.3	19.6	418.0	1.8	12.5
Linseed	6.0	0.5	0.0	0.6	17.5	0.0	0.2	0.0
Coriander	20.6	0.0	0.8	26.6	2.7	171.0	2.6	0.4
Cumin	2830.7	30,875.8	92,594.3	13,467.4	5952.9	14,665.0	3.6	2182.0
Fenugreek	51.7	37.5	145.1	508.0	476.8	1640.0	34.9	7.7
Potato	0.0	0.0	59.7	0.0	0.0	0.0	0.3	128.1
Sweet potato	17.5	4.2	17.4	1.4	2.0	13.0	0.0	0.8
Onion	229.6	25.4	169.1	2091.2	958.1	348.0	2.4	19.8
Tobacco	0.0	0.0	244.6	0.0	0.0	0.0	0.0	0.0
Fennel	229.6	5.1	3286.2	727.2	2365.4	1003.0	0.0	1437.4
Garlic	2.2	0.0	5.8	553.9	16.1	15.0	21.4	6.1
Ajwain	36.3	2.3	350.7	5.0	181.7	20.0	1.9	19.0
Isabgol	4.5	13,570.2	29,405.5	4760.4	3667.2	1029.0	0.0	88.9
Overall	21,523.7	48,887.6	187,735.3	39,377.8	25,304.6	112,706.0	3812.1	26,916.5

Table 7.11 Estimated consumptive water use in irrigation in Luni river basin.

	Consumptive water use in irrigation (in 000′ cu. m.)							
Crops	**Ajmer**	**Barmer**	**Jalore**	**Jodhpur**	**Nagaur**	**Pali**	**Sirohi**	**Overall**
Winter season								
Wheat	37,330.4	12,161.8	113,566.6	35,814.3	25,631.0	203,177.3	70,094.8	497,776.1
Barley	9840.7	20.0	1521.1	138.8	4298.6	14,895.2	2074.0	32,788.3
S. Millets	0.0	0.0	1908.3	1.2	0.0	0.0	1059.6	2969.1
Gram	668.8	3.8	0.0	563.2	3886.6	21,667.3	2445.3	29,235.1
Green peas	0.0	0.0	0.0	0.0	435.9	0.0	0.0	435.9
Masur	8.5	0.0	6.8	0.0	0.0	0.0	0.0	15.2
Other rabi pulses	97.3	0.0	0.0	0.0	0.0	0.0	62.2	159.5
Rapeseed and mustard	15,616.7	8850.7	184,529.9	47,887.2	13,374.5	149,652.6	34,436.7	454,348.3
Fennel	563.7	12.6	8068.3	1785.5	5807.8	2462.6	3529.3	22,229.8
Potato	0.0	0.0	833.5	0.0	0.0	0.0	1788.5	2622.0
Cumin	4246.0	46,313.6	138,891.5	20,201.0	8929.4	21,997.5	3273.0	243,852.1
Isabgol	13.4	40,710.5	88,216.4	14,281.3	11,001.6	3087.0	266.7	157,576.9
Monsoon season								
Sorghum	0.0	23.7	97.0	84.7	71.7	0.0	0.0	277.0
Pearl millet	0.6	8457.5	4404.1	20,318.9	5798.9	4.8	29.8	39,014.7
Maize	84.3	1.1	114.4	3.9	13.8	1415.6	211.5	1844.6
Green gram	0.0	4.8	192.8	903.1	255.1	0.0	0.0	1355.8
Moth	0.0	155.8	31.0	434.3	6.1	0.0	0.0	627.2
Chaula	0.0	0.0	13.8	6.9	3.5	0.0	0.0	24.1
Groundnut	642.5	1276.1	21,782.7	45,602.5	4812.9	0.0	9538.2	83,654.9
Soybean	1.2	0.0	0.0	0.0	0.0	0.0	0.0	1.2
Castor	482.5	68,281.6	495,917.4	48,044.8	667.8	10,312.4	109,283.7	732,990.1
Sesame	0.0	2.1	11.2	212.5	19.7	0.0	0.0	245.5
Cotton	6946.6	8.3	4009.8	18,922.5	19,108.9	30,451.2	4598.7	84,045.8
Chillies	1349.8	77.7	3699.0	3408.2	112.0	5336.0	919.9	14,902.6
Cluster bean	6.375	14.28	14.79	1321.41	77.775	12.75	5.1	1452.48
Total in MCM	77,899.375	186,375.98	1,067,830.39	259,936.21	104,313.575	464,472.25	243,617	2,404,444.78

Source: Authors’ own estimates based on FAO CROPWAT and secondary data on agricultural land use.

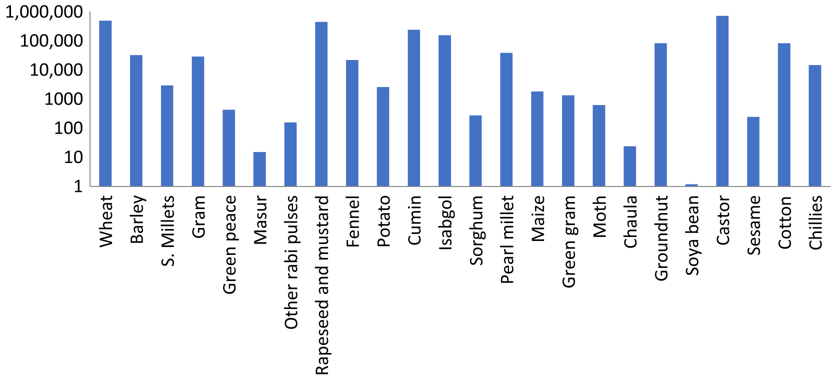

Fig. 7.7 Crop-wise consumptive water use in irrigation: 2011–12.

Table 7.12 Estimated domestic water use (rural) in Luni river basin.

Districts	Estimated population (in 000′)	Domestic water demand Daily (000′ cu. m.)	Domestic water demand Annually (MCM)
Ajmer	345	17.2	6.3
Barmer	564	28.2	10.3
Jalore	1388	69.4	25.3
Jodhpur	373	18.6	6.8
Nagaur	33	1.7	0.6
Pali	1578	78.9	28.8
Rajsamand	89	4.5	1.6
Sirohi	335	16.8	6.1
Udaipur	35	1.7	0.6
Overall	4740	237.0	86.5

Source: Authors' own analysis.

water would get accounted for in irrigated agriculture, as most of the city's wastewater would get diverted for irrigation in peripheral areas.

Rural domestic water demand in the basin was estimated considering a minimum water requirement of 50 L per person per day (lpcd), which is considered to be the basic water requirement for meeting human needs (Gleick, 1996). For estimation of rural population, total population in each district was adjusted as per the proportion of its geographical area falling in the basin. As per the estimates, the overall domestic water demand (rural) in Luni river basin is about 86.5 MCM (Table 7.12).

The norms suggested for water supply in the 12th Five Year Plan document were (1) 135 lpcd for urban areas where piped water supply and

Table 7.13 Estimated domestic water use (urban) in Luni river basin.

Districts	Estimated population (in 000′)	Domestic water demand	
		Daily (000′ cu. m.)	Annually (MCM)
Ajmer	542	65.1	23.8
Barmer	171	20.5	7.5
Jalore	102	12.2	4.5
Jodhpur	1093	131.2	47.9
Nagaur	312	37.4	13.7
Pali	460	55.2	20.1
Sirohi	67	8.1	2.9
Overall	2747	329.6	120.3

Source: Authors' own analysis.

underground sewerage systems are available and (2) 70 lpcd for urban areas provided with piped water supply but without underground sewerage system. In view of the fact that Luni is a scarce river basin, we have considered roughly the mean of the two figures (which comes out to be around 100 lpcd) as the domestic water use in urban areas. Urban population was estimated based on the number of cities and towns falling in the basin. As per the estimates, the overall domestic water demand (urban) in Luni river basin is about 120.3 MCM (Table 7.13). Twenty percent of this (i.e., 24.06 MCM) can be treated as consumptive water use, and the remaining 80% will be available for irrigation in the periurban and rural areas.

7.6.8 Livestock water use in the basin

Livestock water use in the basin was estimated by the following the indicative figures of voluntary water consumption per tropical livestock unit (TLU) for different categories of livestock (as suggested by Pallas, 1986), and the average body weight of different categories of livestock found in the region. Here, we have considered an average body weight of 400 kg for buffaloes and crossbred cows, 250 kg for indigenous cows, 25 kg for goat/sheep, and 450 for camels. The estimates of water use for different types of livestock are presented in Table 7.14.

From Table 7.14, it is evident that small ruminants, which constitute 66% of the total livestock population, account for only 18.3% of the total water use by livestock. Cattle account for nearly 33% of the total livestock water use. Buffaloes account for 46.3% of the total livestock water use in the basin.

Table 7.14 Estimated livestock water use in Luni river basin (2007).

	Livestock water demand (000′ cu. m.)									
Type	**Ajmer**	**Barmer**	**Jalore**	**Jodhpur**	**Nagaur**	**Pali**	**Rajsamand**	**Sirohi**	**Udaipur**	**Overall**
CB cow	94	2	6	119	37	110	49	8	6	432
Indi. Cow	1173	2091	3427	1345	607	4934	340	1151	183	15,251
Buffalo	1690	822	7683	913	1110	7110	464	1516	165	21,473
Sheep	204	583	956	275	155	1687	21	185	4	4071
Goat	314	944	827	394	277	1281	86	252	28	4404
Donkey	2	30	18	5	2	17	1	3	0	78
Camel	9	257	127	73	28	155	4	45	1	700
Overall	3486	4730	13,044	3124	2217	15,294	966	3161	388	46,410

Source: Authors' own analysis based on secondary data on weather parameters (IMD), FAO online catalog on water for animals, based on Pallas (1986) and livestock population as per 2007 livestock census.

Industrial Water Use in Luni River Basin

Since no estimates are available on the manufacturing output for various industrial subsectors for the districts in the basin, industrial water use in Luni basin was estimated on the basis of the consideration that on a per-capita basis, the basin would require a minimum of 20 m^3 of water per annum for manufacturing.[c] Hence, water use during 2011–12 (m^3) was estimated on the basis of population of the basin as per Census 2011 as:

$$CU_{\mathrm{INDUSTRY,LUNI}} = POP_{\mathrm{LUNI}} \times 20 = 149.73\,\mathrm{MCM}$$

7.7 The basin water accounts

The final water accounts for the blue water in Luni river basin for the year 2011–12 are presented in Table 7.15. Here, we have compared the total inflows and the total outflows. The total outflow is exclusive of reservoir evaporation. The difference between the two should be equal to the sum of reservoir storage change, evaporation from the reservoir, and the total stream channel outflow. The total of change in storage and (stream) outflow was estimated to be 309 MCM in 2011–12. The year considered for the study was a wet year and it is quite likely that the basin had some outflows in that year.

Table 7.15 Water accounts of Luni river basin (2011–12).

Water resources and use	Volumetric water use (MCM)
Total inflows	2843.60
Annual surface water resources (2011–12)	403.00
Renewable groundwater resources	2203.86
Water imported into Luni river basin	240.60
Total outflows	2741.31
Consumptive water use for irrigation	2404.00
Consumptive water use in the domestic sector (urban and rural)	110.56
Livestock water use	41.41
Industrial water use	149.73
Evaporation from major, medium, and minor reservoirs	35.61
Groundwater storage change	−207.55
Surface water outflows + water remaining in the reservoirs	309.84

Source: Authors' own estimates based on secondary data.

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[c] This is based on the estimates for industrial water demand in India for the year 2010 (Kumar, 2010), which indicates an average per-capita water demand of 20 m^3 for industrial uses.

The total blue water inflow in the basin during the year was 2843.6 MCM. Of these, the internal renewable water resource is 2606.86 MCM, from a total rainfall of 33,577 MCM for the drainage area of 62,228 km^2.[d] The remaining water is lost in soil evaporation from the large tracts of barren land (a total 48,750 km^2), ET from the purely rain-fed crops of kharif season, which covered an area of 18,520 km^2 (18.52 lac ha) and the trees and other natural vegetation in the basin.

While the figures of "change in storage" appear to be excessively high, this could be because the figures of imported water are quite tentative. It is quite likely that the during a good rainfall year like 2011–12, less amount of water would have been imported into the basin for irrigation purpose from SSP and IGNP. Since the discharge data for Luni river were not available for the year for which the water accounting exercise was carried out (i.e., 2011–12), the inflow and outflows figures could not be tallied to cross-check the figures of outflows, i.e., surface water outflow + water remaining in the reservoirs.

7.8 Conclusions

The water accounting study for Luni basin suggests that the amount of water utilized in the basin annually (2704 MCM for 2011–12) is higher than the renewable water generated within it (2606 MCM in 2011–12) and a large share of this water is used for irrigation (2404 MCM in 2011–12). Though some amount of surface water flows out of the basin in normal and high rainfall years, all the topographically viable catchments in the basin are fully tapped with 13 major and medium reservoirs capable of storing a total of 560.37 MCM of water. The flat topography of the basin in the lower parts and the very shallow embankments do not permit harnessing this water for beneficial uses using conventional technologies. The high level of water use sustained through groundwater mining and water imported from outside the basin, which help maintain the precarious water balance. The only way to improve water management in this water-scarce river basin is to reduce the consumptive use of water in irrigated agriculture through control of evaporation.

Technologies such as drip irrigation and mulching can be adopted to reduce the nonbeneficial evaporation of water used for irrigating the row

[d] This was estimated using the weighted average rainfall of 539.6 mm rainfall during 2011 and the drainage area of the upper catchment, i.e., 62,200 km^2.

crops. While drip irrigation will be effective in reducing the losses due to nonrecoverable deep percolation, mulching can reduce nonbeneficial evaporation of water applied to the soil. In addition to the groundwater and water from surface reservoirs, there is large amount of rainwater directly used by monsoon crops in the basin area. Mulching can conserve this water retained in the soil profile by preventing evaporation and converting it into beneficial transpiration. Though this intervention can alter the blue water availability in the basin only marginally, it can help improve the efficiency of green water use for crop production. To what extent this intervention can help reduce soil water evaporation would be examined in Chapter 8 of this book using a case study of one of the districts falling fully in the basin.

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