CHAPTER 6

Water accounting for understanding water tenures: A case study of water rich Warna sub-basin of Krishna river basin, Maharashtra

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6.1 Introduction

Water tenure is a legally or customarily defined relationship among people, as groups or individuals, with respect to water resources. A water tenure approach to understanding people's relationship with water encourages a comprehensive, rigorous, and interdisciplinary analysis of the rights and uses, rather than understanding the laws and policies in relation to ownership or usufruct rights in water. The proper use of a "water tenure analysis" into designing water governance framework would help bring in transparency, fairness, and accountability in decision making. For water tenure analysis to be effective, it should be supported by proper water accounting data, upon which consensus has to be built among competing users of water (Lopez-Gunn, 2013).

Water accounting studies, based on an analysis of data related to various components of the hydrological system (e.g., rainfall, stream flows, groundwater recharge, evaporation from water bodies and swamps, storage changes in reservoirs, and land use and water use) at appropriate hydrological units (e.g., basin, catchment, or watershed level), can give a range of useful information about potential water-related extreme events, how much of water in the basin is used in different sectors (drinking and domestic uses, municipal use, industrial use, livestock use, power generation, crop consumptive uses,

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and various in-stream uses), how much of the basin's water goes uncaptured into natural sinks (e.g., saline formations, seas), and how much is lost through nonbeneficial uses. It could also help the water administration be active in the basin to plan actions to mitigate the adverse impacts of hydrological stresses on the socioeconomic system, such as drinking water shortages for human and livestock populations in affected areas, crop losses, and reduced income and livelihoods of affected populations, and damage to water infrastructure.

From the point of view of water governance and management, water accounting studies are useful in the sense that they can provide insights into: (1) optimum level of investments in water augmenting measures (e.g., watershed development programs, water harvesting systems); (2) possible measures to (a) increase effective water availability (e.g., reducing evaporation from surface reservoirs and preventing soil moisture depletion from rain-fed crop land), (b) reduce water demand (e.g., reducing nonbeneficial [both consumptive and nonconsumptive] use of water in irrigated fields) and (c) convert other nonbeneficial uses of water in the basin (e.g., evaporation from barren land) into productive uses; and (3) better intersectoral water allocation, including from lower-valued to higher-valued uses.

In this chapter, we discuss a methodology for water accounting and apply the methodology to one sub-basin of a river in western Maharashtra for one hydrological year. The objective is to assess how much of the renewable water resources in the basin are utilized for various consumptive uses, and how much are available for further exploitation to support future uses. The hydrology, socioeconomic characteristics, water resource systems, water balance of surface and groundwater, and water accounts of the sub-basin are presented and discussed. Based on the findings, some inferences are drawn with regard to water tenure for the sub-basin.

6.2 Hydrology and geohydrology of Warna river basin

6.2.1 Topography and geography

Warna is a sub-basin of the Krishna river basin situated in the south-west part of State of Maharashtra (Fig. 6.1). Krishna river basin is an interstate river basin having a total drainage area of 258,948 km^2, falling in four Indian states, viz., Maharashtra, Karnataka, Telangana, and Andhra Pradesh. The total sub-basin area is about 2095 km^2, with elevation ranging from 540 to 1100 m above MSL. Warna river arises in Sahyadri near Patherpunj in Patan block of Satara district of Maharashtra at an altitude of 914 m above MSL.

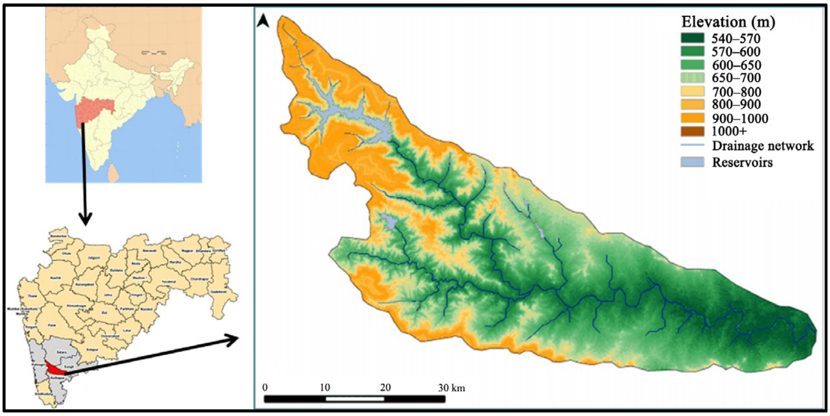

Fig. 6.1 Location of Warna river basin along with its elevation gradient.

The total length of the river is around 150 km. It joins Krishna near Haripur village in Sangli district at an altitude of 548 m. The sub-basin falls in the rain-shadow zone of the Western Ghats and has three distinct seasons, viz., monsoon, winter, and summer. It is spread over nine talukas of four districts, mainly Sangli and Kolhapur, and some parts of Satara and Ratnagiri districts. The talukas it covers are: Shirala, Walwa, and Miraj talukas of Sangli district; Shahuwadi, Panhala, Hatkanangale, and Shirol talukas of Kolhapur district; Patan taluka of Satara district; and Sangameshwar Taluka of Ratnagiri district of Maharashtra.

The sub-basin has a complex topography and bears a transitional character between the Konkan on the west and the Deccan plateau on the east. The eastern boundary of the sub-basin is marked by the flood plain of the river Krishna. The general trend of the sub-basin is from west to east. The western part of the sub-basin comprises a series of elongated hillocks and undulating hilly and rugged terrain. In these areas, the slope is more than 60°. The eastern half of the sub-basin has mostly flat terrain.

6.2.2 Rainfall

There is very high spatial variation in the rainfall within the sub-basin (Fig. 6.2). Rainfall is very high in the western parts of the basin adjoining Konkan and comprising the western ghat portion of the basin. The rainfall falls rapidly from west to east. It varies from 4000 mm in upper western parts around Sahayadries and Konkan portion and less than 700 mm in the lower eastern portions. About 85% of the rainfall occurs during the south-west monsoon, i.e., in the months of June to September.

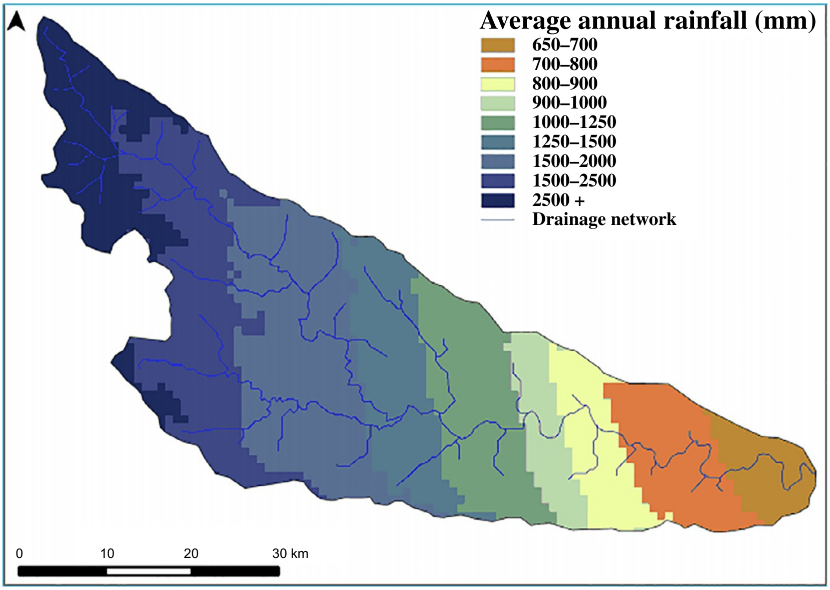

Fig. 6.2 Spatial variation in average annual rainfall in Warna river basin.

Table 6.1 Spatial and temporal variation in rainfall in Warna river basin (1998–2012).

		Rainfall parameters			
District	**Taluka**	**Min (mm)**	**Max (mm)**	**Mean (mm)**	**CV (%)**
Sangli	Miraj	321.0	908.9	588.7	29.3
	Walwa	291.0	1412.6	740.2	37.2
	Shirala	481.8	1794.0	1002.6	33.0
Kolhapur	Shirol	272.0	1050.0	643.4	34.2
	Hatkanangale	364.1	1609.6	843.5	38.3
	Panhala	1290.0	2735.0	1760.7	28.2
	Shahuwadi	1521.5	3450.5	2054.5	26.7

(*Source*: Authors' own analysis based on information available from Department of Agriculture, Government of Maharashtra.)

In Sangli district, between 1998–99 and 2008–09, highest annual rainfall (around 1750 mm) was recorded during 2005–06 in Shirala block and lowest (about 250 mm) in Walwa block during 2003–04. During the same period, the highest recorded rainfall (around 3400 mm) in Kolhapur district was in Shahuwadi block and lowest (about 250 mm) in Shirol block. The spatial varation in rainfall in six talukas of two districts falling partly in Warna sub-basin is analyzed and presented in Table 6.1. However, these figures need to be interpreted carefully, as the gradient of rainfall is very steep, with reducing magnitude of rainfall from west to east (Fig. 6.2). A small shift in location can change the quantum of annual rainfall significantly.

6.2.3 Climate and agroecology

Warna sub-basin of Krishna lies in the temperate climatic zone. Like most other parts of the country, three distinct seasons are observed in the basin: hot summer (from March to May), rainy season (from June to October), and winter (from October to February). Temperature goes up to 45°C in summer, but generally it varies between 20°C and 30°C. The western upper part of the basin is humid, whereas the eastern part exhibits semiarid conditions.

The reference evapotranspiration (PET) gradually increases from western to eastern part of the river basin—from 1300 to 1600 mm in upstream areas, 1600 to 1700 in midstream, and 1700 to 1800 mm in downstream areas of the basin.

The sub-basin falls in two different agroecological zones, viz., south western Maharashtra and north Karnataka plateau (hot dry semiarid ESR with shallow and medium loamy black soils, medium to high available water capacity and length of growing period 90–120 days); and north Sahyadris and western Karnataka plateau (hot dry subhumid ESR).

6.2.4 Hydrology

On the basis of the spatial pattern in occurrence of precipitation in the catchment, the sub-basin can roughly be divided into three parts, i.e., upstream (from the origin up to Chandoli/Warna dam), midstream (from Chandoli dam to Chavare village), and downstream (from Chavare to Haripur village) (Mohite and Samant, 2013). Warna sub-basin is mainly drained by river Warna along with its numerous tributaries. The main river originates in the Sahyadri near Patherpunj in Patan taluka of Satara district. Major tributaries, which join Warna from the northern side, are Morna and Meni. Other major streams are Kadavi and Kansa, both of these flows west to east and join the southern bank of the river.

There are a number of striking features of the river courses of the Warna and its tributaries. Morana river, an important left bank tributary of Warna, takes a "V" bend at Danoli & Samdoli and "U" bend at Khochi. All these bends are mainly controlled by joint structure of the bedrock. In lower reaches, the river flows with prominent loops at Kokarud, between Ambole and Sonarli near Shirla. The length of the loop formed by the river channel is about 10 km. The neck distance is 1.5 km.

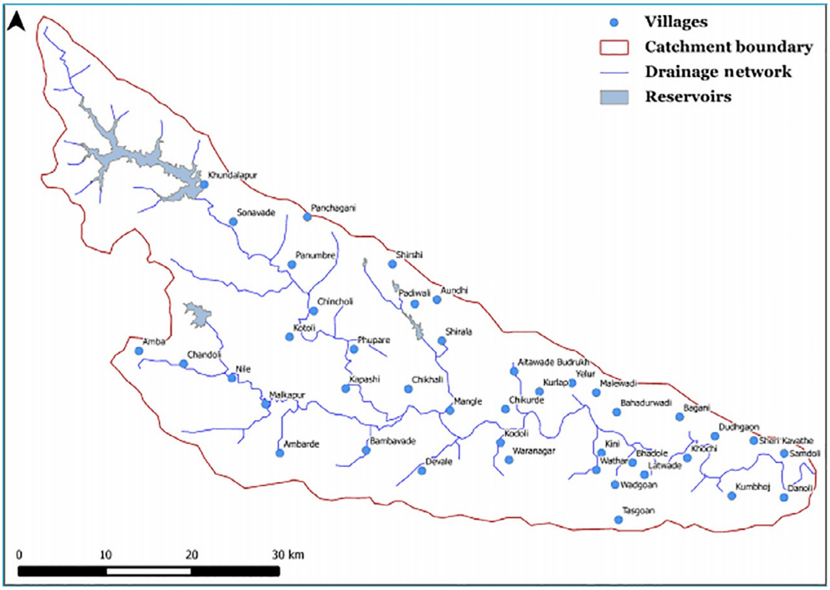

Fig. 6.3 Drainage pattern in the Warna sub-basin of Krishna river basin.

Many drainage patterns of the sub-basin are revealed by first-, second-, third-, and fourth-order streams in the basin (Fig. 6.3). The most common drainage pattern are dendritic, radial, paralleled, and rectangular. However, the drainage is not uniform over the basin. Being less affected by tectonic activities, the drainage pattern is mainly controlled by erosion activities and lithology. The basin's individual drainage pattern is mostly dendritic. Except a few streams in western regions, all major and minor streams are seasonal and are fed by monsoon rains only. Therefore, the period of recharge does not exceed more than 6 months in a year (July to October).

The major water bodies in the basin include 4 waterfalls, 5 reservoirs, 13 streams, 14 minor tanks and ponds, and 21 springs. Due to hilly undulating terrain, local geomorphology, and climatic gradient, the upper catchment represents most diverse riparian habitats, whereas the lower catchment has lowest diversity of riparian habitat. Among the five reservoirs, Warna reservoir is a large one.

6.2.5 Geology and geohydrology

The sub-basin area is mostly underlain by Deccan Traps formations (mainly Basalt). Laterites are also found in some parts of the basin. In Deccan Trap there is no well-defined, uniformly distributed, homogeneous aquifer system. The availability and productivity of groundwater in these formations is entirely dependent in its inherent physical property such as the size and distribution of vesicles, number and spacing of interconnected joints and fractures, and degree of weathering.

Groundwater in the basaltic aquifers occurs under phreatic and semiconfined conditions. The massive lava flows and thick red-bole layers tend to inhibit vertical movement of groundwater and thus act as confining aquiclude. The productive aquifers, when favorably situated, receive recharge and groundwater moves down the slopes till it is withdrawn by groundwater abstraction structures such as dug wells or discharges naturally through springs and wetlands. The average depth of wells varies from 9 to 15 m and diameter varies from 4 to 8 m. The range of water level varies from 3 to 7 m and the yield ranges from 75 to 100 m^3/day. The upper part of the basin is mainly covered with red-brown soil and at places by the lateritic soils, while the lower most portions is known for black cotton soil. The middle part of the basin mostly comprises coarse shallow soils and alluvium.

6.3 Water resource system of Warna sub-basin and water supplies

6.3.1 Surface reservoirs and irrigation projects

There are three main irrigation projects in the sub-basin, Warna being the major and Kadavi and Morna being the medium irrigation projects. Table 6.2 provides the salient features of the dams. The total water availability through these diversion structures is around 1.08 BCM. Out of these, water availability from Warna reservoir is about 0.97 BCM, from Kadavi dam reservoir is 0.07 BCM, and from Morna dam reservoir is 0.03 BCM.

Annually, about 60% (i.e., 0.64 BCM) of the available water in Warna reservoir is consumed for irrigation and industrial use. Whereas, all the available water from Kadavi and Morna dam is diverted for irrigation and industrial use. The gross irrigated area of Warna irrigation project, which includes a lift irrigation scheme (LIS), is about 111,823 ha and that of Kadavi and Morna irrigation projects are about 1160 and 110 ha, respectively.

6.3.2 Groundwater

As per the assessment carried out jointly by Central Ground Water Board and Groundwater Survey and Development Agency of Maharashtra, in 2008–09, the net annual groundwater availability in the basin is around 49 MCM, i.e., 47.4 MCM in noncommand areas and 1.6 MCM in command areas.

Table 6.2 Salient features of the reservoirs in Warna river basin.

Particulars	Reservoirs		
	Warna	**Kadavi**	**Morna**
River	Warna	Kadavi	Morna
Purpose	Irrigation, hydropower	Irrigation	Irrigation
Catchment area (Th ha)	30.10	2.33	8.55
Full reservoir level (m)	626.90	601.25	595.50
Gross storage capacity (MCM)	974.19	71.24	21.16
Live storage capacity (MCM)	779.35	70.56	15.15
Design flood (m^3/s)	2135.00	744.35	1075.00

(*Source*: Water Resources Information system of India.)

This works out to be roughly only around 1.3% of the total precipitation in the basin, or 23.5 mm. The investigation carried out by National Geophysical Research Institute in Deccan trap formations (in Kukadi basin and Godavari–Purna basin) shows that the recharge from rainfall could be in the range of 7.5%–8.6%, with the mean recharge values of 46 mm in Kukadi and 56 mm in Godavari–Purna, respectively (Athavale et al., 1983). However, two points need to be kept in mind, while using the "percentage rainfall" as the basis for arriving at recharge estimates. In hard rock areas with limited groundwater storage potential, the recharge cannot increase with quantum of rainfall. Second: the extent of recharge from rainfall is also a function of the terrain conditions in the hard rock areas. As noted by Raju et al. (1979) based on field studies in South India, hard rock areas with slope more than 5% do not hold surface water for sufficient time for percolation. In the case of Warna sub-basin, nearly 80% of the basin areas have steep slopes, and therefore are not conducive to natural recharge from rainfall. Hence, these low values of recharge estimated the sub-basin can be reconciled.

The gross groundwater draft for irrigation was 0.5 MCM in command areas and 25.3 MCM in noncommand areas. The total groundwater draft for domestic and industrial groundwater use was only 0.3 MCM in command areas and 1.5 MCM in noncommand areas (GSDA and CGWB, 2011). With a stage of groundwater development of 56.3%, the basin can be categorized as safe. However, in some talukas such as Hatkanangale, Shirol, Miraj, and Walwa, groundwater development is already in semicritical or critical stage. Nevertheless, as pointed out by Kumar et al. (2012), these estimates of groundwater balance need to be looked at very carefully, as the assessment of natural recharge from rainfall does not take into account groundwater outflows, which is quite significant in regions with steep topography and groundwater flow gradients, with the result that the utilizable groundwater gets overestimated.

6.4 Socioeconomic system of Warna sub-basin

Based on isohyets, Warna sub-basin is divided into three different zones (Fig. 6.4) (Joy and Paranjape, 2011). Isohyets were chosen in a way that they closely matches with the characterization and zoning of the sub-basin based on slopes, soils, and socioeconomic conditions of the sub-basin.

Zone 1 is the western part of the basin and receives an average annual rainfall of above 1600 mm. This zone covers 42.5% of the total basin area. This zone is mostly hilly and comprises western part of the Shirala and Shahuwadi taluka. It includes the Chandoli National Park and the catchments of two large dams. Out of the total area of 89,000 ha, only 15.5%

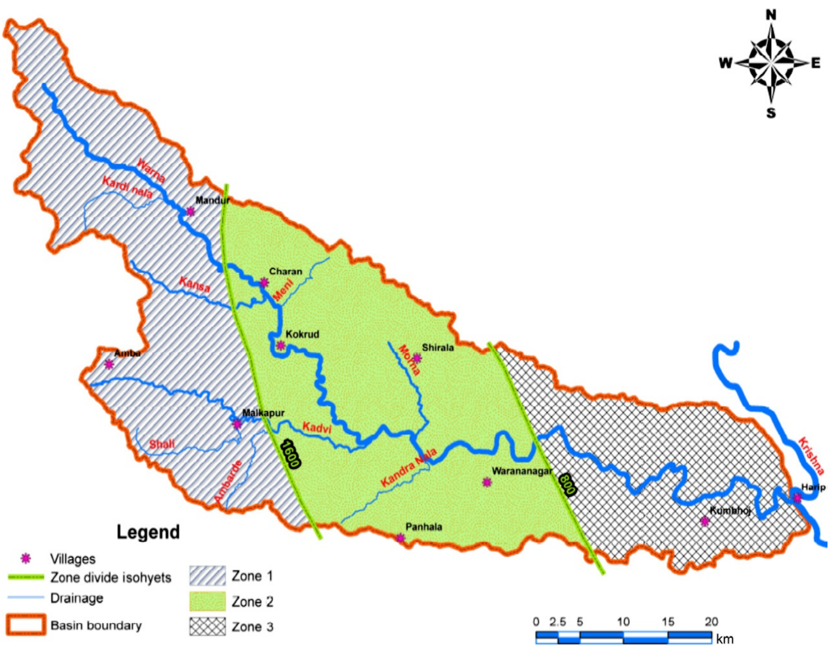

Fig. 6.4 Different zones of Warna river basin. (Source: *From Joy, K.J., Paranjape, S., 2011. Water resources planning and people's livelihoods in the Northern part of the Western Ghats: the case of Warna basin. Paper Presented at the Consultation Meeting on Water Resources of the Western Ghats by WGEEP. KFRI, Trichur.)*

is under agriculture. Almost 64% of the area is under reservoir submergence and covered by the National Park. The area under wasteland is 16%. Because of the presence of large amount of forest land and common land, the arable land availability is very low in this part of the sub-basin. Farming is not a major economic activity in this sparsely populated and remote region. With excessively high rainfall and humid climate, water demand for agriculture is also negligible.

The zone has about 19,600 households comprising a total population of 93,500. Total cattle population is around 37,700 U. Majority of the farmers belong to small land holding category. Almost the entire cropping is rain-fed and only single crop is taken by the farmers. Major crops include rice and finger millet. Only a small proportion of cultivated area is irrigated through wells and bore wells. Thus, this zone is characterized by subsistence form of agricultural practice. Large-scale migration to towns and cities has also been reported from this region.

Zone 2 is the central part of the basin and receives an average annual rainfall between 800 and 1600 mm. It is the considered to be the transition zone between the western and eastern part of the basin. It is spread over 35.4% of the total basin area. Out of the total area of 74,200 ha, about 55% is under agriculture and 44% comprise of wasteland.

The zone has about 94,200 households comprising a total population of 4.4 lac people. Total cattle population is around 1.05 lac. Though most of the agricultural area is rain-fed, irrigation is performed in about 30% of the flat terrain of the region. Major crops include rice, finger millet, sugarcane, and groundnut.

Zone 3 comprises the portion of the sub-basin, which receives an average annual rainfall of less than 800 mm. It comprises the eastern most part of the basin, which is in a low-lying plain area and has fertile alluvial soil. It has characteristics of a semiarid region with high variability in annual rainfall.

The zone is spread over 22.1% of the total sub-basin area. Out of the total area of 46,300 ha, almost 91% is under agriculture and only 8.8% comprises wasteland. The zone has about 52,300 households comprising a total population of 2.6 lac people. Total cattle population is around 72,600. Most of the agricultural land is irrigated as the zone lies in the command of the upstream dams and is also served by a number of lift irrigation schemes on the river itself. Sugarcane is the major cultivated crop in this zone. In some parts, soybean and potato are also grown.

6.5 Methodology and analytical framework for water accounting study

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) how much 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 use of water naturally available in the soil profile by the crops) 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:

$$\begin{aligned} \mathrm{INFLOW}_{\mathrm{TOTAL}} = {} & \mathrm{CU}_{\mathrm{IRRIGATION}} + \mathrm{CU}_{\mathrm{RURAL-DOMESTIC}} + \mathrm{CU}_{\mathrm{URBAN}} \\ & + \mathrm{CU}_{\mathrm{LIVESTOCK}} + \mathrm{CU}_{\mathrm{INDUSTRY}} \\ & + \mathrm{EVAP}_{\mathrm{RESERVOIR}} + \mathrm{OUTFLOW}_{\mathrm{STREAM}} \\ & + \mathrm{GWS}_{\mathrm{CHANGE}} + \mathrm{SC}_{\mathrm{RESERVOIR}} \end{aligned} \quad (6.1)$$

$$\mathrm{INFLOW}_{\mathrm{TOTAL}} = \mathrm{VFLOW}_{\mathrm{STREAM}} + \mathrm{GWR}_{\mathrm{RENEW}} \quad (6.2)$$

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 virgin flow ($VFLOW_{STREAM}$) can be estimated as:

$$VFLOW_{STREAM} = OUTFLOW_{STREAM} + EWD \tag{6.3}$$

If we assume that the return flows from irrigated fields only contribute to groundwater recharge in the command area, return flows from irrigation schemes can be treated as zero. However, it can be considered that the wastewater outflows from urban areas return to the streams.

In such situations, EWD can be estimated as the sum of total water released from reservoirs, water lifted from diversion points along the stream/river through the KT weirs and other river lifting points, evaporation from the reservoirs and their annual (+ve) storage change minus the wastewater return flows from urban areas:

$$EWD = RELEASE_{CANAL} + LIFT_{RIVER} + EVAP_{RESERVOIR} + SC_{RESERVOIR} - RF_{WASTEWATER} \tag{6.4}$$

The consumptive use of water in urban area (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 $CU_{RURAL-DOMESTIC}$.

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:

$$\text{Irrigation water consumed in crop production } (CU_{IRRIGATION}) = AX\left[\Delta_{IRRIGATION} - \{(\Delta_{APPLIED} - ET) \times F\}\right] \tag{6.5}$$

Here, $\Delta_{APPLIED}$ is the sum of irrigation dosage ($\Delta_{IRRIGATION}$) 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 subhumid climatic conditions, the nonbeneficial evaporation from the barren soil will be insignificant. Though a small part of the basin has semiarid climate, we ignore the effect of the same for simplifying the analysis. Again, since the area has shallow water table conditions, the deep percolation from the irrigated field will be recoverable, meaning water applied in excess of ET would return to groundwater.

Hence, 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 $\Delta_{\text{IRRIGATION}}$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.

$$\Delta_{\text{IRRIGATION}} = (\text{ET} - \text{P}_{\text{EFF}})/\text{IE}_{\text{APPLICATION}} \tag{6.6}$$

Since we do not have the estimates of irrigation water application, the estimate of irrigation water requirement based on FAO CROPWAT was treated as the consumptive water use from irrigation (without factoring in water application efficiency). It was assumed that the allowance in irrigation dosage provided for taking care of inefficient water application in the field would be recoverable from the shallow aquifer, and therefore would not change the final values of consumptive use of irrigation water applied.

6.6 Data used for the analysis and sources

Data on groundwater resources (block-wise) in the basin were obtained from Groundwater Survey and Development Agency (GSDA) of Maharashtra, which are the estimates provided by GSDA, which were validated by Central Ground Water Board. Data on point rainfall for different locations in the basin for the period from 1998 to 2012 were obtained from http://mahaagri.gov.in/rainfall/hlevelSelect1.asp (*Source*: Department of Agriculture, Government of Maharashtra). Data on stream-flows for 1986–87 to 2009–10 were obtained from CWC's published hydrological data books. Time series data on reservoir inflows, live storage, volumetric water utilization for various uses, and reservoir evaporation for Warna irrigation scheme for 5 consecutive years (i.e., 2006–07 to 2007–08, 2008–09, 2009–10, and 2010–11) were obtained from the water audit reports of major and medium irrigation projects of Maharashtra (GoM, 2007, 2008, 2009, 2010, 2011). Data on area under different irrigated crops (for the year 2011–12) were obtained from Directorate of Agriculture, Eco-state division, Government of Maharashtra. Blockwise data on population for the blocks/districts falling in the basin were obtained from Census 2011 report. In addition to these, maps showing isohyets and variation in reference evapotranspiration (ET_0) were obtained from various online sources and report of the study "Sustainable Livelihoods and Biodiversity in Developing Countries," Deliverables 5.1 (Phuong and Xuan, 2011). In addition, some scientific papers available on topics such as rainfall-runoff modeling and groundwater recharge (Athavale et al., 1983; Krishnaswamy et al., 2012; NIH, 1998–1999; Raju et al., 1979) were used.

6.7 Analysis of water accounts of Warna sub-basin

6.7.1 Basin outflows, reservoir storage and water utilization pattern

The data on annual streamflow recorded at Samdoli gauging station, which is near the confluence point of Warna river with the Krishna river, are available for the period from 1986–87 to 2009–10. They are analyzed and presented graphically in Fig. 6.5. The highest streamflow during the 24-year period (5839 MCM) occurred during 2005–06, when all the six rain-gauging stations in the basin experienced excessively high rainfall.[a] The runoff rate for the year was 2.79 m. These stations recorded very high rainfall during the successive year (i.e., 2006–07) also, which was reflected in the second highest streamflow (5650 MCM) observed during 2006–07. But, the streamflow declined sharply in the subsequent years, as the rainfall was much lower as compared to 2005–06. The lowest runoff observed in the basin during the 24-year period was in 2002–03 (1361 MCM)

[a] The rain-gauging stations in the basin are Shahuwadi, Panhala, Hatkangle, and Shirol in Kolhapur and Miraj, Valva, and Shirale in Sangli district.

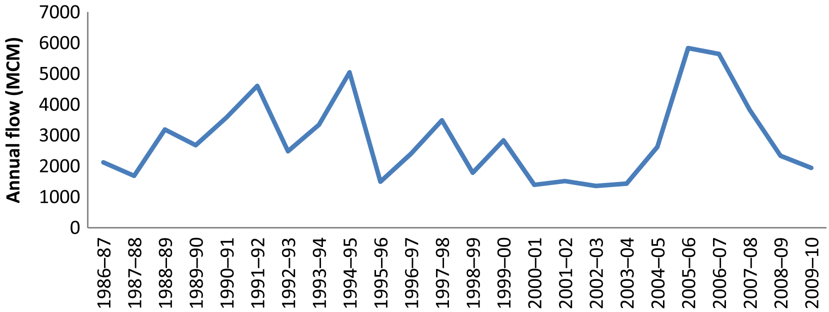

Fig. 6.5 Streamflows in Warna sub-basin, at Samdoli (1986–87 to 2009–10). (Source: *Authors' own analysis based on CWC (2006, 2007, 2009, 2012).*)

Fig. 6.6 Live storage of Warna reservoir (2004–05 to 2010–11).

(a drought year), in which most parts of the basin experienced very low rainfall. This corresponds to a runoff rate of 0.66 m.

But, these figures do not provide clear indications of the total runoff generated in the basin. The reason is the flows are altered by a major reservoir (Warna reservoir), which diverts water for irrigation through canals, in addition to several small water-lifting schemes along the river. Since the command area of this major irrigation scheme is not fully developed, the potential utilization is very low. However, there are several lift irrigation schemes, which utilize the water released from the reservoir irrigating a total area of around 1.18 lac ha using river lifting and canal lifting. We assume that the total amount of water "effectively diverted" by the reservoir is equal to the gross storage capacity of the dam.

Inflows in Warna reservoir for the period from 2004–05 to 2010–11 are presented in a graphical form in Fig. 6.6. The 7-year data do not show any sharp variations in live storage of the reservoir. The lowest live storage was 746.5 MCM, while the highest was 783.4 MCM (during 2009–10).

One reason for this is the carryover storage from the previous year. The carryover storage is significant in most years, ranging from a lowest of 149.5 MCM in 2008–09 to a highest of 357.44 MCM in 2010–11.

In order to understand the actual utilization of water from Warna reservoir, it is important to look at the water audit report of the reservoir (which is available for 5 consecutive years). It provides data on the following: the total live storage on October 15 of every year soon after the monsoon inflows; total amount of water utilized for the river lift irrigation schemes of the government, the water released for canal irrigation during winter and summer, water released for nonagricultural uses, evaporation from the reservoir; the inflow received from the upper catchment during the lean season; and the total amount of storage in the reservoir at the end of the hydrological year (i.e., June 30). However, the data on water utilization do not confine to the geographical area of the basin alone. It also includes areas outside the basin that are being served by the reservoir and lift irrigation schemes.

Since there is no irrigation water use in the basin during kharif season, the outflows from the reservoir during the monsoon season would go up-captured and would get recorded in the last drainage point in the basin. The irrigation demand is during the winter and summer. Since there is no outflow at the last drainage point of the basin in any of the years, it can be assumed that the water releases from the reservoir through canals and river for gravity irrigation, river lift irrigation (by both farmers and the LISs), and nonirrigation uses are fully utilized and there is no effective return flow to the main trunk of the river. Hence, by applying the simple continuity equation, the total water utilized from the reservoir can be estimated. The estimates are provided in Table 6.3 (Column 9). The annual water utilization varies from a highest of 710.9 MCM in 2006–07 to 420.55 MCM in 2010–11. The table provides us the estimates of volumetric consumption of water released from the reservoir by private lift irrigators (Column 10).

In order to estimate the effective water diversion from Warna river during 2009–10 due to the presence of the reservoir, we consider the storage change in Warna reservoir during 2008–09 and 2009–10, which is 265.55–149.52, i.e., 116.03 MCM. Hence, going by Eq. (6.4) defined in the methodology section, the effective water diversion from the river is 692.03 MCM.

Since the command area development of Warna irrigation project is not yet completed, a large share of the water from the reservoir is released in the river for the lift irrigation schemes of the government. They utilize a significant share of the water from the reservoir scheme. The volumetric water use by the LISs ranges from 250.69 MCM in 2010–11 to a highest

Table 6.3 Effective water utilization for various sectors and storage changes in Warna reservoir.

Hydrological year	Live storage as on Oct. 15 (MCM)	Inflow during lean season (MCM)	Balance storage on June 30 (MCM)	Reservoir evaporation (MCM)	Irrigation through		Nonirrigation use (MCM)	Total water utilization (MCM)	Water use for river lift
					Canals (MCM)	LIS (MCM)			
2006–07	778.03	190.02	257.15	22.85	7.66	343.43	7.50	710.90	329.45
2007–08	746.52	89.83	258.99	20.80	9.54	264.01	5.46	577.36	277.55
2008–09	782.06	0.0	149.52	22.41	8.35	287.80	5.35	632.54	308.63
2009–10	783.41	58.24	265.65	22.96	7.00	348.78	8.57	576.00	188.69
2010–11	777.99	0.0	357.44	21.99	6.81	250.69	9.89	420.55	131.18

(*Source*: Authors' own estimates based on Reports on water auditing of irrigation projects of Maharashtra state for 5 years from 2006–07 to 2010–11.)

of 348.78 MCM in 2009–10. Over and above this, there is large amount of water, which farmers directly lift from the river for irrigation. This water available for lifting is also from the reservoir releases, as the river doesn't have flows during times of the year when there is demand for irrigation. The volumetric diversion from the river ranges from 329 MCM in 2006–07 to 131.18 MCM in 2010–11. Not all that water might get used up in the basin. Substantial amount of water is taken out of the basin for irrigation purpose, as the basin does not have extra arable land, which lies uncultivated and which can absorb the water.

Under lift irrigation, water application is more controlled than under gravity irrigation and therefore watering of the fields does not lead to excessive surface and underground drainage. Since slopes in the area receiving water from lifting are mild, field runoff does not expect to return to the streams. However, since the irrigation service provided through the LIS is highly subsidized, water intensity is unlikely to be the main consideration for farmers in selecting their cropping pattern.

Farmers receiving water by gravity tend to grow highly water intensive crops such as paddy, which are also less sensitive to water availability and stress. This is due to the comparatively poor reliability of water supply under gravity irrigation and inadequate control over water application. Further, since the farmers are not confronted with marginal cost of using irrigation, there is less incentive to adopt water-efficient crops and efficient irrigation methods. Since irrigation dosage is likely to be excessive, the chances for return flows from irrigated fields are high. Such return flows would be particularly high for paddy. But, because of plain topography of the areas receiving canal water, the chances of surface runoff would be less, and the excess irrigation dosage is likely to end up in the shallow aquifers. The alluvial nature of the aquifer further results in steady replenishment of the wells in the command area, benefiting both the farmers in the designated command area and farmers dependent on only wells.

This is evident from Table 6.3, which provides estimates of groundwater resource availability in Warna sub-basin. As Table 6.4 indicates, the noncommand areas have higher degree of exploitation of groundwater. This could be because of two reasons. First: in the noncommand areas, which are mostly in the hilly and hard rock terrain (basalt and laterite), the utilizable recharge figures generally tend to get overestimated. Second: in the command areas, which are located in the alluvial plains, good replenishment of groundwater also encouraged abstraction. Table 6.4 also indicates that the overall groundwater balance is positive, with a net change in storage of 2662 ha m (i.e., $5806-3144=2642$), i.e., 26.44 MCM.

Table 6.4 Ground water availability and draft in Warna river basin (ha m per year).

		Renewable groundwater recharge			Gross groundwater draft		
District	**Block/taluka**	**Noncommand**	**Command area**	**Total**	**Noncommand**	**Command area**	**Total**
Kolhapur	Hatkanangale	908.53		908.53	784.76		784.76
Kolhapur	Shirol	123.93		123.93	108.08		108.08
Kolhapur	Shahuwadi	1448.20		1448.20	411.21		411.21
Kolhapur	Panhala	317.55		317.55	243.82		243.82
Sangli	Miraj	417.08	21.48	438.56	390.96	22.26	413.23
Sangli	Walwa	947.02	190.79	1137.81	620.67	67.75	688.42
Sangli	Shirala	1427.79	3.62	1431.41	492.21	2.78	494.99
Total		5590.1	215.9	5806.0	3051.7	92.8	3144.5

(*Source*: Central Groundwater Board and Groundwater Survey and Development Agency, Maharashtra.)

Table 6.5 Difference in (irrigated) cropping pattern among different categories of farmers.

	Total cropped area of farmers using			% of area under irrigated crops of farmers using		
	Canal	Well	River	Canal water	Well water	River lifting
Paddy	7.66		31.56	26.83	0.00	26.16
Wheat	0.175		5	0.61	0.00	4.14
Jowar	0.625	0.175		2.19	1.01	0.00
Barley	0.0075			0.03	0.00	0.00
Maize	1.881		16.25	6.59	0.00	13.47
Groundnut	0.5	0.0043		1.75	0.02	0.00
Green gram	0.125			0.44	0.00	0.00
Bengal gram			6	0.00	0.00	4.97
Chick pea			2	0.00	0.00	1.66
Maize			6	0.00	0.00	4.97
Fodder			1.5	0.00	0.00	1.24
Sugarcane	17.575	17.15	52.32	61.56	98.97	43.37

(*Source*: Authors' own estimates based on primary survey in four locations in Warna river basin.)

The well irrigators in the sub-basin are mostly concentrated in the lower zone (zone 3), owing to the alluvial strata and the influence canal irrigation on groundwater replenishment. Well irrigators are likely to adopt crops, which are water sensitive, owing to the fact that there is greater access to and control over irrigation water as compared to lift irrigation and gravity irrigation. The irrigation wells are shallow open wells. The continuous recharge from canals ensures high water table and sustainable well irrigation. Well irrigation on the other hand prevents waterlogging conditions. Table 6.5 shows that farmers using well as a source of irrigation allocate most of their land for sugarcane, which yields higher returns as compared to paddy and other cereals, as compared to those who access canal water and water from lift irrigation schemes.

6.7.2 Water consumption in domestic sector

The water demand for domestic uses in rural areas is estimated considering a minimum water requirement of 70 L per person per day. The basin being water abundant, such levels of water use are quite probable. Table 6.6 provides the taluka-wise domestic water demand in rural areas. Maximum water

Table 6.6 Annual domestic water use (rural).

Taluka	Rural population A	Domestic water demand for rural area in lpcd $D = A \times 70$ lpcd	Domestic water demand per year (rural)	
			$D \times 365$ days (in 000′ liters)	In billion liters
Shirala	41,577	2,910,390	1,062,292.4	1.1
Walwa	39,799	2,785,930	1,016,864.5	1.0
Miraj	12,649	885,430	323,182.0	0.3
Shahuwadi	64,130	4,489,100	1,638,521.5	1.6
Panhala	15,073	1,055,110	385,115.2	0.4
Hatkanangale	37,920	2,654,400	968,856.0	1.0
Shirol	6304	441,280	161,067.2	0.2
Total	217,453	15,221,710	5,555,924.2	5.6

demand is from Shahuwadi taluka and minimum is from Shirol taluka, both in Kolhapur district. The total domestic water demand in rural areas of the basin is estimated to be 5.6 billion liters per annum or 5.6 MCM per annum. Further, in view of the fact that there are no centralized wastewater collection systems in rural areas, it is assumed that the return flows do get back to the natural water systems.

6.7.3 Water consumption by livestock

The estimates of total water consumption by livestock are based on the animal body weight and annual average of the daily minimum temperature of the region. Table 6.7 presents the estimates of total number of livestock and water consumption by different categories of livestock in Warna sub-basin. Maximum water demand for livestock is from Shahuwadi followed by Shirala, Walwa, Hatkanangale, Miraj, Panhala and least from Shirol taluka. The total livestock water demand in the basin is estimated to be about 1065 million liters (1.065 MCM) per annum.

6.7.4 Water consumption in irrigation (only irrigation water)

Table 6.8 presents the estimates of water consumption by irrigated crops in Warna river basin. The estimation used FAO CROPWAT mode for estimating the PET of crops and effective rainfall, in order to arrive at the irrigation water requirement. The estimation is based on the assumption that the total water depleted in crop production is same as the PET, or in other words, the farmers apply sufficient water to meet the entire ET demand of

Table 6.7 Water consumption by livestock in the basin.

Taluka	Crossbreed cow		Indigenous cow		Buffaloes		Sheep		Goats		Horse		Others		Total water demand (million liters/year)
	No.	Water requirement (000′ liters per annum)	No.	Water requirement (000′ liters per annum)	No.	Water requirement (000′ liters per annum)	No.	Water requirement (000′ liters per annum)	No.	Water requirement (000′ liters per annum)	No.	Water requirement (000′ liters per annum)	No.	Water requirement (000′ liters per annum)	
Shirala	3242	39,982.2	2826	34,736.2	9491	137,773.1	86	98.0	1881	2155.4	424	4853.4	48	55.3	219.65
Walwa	1441	20,816.2	1552	19,297.8	10,725	155,333.6	2491	2855.2	3527	4042.5	7	79.4	291	333.4	202.76
Miraj	1953	22,956.9	2335	27,438.5	2130	29,112.0	378	433.6	1429	1637.5	116	1324.4	84	96.3	83.00
Shahuwadi	2129	31,298.7	6609	82,775.3	14,570	207,141.9	1300	1489.3	8264	9470.2	23	260.7	16	18.5	332.45
Panhala	894	13,131.1	751	9327.9	3420	51,404.7	633	725.4	867	993.3	5	53.6	2	2.4	75.64
Hatkanangale	949	13,712.8	863	10,838.6	6777	97,726.8	3785	4338.0	1928	2209.9	50	574.2	184	211.3	129.61
Shirol	134	1912.4	157	2001.5	1220	17,670.6	267	306.1	280	320.7	7	76.6	6	7.3	22.30
Total	10,742	143,810.3	15,093	186,415.8	48,333	696,162.7	8940	10,245.6	18,176	20,829.5	632	7222.3	631	724.5	1065.41

(*Source*: Authors' own estimates based on secondary data on livestock population and estimation of water requirement of different categories of livestock.)

Table 6.8 Irrigation water consumption over a decade.

Name of the crop	Irrigated area of the crop (ha)		Water demand (MCM)	
	2000–01	2010–11	2000–01	2010–11
Rice	6821.2	9005.7	64.835	84.465
Wheat	1264.5	1195.4	4.986	5.116
Kharif sorghum	2971.1	1611.2	1.396	0.749
Rabi sorghum	5418.1	1528.3	20.857	6.015
Pearl millet	775.6	0.0	0.723	0.000
Maize	1168.1	1494.8	1.197	1.821
Common millet	202.3	0.0	0.082	0.000
Finger millet	1184.8	1191.6	0.529	0.458
Foxtail millet	68.6	0.0	0.064	0.000
Little millet	45.3	0.0	0.020	0.000
Other cereals	223.3	610.3	0.161	0.278
Whole Bengal gram	1361.5	3151.4	1.026	2.793
Red gram	155.0	142.6	0.120	0.108
Green gram	369.9	278.8	0.287	0.237
Black gram	514.5	222.0	0.361	0.178
Horse gram	172.6	0.0	0.139	0.000
Kidney beans	432.0	0.0	0.383	0.000
Cowpea	155.6	0.0	0.103	0.000
Chickpea	8.6	0.0	0.005	0.000
Other pulses	142.2	520.5	0.108	0.375
Sugarcane	9202.2	8295.6	116.396	110.389
Cotton	25.5	1.2	0.079	0.004
Roselle	11.6	0.0	0.034	0.000
Other fiber crops	2.8	0.0	0.010	0.000
Groundnut	5699.7	3251.1	5.171	3.469
Soybean	2149.8	4941.9	3.635	7.253
Coconut	1.6	33.0	0.006	0.117
Sunflower	150.5	94.1	0.683	0.394
Niger seed	214.9	28.0	0.768	0.128
Other oil seeds	4599.7	144.5	16.431	0.548
Total	45,512.8	37,741.9	240.592	224.894

(*Source*: Authors' own analysis based on data provided by district agricultural department.)

the crops and in situations where water application exceeds the shortfall of soil moisture availability, the excess water percolates downs to join the shallow aquifer. The field investigations carried out in four locations, spread across the basin, involving interview of farmers also did not bring out the problem of water availability really affecting irrigated crop production.

Overall, between 2000–01 and 2010–11, irrigated area has decreased from 45,500 to 37,700 ha. This is mainly due to decrease in irrigated area under rainy season crops, which include sorghum, pearl millet, other small millets, and pulses. Further, area under irrigated oil seeds has decreased by 4400 ha. However, irrigated area under paddy, finger millet, Bengal Gram, and soybean has increased. As per the latest cropping pattern (2010–11), irrigation water use in the basin is estimated to be around 225 MCM. Therefore, there is some reduction in irrigation water. The reduction is to the tune of 6.5%.

6.7.5 Summary of water accounts

The total surface inflow in the basin for the year 2009–10 (the year for which the most recent data are available) is the sum of annual outflow and the total effective water diversion from Warna reservoir (1949 MCM) for the hydrological year. It was thus estimated to be 1949.0 + 692.03 MCM, i.e., 2641.03 MCM. As per the mean annual rainfall in the catchment (as shown in Fig. 6.2), the total rainfall falling in Warna sub-basin would work out to be around 3550 MCM per annum. As the rainfall in 2009–10 was a little above the normal, an increase of 10% can be reasonably assumed. Hence, the total quantum of precipitation works out to be 3904 MCM for that year. This makes the total runoff 67% of the annual rainfall. These figures need to be carefully examined as they mainly determine the availability of water for various uses in the sub-basin. But, there are no studies available on Warna, which either estimated or can be used to estimate the runoff (stream flows) possible in the basin. However, there are two important studies available for similar basins in the Western Ghats, which we would like to discuss here.

A recent study in microcatchments inside an east-flowing western ghat river of Kodigibail in North Karnataka for 3 consecutive years (i.e., 2003, 2004, and 2005) showed (surface) runoff coefficients ranging from 21.9% to 40.3% in 2003 (for a rainfall of 2252 mm); 21% to 43.2% in 2004 (for rainfall of 2848 mm); and 28.8% to 67.6% in 2005 (rainfall 3662 mm), for natural forests to degraded forests, respectively. The catchments with (Acacia) plantations had runoff values, higher than that of natural forests but less than that of degraded forests in 2004 and 2005 (*Source*: based on fig. 6.4, a, b, and c in Krishnaswamy et al., 2012: p. 226). However, these hydrological observations were limited to catchments of first order streams—with size varying from 4 to 10 ha. Hence, the stream discharge did not include the base flow component. But, for rivers originating from the western ghat, the base flow component of stream flow (runoff) could be quite substantial. As per the study carried out by National Institute of

Hydrology (1998–1999),[b] the base flow component was estimated to be ranging from 44% for 1000 mm of annual rainfall to 24.5% for 4000 mm of annual rainfall in Netravati river basin, and 11% for 500 mm of annual rainfall to 14.5% for 4000 mm of annual rainfall in Dandavathi river basin (NIH, 1998–1999). Hence, the figures of runoff coefficient estimated by Krishnaswamy et al. (2012) cannot be reckoned with for checking the veracity of our estimates.

The NIH study, which had modeled the rainfall-runoff relationships for five basins, based on daily discharge measurements and the estimated base-flow component of the runoff, further showed that in all the five basins, the runoff coefficient increased linearly with increase in magnitude of rainfall. For the catchment of Dandavathi, which is an east-flowing river of Krishna, the runoff coefficient, as per the rainfall-runoff model, ranged from 0.16 (for 500 mm) to 0.755 (for 3000 mm) to 0.81 (for 4000 mm). Given the rainfall regime of the basin under investigation (600–4000 mm), the climate and the predominantly sloppy terrain, the estimates of basin yield seem to be quite reasonable. However, detailed long-term studies of water inflows and out-flows will have to be carried out for the three physiographic-cum-agroclimatic units of the basin by separately considering the rainfall-runoff relationships for these units to obtain more accurate results.

The total annual groundwater replenishment in the basin was estimated to be 58.06 MCM, which includes the additional recharge from irrigation return flows in the command area. We have estimated the additional recharge in the canal command area to be 0.922 MCM. This was based on the assumption that the incremental recharge rate observed in the canal command area (of around 4500 ha) is due to recharge from return flow. The incremental recharge was estimated to be 0.02 m (0.047–0.027) and considering an area of 45 km^2 of recharge area, the incremental recharge from return flow was estimated by multiplying the area by recharge rate (45×0.0206). Hence, the net renewable recharge from precipitation was worked out to be 57.14 MCM.

The estimates of net change in groundwater balance are available from groundwater assessment reports, as $58.06 - 31.44 = 26.62$ MCM. The change in reservoir storage during the year 2009–10 (for only Warna) is 116.03 MCM. The total water consumption in agriculture within the basin area

[b] The NIH study covered five large catchments, viz., Nethravathi, Sithanathi, Malaprabha, Dandavathi, and Barchi. The lowest catchment area was for Dandavathi (118.88 km^2), and the highest was for Nethravathi (3657 km^2) (NIH, 1998–1999).

was estimated to be 224.89 MCM for the year 2010–11 for which land use data were available. This can be assumed as the water consumption in the previous year, i.e., 2009–10 as well as one does not expect any major change in land use and water use in 1 year. The total water use in agriculture, rural domestic, and livestock sectors put together therefore is 231.06 MCM. The water accounting study did not consider urban water use as the town in the downstream of Warna secures its water supplies from Krishna river.

The evaporation loss from Warna reservoir is 22.96 MCM as per the water audit report (GoM, 2010). The nonirrigation use of water from the reservoir is 8.57 MCM (GoM, 2010), and the unutilized flow in Warna at the large drainage point is 1949 MCM (CWC, 2012). The annual storage change (+ve) in groundwater is 26.44 MCM. By applying the continuity equation, the difference between the left- and right-hand side of the equation is 343.93 MCM. This could be roughly the amount of water taken out of the basin for agriculture. The final result of water accounting is shown in Fig. 6.7 and Table 6.9. From Fig. 6.7, it is evident that agricultural water consumption within the basin is only 8% of the total renewable water in the basin.

6.8 Findings

Warna, which is a sub-basin of Krishna river basin of Peninsular India, is considered to be a water abundant sub-basin, as per the classification made by the water resource department of Maharashtra. The annual renewable water resource of the basin, including groundwater, for the year 2009–10 was estimated to be 2698 MCM.

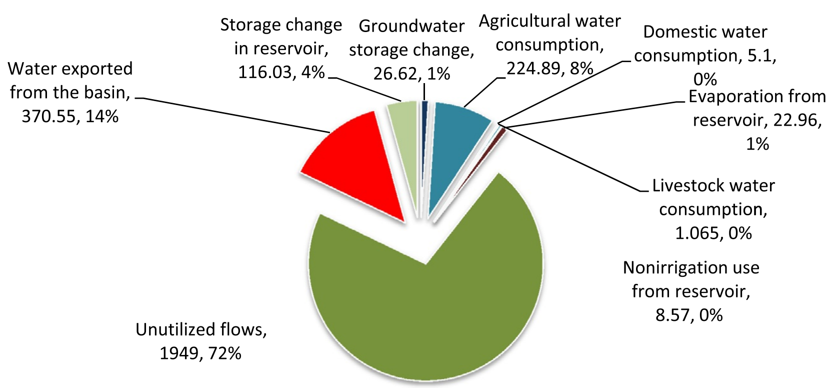

Fig. 6.7 Water accounts for Warna sub-basin: 2009–10.

Table 6.9 Water accounts of Warna sub-basin (2009–10).

Components of water accounts	Amount in MCM
Total inflows	2698.165
Outflows	
Agricultural water consumption	224.89
Domestic water consumption	5.10
Livestock water consumption	1.065
Evaporation from reservoir	22.96
Water diversion for nonirrigation use from reservoir	8.57
Storage change	
Unutilized stream flows	1949.00
Groundwater storage change	26.44
Water exported from the basin	343.93

(*Source*: Authors' own estimates based on secondary data.)

Surface water accounts for a major component of the total renewable water resources of the basin (97.9%). The upper catchment of the basin, though small in size, is the main source of inflows into Warna reservoir, generates nearly 900 MCM of water during the monsoon season every year, by virtue of the excessively high rainfall, humid climate, and rocky terrain in the basin's upper catchments. Groundwater accounts for a small fraction (2.1%) of the total renewable water resources in the basin.

In spite of heavy rainfall, which large parts of the basin receive, gross groundwater recharge is very small, i.e., 58.06 MCM, due to the hard rock geology and sloppy terrain in the upper catchment. This quantity includes recharge due to return flows (0.922 MCM) from surface irrigation in the command areas of lift irrigation schemes and gravity irrigation.

The rapid water accounting study carried out for Warna sub-basin shows that the total amount of water consumed in four major competitive use sectors, i.e., agriculture, domestic use, livestock use, and industrial water use, within the basin is much less than the difference between annual renewable water resources of the sub-basin, the outflows, and the storage change (carry over storage) in Warna reservoir. The difference is to the tune of around 343.93 MCM for 2009–10. This could be the quantum of water exported from the basin for irrigation through river lift schemes and gravity irrigation scheme. However, since the data on the actual amount of area served by the scheme inside and outside the sub-basin are not available, this estimate could not be crosschecked.

Agriculture is the largest user of water in the sub-basin. Paddy and sugarcane account for a major portion of the irrigation water use in the basin, and the total agricultural water use was 224.9 MCM in 2009–10, which came down marginally from 240.6 MCM in 2000–01. There are a wide range of cereals, vegetables, fruits, and cash crops grown in the basin area, by virtue of the vast difference in climatic conditions from the upper to the lower catchment. Nevertheless, sugarcane consumes the largest amount of water.

A quick analysis of the water audit reports of Warna reservoir scheme for 5 hydrological years, i.e., from 2006–07 to 2010–11 shows that the reservoir live storage varies only marginally over the years in spite of significant variations in rainfall in the catchment, as the storage system harnesses only a portion of the dependable flows. Though the audit reports indicate the presence of inflows during lean season in some of the years, analysis suggests that the reservoir has sufficient quantum of storage even at the end of the hot summer, i.e., June 30, most of which is due to the unutilized storage from monsoon flows. The evaporation from Warna reservoir is a small fraction of the total inflows impounded by it—in the range of 2.5%–3%.

The analysis of discharge at the last drainage point of Warna river shows that there is significant amount of outflow contributing to the stream flow of Krishna, 1949 MCM in 2009–10. This is 72% of the total annual flows in the sub-basin. The amount varies from a lowest of 1361 MCM in the driest year (2002–03) to 6739 MCM during the wettest year of the observation period (2005–06). However, there is no stream flow during the lean season. This suggests that all the water released from Warna reservoir for direct lifting from the river for irrigation gets consumed before it reaches the last drainage point. This has serious implications for the in-stream uses of water of the river, particularly fisheries. There are reports of land use changes (particularly agricultural expansion, excessive withdrawal of water from the river, and pollution of river) resulting in large-scale dying of fish in the river, and its undesirable consequences for the livelihoods of the traditional fishing community (Mohite and Samant, 2013).

Since Warna reservoir appears to have sufficient carry over storage every year, the scope for releasing water during the lean season for meeting the environmental flow needs exist.

6.9 Implications of water accounts for water tenure in the sub-basin

Though the total drainage area is only 2097 km^2, the wide spatial heterogeneity in hydrological regime, topography, geology, climatic conditions, and socioeconomic characteristics make water resource availability and conditions with respect to water access and use in Warna sub-basin very complex. The elevation difference between upper and lower catchments is 660 m.

The upper catchment of the sub-basin has hilly terrain and is covered with good forests. The climate in the upper catchment is humid to subhumid. By virtue of the excessively high rainfall, cold and humid climate, and rocky and sloppy terrain, this part of the sub-basin yields large amount of runoff during the monsoon season. It also produces stream flows during lean season on account of base flows. For an annual rainfall of 3600 mm, the runoff from the catchment of 301 km^2 (source: Table 6.1) could be as high as 921 MCM if we consider a runoff coefficient of 0.85.

The upper catchment faces least human interference, and majority of the drainage area of the upper catchment is under a national park. The land use is mainly natural forests, and population is very low. Warna reservoir impounds water from this portion of the catchment, with a catchment area of 301 km^2, which falls entirely in the forests and Chandoli National Park area. The reservoir receives inflows much in excess of the amount needed for realizing the full storage capacity, as is evident from the observed flows in the last drainage point in the basin. This area being part of the western ghat and therefore being protected, land use there is unlikely to change over the years, posing no threat to the hydrological system. This means the rights of those who depend on the water from the reservoir would be quite secured.

Toward the lower catchment, the climatic conditions change rapidly. The major variation is in the rainfall and humidity. While the rainfall decreases sharply, the humidity also reduces. This phenomenon increases the aridity and water requirements for crop production. Since the rainfall is lower, the irrigation water demand for crops also increases gradually toward the middle and lower parts. More importantly, toward the lower parts, major change in the land use is observed, from forests to wastelands, pasture land, and agricultural land. The lower plains have more arable land and higher population density.

The major source of water toward the middle portion of the sub-basin however is flows in Warna river. The flow in Warna river is however regulated by the presence of Warna reservoir in the upper catchment area. Due to the underlying hard rock formations, groundwater availability in the middle portions of the basin is not significant. Therefore, the population in this part of the basin is heavily dependent on the river flows. A large number of KT weirs are constructed by the irrigation department across the river for lifting water for irrigation (under the LISs). The unique spatial pattern in distribution of water endowment also influences the distribution of population in the middle parts. In these parts, the human settlements are all concentrated along Warna river and its tributaries.

The land use in the lowest part of the basin is distinctly different from the upper parts. The lowest part is intensively cultivated. Unlike the upper and middle (transitional) parts, the lower parts consist of alluvium. Because of this, the water availability in the lower parts is more or less uniform. The lower part of the sub-basin is also part of the command area of Warna irrigation scheme. The water released through gravity to this part of the basin, besides adding to the water supplies for irrigation, also adds to groundwater recharge. Recharge occurs from both canal seepage and deep percolation of water from irrigated fields.

The land use and cropping systems in the lower catchment is also different from that of middle catchments, with water-intensive crops such as sugarcane and paddy occupying a significant proportion of the total cropped area. Another important factor, which influences water use in this part of the sub-basin, is the presence of a town and the higher density of population. This increases water demand in the competitive use sectors, viz., agriculture, urban and rural domestic use, and livestock use. Owing to the presence of water in the alluvial formations, water from canals and the river, and the presence of highly productive arable land, agriculture in this part of the basin is intensive and also commercially oriented.

In spite of intensive land use in the lower parts, the sub-basin has significant amount of excess flows contributing to the inflows in the lower parts of the basin. The Warna reservoir, which has a gross storage capacity of around 974.19 MCM, is still not able to utilize all the water in the reservoir for gravity irrigation, as canal network for the scheme is yet not ready. This is evident from the fact that the potential created (4500 ha) is much less than the ultimate irrigation potential of 127,700 ha. However, there is large-scale irrigation occurring in and outside the basin through river lifting and canal lifting. The total irrigation from Wakurde lift irrigation project, which is separated from Warna irrigation project, alone has a potential of 6400 ha. Hence, the gross irrigation from the water stored in the reservoir is around 111,820 ha, with a net irrigated area of 87,000 ha.

Even in situations when the entire canal system within the sub-basin is ready for utilizing the irrigation potential created, the flows in the basin may not be much altered. This is because increased use of water from canals could result in reduced river lifting, and reduced abstraction of groundwater in the lower alluvial parts. This in turn can increase the recharge to groundwater through return flows, which is now quite insignificant. The latter can result in rising of water table and groundwater outflows into the streams. However, the challenge would be in mitigating the water quality impacts. Excessive irrigation from the canals, while increasing groundwater recharge through percolation, can also lead to fertilizer and pesticide contamination of the shallow aquifer. In addition, there could be surface runoff from irrigated fields, which would directly enter the streams and pollute river water. This can seriously threaten the drinking water supply schemes based on river lifting in the downstream areas.

It is important to note that there is a significantly large population in the middle and lower reaches of the sub-basin, depending on the river, whose traditional occupation is fishing. Water quality deterioration resulting from fertilizer residues and untreated effluent from the towns can cause eutrophication and cause death of native fish population, affecting the livelihoods of these communities (Mohite and Samant, 2013). Possibilities might exist for release of unutilized water in Warna reservoir for meeting the in-stream water needs such as fisheries.

Another important potential driver of change in the sub-basin hydrology is the change in land use in the middle portion. Currently, this part of the sub-basin has less area under cropping and more area under natural vegetation such as grasses. With increasing population, this is likely to change. More of such common land would be brought under cultivation, with the result that the runoff generated in this part of the drainage area would be captured in situ in the farms. Farmers normally construct bunds to harvest the runoff over and above the direct storage of a portion of the precipitation, which they get in the soil profile (effective rainfall). This is particularly significant in view of the fact that farmers in both the districts have started allocating increasing amount of land under water-intensive crops such as sugarcane and paddy.

The sub-basin has a net sown area of 45,512 ha from the two districts of Sangli (23,237 ha) and Kolhapur (22,275 ha). If we assume that the entire cultivated land within the sub-basin area gets allocated to sugarcane cultivation, the total annual water consumption from irrigation would be 589.4 MCM. This is 364.48 MCM higher than the current irrigation water consumption in the sub-basin. The volume of water to be diverted to meet this consumptive water requirement would be even higher. Under such a scenario, there could be sharp reduction in the stream discharge from the (sub) basin, especially in low rainfall years.

Increasing urban population is likely to put enormous pressure on the reservoirs located in the western ghat region. This is because of two reasons. First: apart from being plenty, flow of the rivers of originating from the western ghat region has very high dependability given the very low variability of rainfall in the region, and as a result, the reservoirs are likely to receive full storage in every year. This means that the water supply schemes based on such sources are likely to perform much better than the groundwater-based schemes. Second: the quality of surface water from the virgin catchments like that of Warna is comparatively much better than that of water from the aquifers.

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