Project Report

Situational Analysis of the Upper Bhima sub-basin in the context of the Water-Food-Biodiversity Nexus

Authors:

Radhika Kanade[1], Kiran Lohakare[1], Neha Bhadbhade[1], K. J. Joy[1], Bejoy K. Thomas[2], Juliette Martin[3] and Barbara Willaarts[3]

[1] Society for Promoting Participative Ecosystem Management, Pune, India

[2] Indian Institute of Science Education and Research Pune, India

[3] International Institute for Applied Systems Analysis, Laxenburg, Austria

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Foreword

This report was prepared as part of a research project titled "*Soft systems analysis: Streamlining participatory approaches and agent-based models to explore ideas of fairness at the food-water-biodiversity (F-W-B) nexus* (fairSTREAM)". This project is funded by the International Institute for Applied System Analysis (IIASA) and is implemented in collaboration with two partners from India: Society for Promoting Participative Ecosystem Management (SOPPECOM) and Indian Institute of Science Education and Research Pune (IISER Pune). The project started in September 2021, and it will run till December 2024. The main goal of fairSTREAM is to develop and demonstrate a co-production methodology for including equity and justice (fairness) alongside efficiency in developing sustainable policy options across the Water-Food-Biodiversity nexus (WFB nexus). The demonstration component is placed in the Upper Bhima basin, and the specific objectives here are to design and test a systems-informed stakeholder knowledge co-production process with the purpose of developing fair and sustainable policy options for WFB nexus. The co-production process involves several steps, namely: the assessment phase (including preparatory work, problem framing, and exploration of options) and the action planning phase. An evaluation process is also embedded across the different steps and phases. This report summarizes the findings of the preparatory and problem-framing phase, to contextualize the WFB nexus in the Upper Bhima, and what specific challenges it raises, both from a sustainability, equity and fairness perspective. Other than serving as a reference document for primary stakeholders - farmers, fishers and forest dependent communities to contextualize the WFB nexus in the Upper Bhima, this situational analysis is intended to inform future phases, including the development and co-production of options using a combination of modelling and soft approaches.

About the authors

Radhika Kanade is a IIASA funded Postdoctoral Researcher at the Society for Promoting Participative Ecosystem Management (SOPPECOM) (Contact: radha.kanade@gmail.com)

Kiran Lohakare is a Research Associate at the Society for Promoting Participative Ecosystem Management (SOPPECOM) (Contact: kiran.lohakare@gmail.com)

Neha Bhadbhade is a Research Associate at the Society for Promoting Participative Ecosystem Management (SOPPECOM) (Contact: neha2282@gmail.com)

K. J. Joy is founder and Senior Fellow at the Society for Promoting Participative Ecosystem Management (SOPPECOM) (Contact: joykjjoy2@gmail.com)

Bejoy K. Thomas is an Associate Professor and Associate Dean at Indian Institute of Science Education and Research Pune (IISER Pune) (Contact: bejoy@iiserpune.ac.in)

Juliette Martin is a Research Scholar at the Equity and Justice Research Group and Biodiversity, Ecology, and Conservation Research Group in the International Institute for Applied Systems Analysis (IIASA) (Contact: martinj@iiasa.ac.at)

Barbara Willaarts is a Research Scholar at the Water Security Research Group in the International Institute for Applied Systems Analysis (IIASA) (Contact: willaart@iiasa.ac.at)

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List of abbreviations

amsl	Above mean sea level
bgl	Below ground level
CFRMC	Community Forest Rights Management Committee
CGWB	Central Ground Water Board
CWC	Central Water Commission
FRA	Forest Rights Act
F-W-B	Food-Water-Biodiversity
GSDA	Groundwater Survey and Development Agency
ISWP	Integrated State Water Plan
JFMC	Joint Forest Management Committee
KWDT	Krishna Water Dispute Tribunal
Lpcd	Litres Per Capita Per Day
MCM	Million Cubic Meters
MIDC	Maharashtra Industrial Development Corporation
MKVDC	Maharashtra Krishna Valley Development Corporation
MKVWRC	Maharashtra Krishna Valley Water Resources Corporation
MPCB	Maharashtra Pollution Control Board
MWH	Megawatt hour
MWRRA	Maharashtra Water Resources Regulatory Authority
MWSIP	Maharashtra Water Sector Improvement Project
NTFP	Non-timber Forest Produce
PMR	Pune metropolitan region
PMRDA	Pune metropolitan region Development Authority
RBO/As	River Basin Organizations/Agencies
SOPPECOM	Society for Promoting Participative Ecosystem Management
ST	Scheduled Tribes
TMC	Thousand Million Cubic Feet
VWC	Village Watershed Committee
WG	Western Ghats
WRD	Water Resources Department
WUA	Water Users' Association

Chapter 1 Introduction

The Bhima is one of the major tributaries of the river Krishna, the fifth largest river system in India. The Bhima sub-basin of the Krishna is divided into the Upper Bhima (K-5) and the Lower Bhima (K-6) sub-basins. The Upper Bhima sub-basin is situated almost entirely within the state of Maharashtra. The headwaters of the three major rivers in the Upper Bhima sub-Basin (the Sina, Bhima and Nira), drain the upper catchment. They originate in the dense forests on the eastern side of the Western Ghats range. These rivers flow to the southeast, over the plains of the Deccan Plateau, a fertile agricultural area with densely populated riverbanks (see Figure 1).

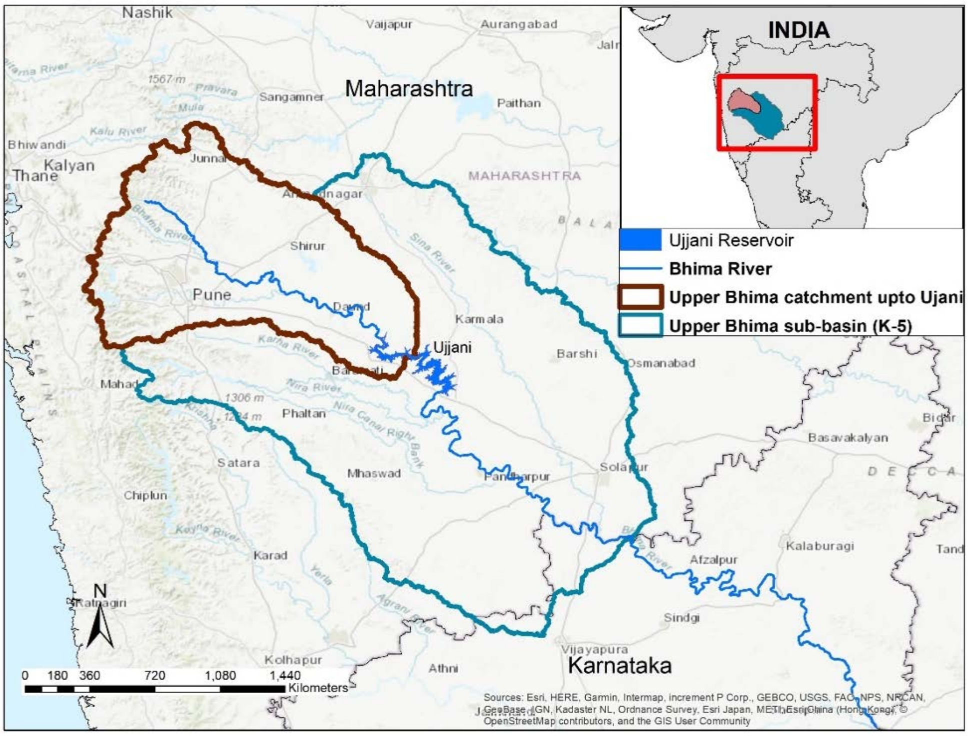

Figure 1 : Location of the Upper Bhima sub-basin (up to Ujjani) within the Upper Bhima (K-5). Source: Map prepared by SOPPECOM

The Bhima originates near the Bhimashankar Temple in the northern Western Ghats in Pune district and flows through the Bhimashankar Wildlife sanctuary. It flows southeast for 861 kilometers and enters the Krishna along the border between Karnataka and Telangana near Raichur. The Bhima has many smaller tributaries most of which have been obstructed by dams and barrages. Water is distributed through a network of reservoirs and canals supporting the domestic requirements of the population in the basin as well as that of the agriculture. The largest dam by water storage capacity in the Bhima basin is the Ujjani dam (water storage capacity: 118 TMC). This document presents the situational analysis of the upper section of the Bhima basin with the Ujjani reservoir as the exit point (Figure 1). It is the rapidly urbanizing section of the Upper Bhima basin surrounding the Pune metropolitan region (PMR), with a population of more than seven million residing in the urban areas.

Different parts of the Upper Bhima basin are experiencing challenges pertaining to different pressures such as climate change, urbanization and land use changes, putting the hydrological, food production and natural systems in the basin under immense stress (Gartley et al., 2009; Karutz et al., 2022; Samal & Gedam, 2015). These challenges are manifested differently in various parts of the basin in terms of water inadequacy for agriculture as well as domestic use, livelihood challenges for local communities, over abstraction of groundwater and habitat loss for species (Gole et al., n.d.; Karutz et al., 2022).

We have used a desk review approach to describe the study area in terms of its physiographic, socio-economic and land cover context in the second chapter. In the third chapter, we provide a detailed profile of the three sectors of water, agriculture and biodiversity, based on the available literature and resources. In the last chapter, we identify and discuss the main sectoral and nexus challenges as perceived by the different stakeholders engaged and consulted throughout the problem framing exercises, through interviews, focus group discussions and a stakeholder workshop. We consulted various actors in the basin including experts, farmers, Adivasis (tribals), social activists and managers to understand current challenges in the study area.

Based on the review and consultations we also try to map the challenges on the water-food-biodiversity (W-F-B) nexus links to understand the trade-offs and synergies within the nexus. We use an approach based on normative goals of sustainability, equity and fairness in the distribution of environmental resources, gains, and costs of economic activities, consumption of resources, and the winners and losers from the changes in the basin. The purpose of this situational analysis is to identify the main sectoral and intersectoral challenges within the W-F-B nexus of the Upper Bhima basin. It also highlights critical knowledge gaps in these sectors.

Chapter 2 Study Area

2.1. Geographical and physiographic context

The study area forms the extreme north-western part of the larger interstate Krishna River Basin. It is largely situated in the Pune district of Maharashtra, covering Junnar, Ambegaon, Khed, Maval, Mulshi, Haveli, Shirur and Indapur Tehsils of the Pune District. It also partially covers Parner, Shrigonda and Karjat Tehsils of the Ahmednagar District (Figure 2). The elevation in the sub-basin ranges from about 500 m to more than 1200 m.

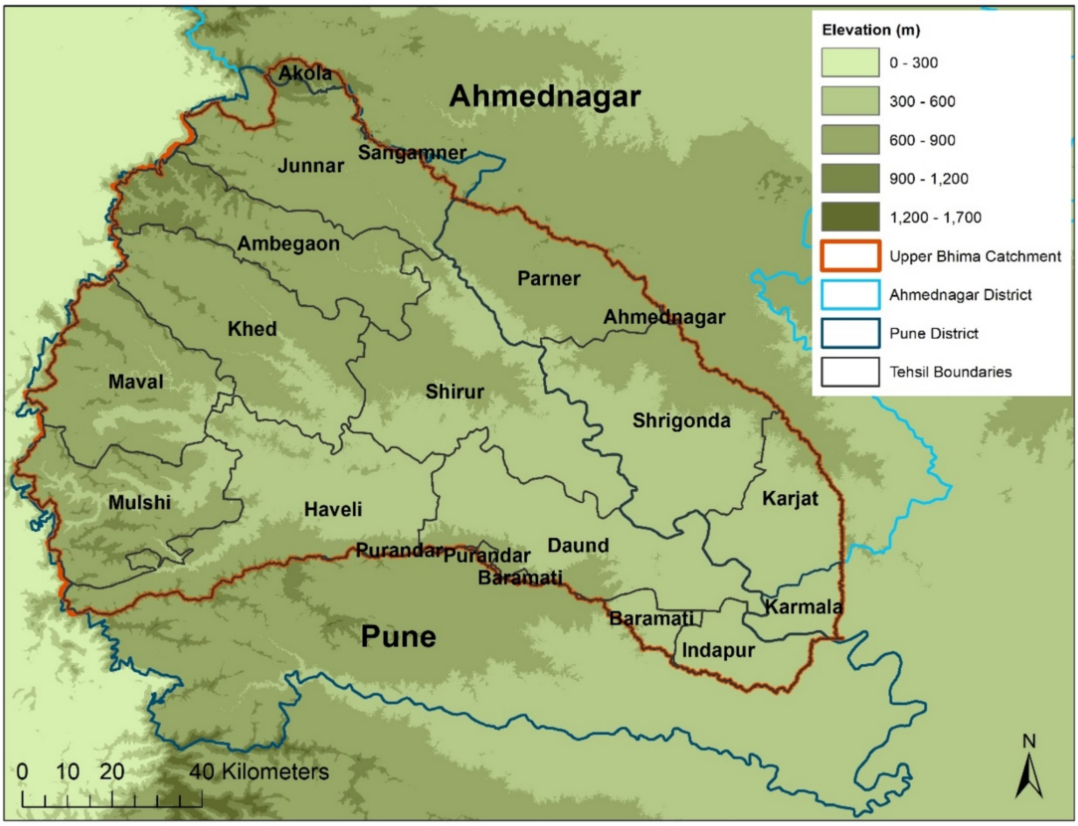

Figure 2: Administrative boundaries and topography in the study area. Source: Map prepared by SOPPECOM

Figure 3 describes important features in the study area. It covers a geographical area of 14858 sq. km and is bounded by the sub-basins of major tributaries of the Bhima such as Ghod, Indrayani, Pavana, Mula-Mutha, Bhama and Velu. Important projects/dams in the sub-basin are the Kukadi project (comprising Dimbhe, Manikdoh, Wadaj, Pimpalgao Joge and Yedgao), Ghod, Chaskaman, Bhama Askhed, Andhra, Khadakwasla-Panshet-Warasgao, Temghar, Pavana and Mulashi. The area harbours two protected areas, viz., Bhimashankar wildlife sanctuary and Tamhini wildlife sanctuary, both situated in the western part of the sub-basin. Pune city and the Pune Metropolitan region are almost centrally situated in the study area.

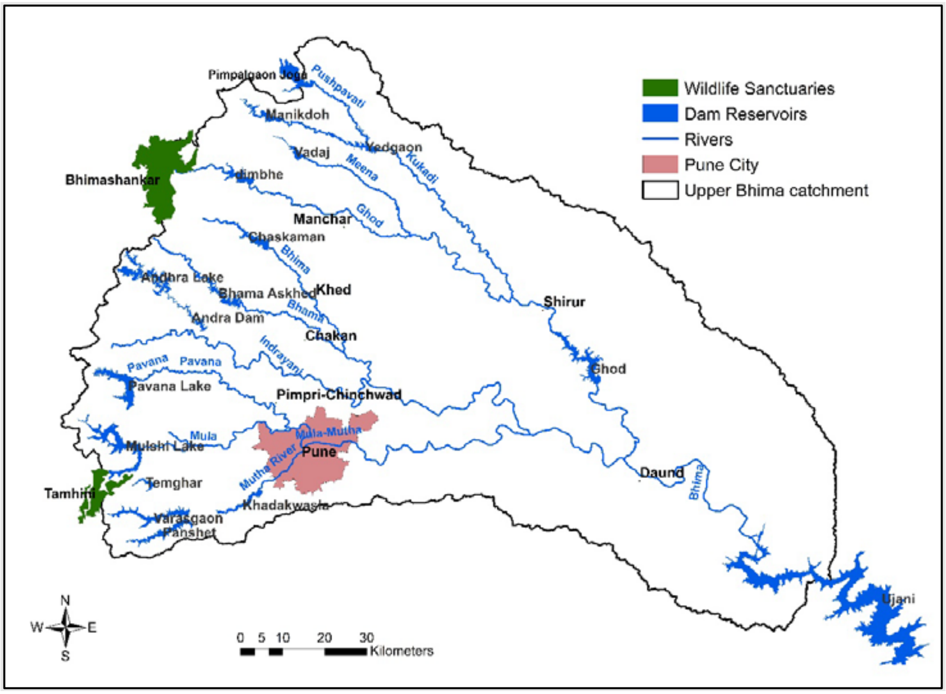

Figure 3:Important features in the Upper Bhima sub-basin. Source: Map prepared by SOPPECOM

Physiographically, the upper Bhima sub-basin can be divided into three distinct zones (CGWB, 2013). The western zone or the upper part of the sub-basin is the hilly area with rugged terrain that largely covers Junnar, Ambegaon, Khed, Maval and Mulshi Tehsils (elevation approximately 900 m and above). The middle section roughly extends for about 30 km east of the upper part, covering eastern parts of Ambegaon and Khed, Parner, Shirur and Haveli Tehsils and is marked by a series of small hills stretching into valleys and large spurs from plateaus (elevation 600–900 m). The eastern or the lower part of the sub-basin has rolling topography with low hills sinking slowly into plains and broader valleys (elevation 500–600 m). This part covers Daund, Shrigonda, Baramati and Indapur Tehsils in the study area (see Figure 2).

The soil type also varies for the upper, middle and lower parts of the sub-basin. Several feet of deep black soil is found in the lower part, i.e., Shirur, Daund, Baramati and Indapur. Brown soil—which is shallower and coarser than black soil—is found in the middle section, covering parts of Daund, Shirur, Shrigonda and Parner. Red soil is found in Junnar and Ambegaon and a small part of Khed in the upper part of the sub-basin. Clayey soil suitable for paddy is available in Maval, Mulshi, Bhor, Velhe and western parts of Khed, Ambegaon and Junnar.

The climate in the study area can generally be characterized as a hot tropical one. Rainfall is mostly received during the south-west monsoon from June to October. The sub-basin experiences high spatial variability in annual rainfall. The Western Ghats ranges receive more than 4000 mm/year of rain, and it decreases sharply down the Deccan plateau area to less than 500 mm/year. The lowest part of the sub-basin can be characterized as semi-arid or drought prone area.

2.2 Socio-economic context

As per the Census of India, the Pune district with almost 9.5 million population is the second most populated district in Maharashtra (Chandramouli & General, 2011). It is also one of the most urbanized districts, with 61% of its population residing in urban areas. Within the study area, the Pune Metropolitan Region (PMR)—which encompasses Pune city, and the surrounding metropolitan area (spread over 6,914 sq. km)—is the most densely populated area, with a population exceeding 7 million (Chandramouli & General, 2011). As per the draft development plan prepared by the PMR Development Authority (PMRDA) (2021) the population in the PMR in 2021 was projected to be 10 million.

Within the sub-basin under study, the hilly areas in the upper section support the highest tribal proportion of the population. In the Ambegaon, Junnar and Khed Tehsils, the proportion of Scheduled Tribes (ST) population is as high as 21%, 20% and 10% of the total population, respectively. In the middle and lower sections, the proportion of ST population varies from 1-4 % of the total population.

Outside the PMR, agriculture is the main occupation in the study area (Table 1). In the upper section (Ambegaon, Junnar) and the middle section (Shirur, Parner, Karjat and Shrigonda) the proportion of cultivators is higher. In the areas closer to the PMR (Khed, Maval and Mulshi) a higher proportion of the population is engaged in other income generation activities and has a lower dependence on agriculture. In the lower section of the sub-basin, the proportion of agriculture labourers is higher as compared to other areas.

Table 1: Percentage of working population under different occupations Source: Census of India (Chandramouli & General, 2011)

	Cultivators[1]	**Agriculture Labourer**[2]	**Household Industries**[3]	**Other Workers**[4]	**Marginal Workers**[5]
Ambegaon	62.1	18.8	1.3	17.8	7.8
Junnar	51.5	27.8	1.7	19.0	7.2
Khed	45.1	13.0	2.1	39.8	9.3
Mulshi	34.5	8.9	3.3	53.2	14.8
Maval	22.5	8.3	2.8	66.4	12.6
Shirur	55.7	14.5	1.5	28.3	4.9
Parner	65.9	18.8	1.6	13.6	5.7
Karjat	62.7	23.9	1.2	12.2	5.6
Shrigonda	59.3	25.2	1.5	14.0	5.8
Daund	44.4	24.5	1.9	29.2	9.0
Indapur	45.2	34.7	1.6	18.5	6.7

[1] A worker who is engaged in cultivation of land owned/held from the government or from private person(s) or an institution for payment in money, kind or share.
[2] Those who earn their primary income by working on other people's farms for a fee
[3] An industry conducted by one or more members of the family at home or within the village in rural areas and only within the precincts of the house where the household lives in urban areas.
[4] Other workers include factory workers.
[5] Those workers who had not worked for at least 183 days i.e., a major part of the reference period.

2.3 Land use and land cover

Figure 4 describes the main land cover features in the study area. This Global land cover classification conducted by European Space Agency (Zanaga et al., 2022) revealed that agriculture and grassland together constitute the largest proportion of land cover in the upper Bhima sub-basin (approximately 79%), followed by built-up area (11%) and tree cover (5%). An earlier study conducted by Samal and Gedam (2015) in the upper Bhima sub-basin also showed similar results. The forested area is largely confined to the hilly areas of the northern Western Ghats. Larger parcels of agricultural land are predominantly distributed towards the eastern part of the sub-basin on the plains of the Deccan plateau. The grasslands are mostly found on the hill slopes in the western part of the sub-basin, constituting the transition area from the more forested steep slopes on the west to the agricultural plains on the east. The surface water bodies constitute the dam reservoirs and are largely concentrated towards the western part of the sub-basin that experiences high rainfall.

The landscape has been changing continuously, and this has been more rapid in recent times due to various anthropogenic activities centered mostly in and around Pune city. Pune, one of the fastest growing cities in India, is the epicenter of urbanization in the sub-basin under study (Figure 3 and Figure 4). The built-up area is largely confined to the Pune urban agglomeration, which constitutes the Pune city and the Pimpri-Chinchwad town. The Pimpri-Chinchwad region is located north-west of Pune city. A significant increase in built-up areas has been observed from the 1990s to 2010, surrounding the city and in a linear pattern along major transportation networks such as national highways (Samal & Gedam, 2015). Pimpri-Chinchwad along with Chakan are the expanding industrial areas in the suburbs of Pune. Many industries, especially that of automobiles, have their headquarters in these areas.

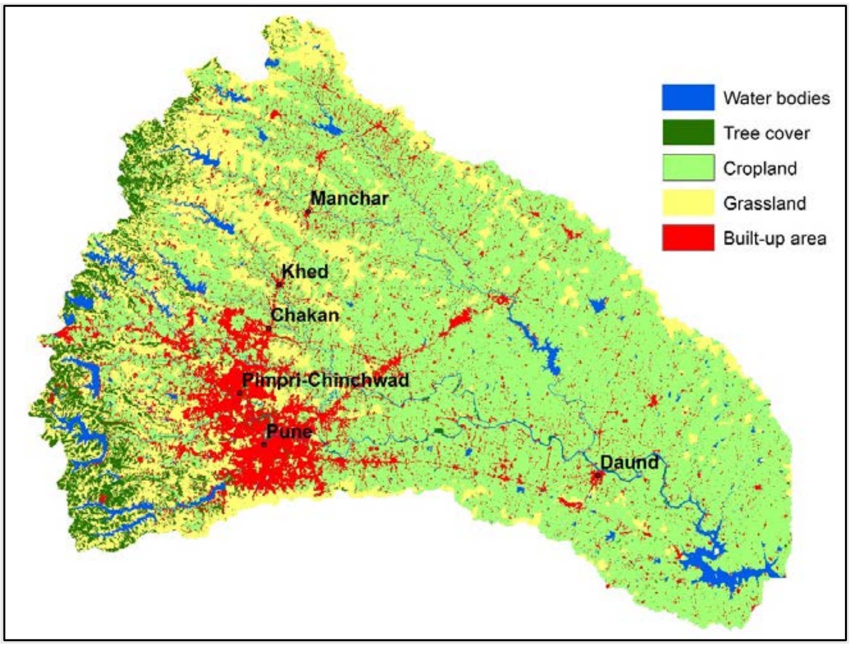

Figure 4: Land cover Map of the study area. Source: Zanaga et al. (2022)

Like many other cities in India, PMR is experiencing rapid economic growth, uncontrolled expansion of urbanization and population growth mainly due to migration (Butsch et al., 2017). This rapid urbanization has been influencing the natural resources and the overall ecology in the larger geographical area in the sub-basin (Samal & Gedam, 2012). For example, increase in built-up area and impervious paved surfaces has resulted in increased surface run-off and decreased infiltration which may lead to flash floods during heavy rains (Shukla et al., 2014a). Studies have also shown that the surface water quality is also negatively affected due to pollution from urbanization and industrialization (Shukla et al., 2014b).

Chapter 3 Water, Food and Biodiversity profiles

3.1 Water resources profile

3.1.1 Surface water resources

The Bhima along with its major tributaries, including Ghod, Mula-Mutha, Indrayani, Pavana, Kukadi and Bhama, originate in the hills in the west and flow towards the east. The Upper Bhima sub-basin is highly stressed in the context of water availability due to high intersectoral water demands, including agriculture, domestic, industrial and hydropower as well as interstate demands (Garg et al., 2012). The basin (K-5) serves a population of over 16 million, of which about 8 million resides in urban areas (Integrated State water plan, 2018). The upper sub-basin of Bhima, where the maximum rainfall is received, plays a very important role in fulfilling the water requirements across the basin. Here, the headwaters of Bhima are highly regulated with a number of major and medium reservoirs. Table 2 gives the salient features of important irrigation projects in the upper sub-basin of Bhima.

Table 2: Details of major projects in the Upper Bhima sub-basin. Source: Garg et al (2012)

Project	River	Purpose	Live Storage (Mm^3)	Gross Storage (Mm^3)	Installed capacity (MWH)
Ujjani	Bhima	Irrigation and hydropower	1518	3320	12
Ghod	Ghod	Irrigation	155	216	-
Chas Kaman	Bhima	Irrigation and hydropower	214	241	3
Bhama Askhed	Bhama	Irrigation and domestic	217	230	-
Panshet	Ambi	Irrigation and domestic	301	310	-
Warasgaon	Mose	Irrigation and domestic	363	375	-
Khadakwasla	Mutha	Irrigation, domestic and hydropower	56	86	8
Pavana	Pavana	Irrigation and hydropower	274	318	10
Dimbhe	Ghod	Irrigation and hydropower	355	382	5
Manikdoh	Kukadi	Irrigation and hydropower	288	308	6
Vadaj	Meena	Irrigation	33	36	-
Yedgaon	Kukadi	Irrigation	79	93	-
Pimpalgaon Joge	Pushpavati	Irrigation	110	235	-
Mulshi	Mula	Hydropower	523	554	150
Tata Lakes		Hydropower	265	274	72
Andhra	Indrayani	Hydropower	353	353	72

Water is received by the reservoirs largely during the monsoon (85% of the rainfall is received during June–October). The stored water is utilized for mainly three water uses—domestic, agriculture and industrial—throughout the year, depending on the water availability.

The downstream water availability primarily depends on the release of water from the upstream reservoirs. The reservoirs are operated in an integrated manner to serve both flood control as well as water storage. The projects in the basin were planned and designed with the primary objective of providing water for irrigation for dry season crops and for dryland agriculture. However, the water resources in the basin remained under stress due to changing sectoral and intersectoral water demands. The shift in cropping pattern towards more water intensive crops, increased urbanization and industrialization are the primary drivers of changing demands (Garg et al., 2012).

3.1.2 Groundwater resources

The geology of the Upper Bhima is almost entirely of Deccan Volcanic Traps. The basalts possess very little porosity and the groundwater resource potential is controlled by the degree of weathering, geomorphological and geological features (Kulkarni et al., 2000). In basalt, the groundwater generally occurs under unconfined to semi-confined conditions. Alluvium and Basalt aquifers are the main aquifers found in Pune district. Groundwater is generally extracted from dug wells that have a large diameter or from bore wells with narrow diameter. The Shallow Aquifer (alluvium) is generally tapped by dug wells of 9 to 30 m depth, have water levels ranging from 2.1 to 25.0 m below ground level (bgl) and the yield varies from 10 to 100 m3/day. The deeper Aquifer tapped by borewells has depth ranging from 50 to 180 m bgl and the water level from 6 to 45 m bgl (CGWB, 2018). The water table varies from 480 m above mean sea level (amsl) in the south-eastern part of the study area to about 700 m amsl in the north-west.

The three sections of the Upper Bhima sub-basin roughly divided based on the topography, vary in their suitability for groundwater potential. In the hilly areas in the sub-basin, there is heavy run-off and poor infiltration due to steep slopes and thin soil cover. The foothills also exhibit high run-off and less infiltration and are moderately favourable areas for groundwater development. The plateaus are not much suitable for groundwater resources either, due to heavy seepage losses. The valleys and plains of the river basins are the most suitable areas for high groundwater potential. They show higher rates of infiltration, a thick layer of soil and lower run-off.

The net groundwater availability in the Upper Bhima basin is 3440 MCM. The district wise groundwater availability in the Upper Bhima basin is summarized in Table 3.

Table 3: District-wise groundwater availability. Source: Integrated State Water Plan (2018)

District	Groundwater availability	Utilizable groundwater (MCM) 70% of the availability	Groundwater use (MCM)
Pune	1720	1192	1287
Ahmednagar	639	426	441
Solapur	1421	1092	1136
Osmanabad	283	177	181
Beed	175	88	96
Satara	392	278	291
Sangli	276	187	193
Total	**4906**	**3440**	**3627**

The groundwater use in the basin exceeds the utilizable quantum and hence there is no scope for future development of groundwater in the basin (ISWP, 2018).

3.1.3 The Krishna Water Dispute Tribunal

The Upper Bhima basin is a sub-basin of the larger Krishna basin which is an interstate river. The Krishna basin is shared by the states of Maharashtra, Karnataka, Telangana and Andhra Pradesh. As per the Constitution of India, water is primarily a state subject. However, in the case of the interstate rivers, the Centre can intervene if there is an interstate water conflict amongst the co-basin states. The Centre can appoint a Tribunal under the Interstate Water disputes Act 1956.

The Krishna Water Dispute Tribunal I (KWDT-I) was first set up for the conflicting states of Maharashtra, Karnataka and the undivided state of Andhra Pradesh (now Telangana and Andhra Pradesh) in 1969. According to the tribunal award given in 1975, the total surface water availability in the Krishna basin for allocation to different states was assessed at 75% dependability[6] and was around 58,298 MCM. This total quantum of available surface water was apportioned amongst the three conflicting states.

The KWDT-I provided a review for its award in the year 2000 to determine the allocation of the unutilized water. However, no review was taken up for more than three years and in 2004, the Krishna Water Dispute Tribunal II (KWDT-II) was set up, based on the requests of all the three states. In the tribunal verdict, passed in 2013, KWDT- II ordered that during the years of surplus water (years when the rainfall is higher than the average), it should be apportioned equitably amongst the basin states. According to Clause V and VI of the Tribunal order,

[6] Dependability which is generally used mostly as either dependable flow or dependable yield is the flow or amount of surface/ groundwater that is available continuously at a particular point (reservoir/ discharge point etc. For example, 75% dependable flow means that out of 100 years, one can observe this particular flow for 75% of years. Higher dependable flows means that there would be lower flow/yield but for more number of years and lower dependable flow means there would be more yield/flow but for lesser number of years (for example 65% and 50% dependable flows)

these surpluses were determined for the entire Krishna basin as 4613 MCM at 65% dependability and 8066 MCM (average flows) respectively (ISWP, 2018). Therefore, according to the verdict, the total allocation to the state of Maharashtra is as summarized in Table 4 below:

Table 4: Allocation of the surface water to Maharashtra (in Million Cubic Meters, MCM) as per KWDT award I & II Source: Krishna Water Dispute Tribunal (2010)

Allocation at 75% dependability (based on KWDT-I order)	16567
Allocation of the excess water as assessed at 65% dependability (based on the KWDT-II order)	1218
Allocation of surplus flows (assessed at average flows)	991
Total	18776
Minimum flows to the be maintained in the river	85
Total available for use	18691

Thus, the KWDT-II award has implications in terms of planning and management of all the water resources that fall within the Krishna basin in the state of Maharashtra, including the Upper Bhima basin. The total water availability assessed in the Upper Bhima basin (K-5), as derived from the KWDT-II order, is summarized in Table 5.

Table 5: Utilizable water in the Upper Bhima Basin (K-5) as per KWDT-II (in Million Cubic Meters (MCM). Source: ISWP (2018)

Water Source	Average	65% dependability	75% dependability
Surface water	11439	10686	9484
Groundwater	3440	3440	3440
Total water availability	**14879**	**14126**	**12924**

The study area or the sub-basin of interest is only the part of the Upper Bhima basin up to the Ujjani dam, hence a rough water balance estimate has been attempted for the particular sub-basin of interest (Table 6). The assumptions made for deriving the water balance are as follows:

a) *Domestic water use:* the exact population within the sub-basin (hydrological boundary) is not available. Since the Pune district occupies the majority of the sub-basin and the urban section uses the largest amount of water for domestic purpose, for the estimation of the domestic water use, the figure of the total population of Pune district has been used. The per capita water consumption, irrespective of rural or urban population has been assumed as 100 lpcd (liters per capita per day).

b) *Industrial water use:* The industrial water use has been kept at the same value as the mentioned in the Integrated State Water Plan (ISWP, 2018) report at 279 MCM. The rationale for this is that there is no exact water use data available for the industries within the study area and it would not make a significant difference to the overall water balance even if the industrial water use in the entire Upper Bhima basin were to be considered.

c) The total agriculture water use in the basin is 11942 MCM (from both surface and groundwater) (ISWP, 2018). The total irrigated area in the basin is 1273810 ha. Therefore, the total applied water use per hectare is 9375 m3/ha. The total irrigated area in the sub-basin (study area) is 212,172 ha. Therefore, the total irrigation water use has been estimated to be 1989 MCM. The estimated water balance for the study area is summarized in Table 6.

Table 6: Estimated water balance for the study area (in Million Cubic Meters (MCM). Source: ISWP (2018)

	Study Area (estimated)		
Available Water			
Source	**Average**	**65% dependability**	**75% dependability**
Surface water	7349	6616	5424
Groundwater	1400	1400	1400
Total water availability	**8749**	**8016**	**6824**
Total storage capacity available for various uses	**3800**		
Water Use			
Domestic	346	346	346
Industrial	279	279	279
Agriculture	1989	1989	1989
Evaporation	260	260	260
Total water use	**2874**	**2874**	**2874**
Surplus/ deficit	**5875**	**5142**	**3950**

From the above table, the present water use in the sub-basin is less compared to what is available. Though on an aggregate basis, it appears that there is surplus water available, there is not much utilization in the upper reaches of the sub-basin. Most of the water use that takes place is mostly downstream. The total water storage capacity created in the sub-basin to date is around 3800 MCM. In comparison to this, the storage capacity of Ujjani dam itself is 3320 MCM. About 40–50% of the flows available in the sub-basin are getting stored in the Ujjani dam.

Here, it is important to note that the water from the Ujjani dam is largely used to irrigate sugarcane in the downstream district of Solapur. According to experts like Prof. Pradeep Purandare, though sugarcane occupies only 4% of the gross cropped area, it requires 100% irrigation and its share in the gross irrigated area is as high as 23%. Also, according to Dandekar and Thakkar (2013), the total irrigated are under sugarcane in Solapur district in 2013 was 1,55,684 ha. The amount of water required to irrigate the sugarcane alone in this area is around 2630 MCM. So, around 30–40% of the total water available is used for catering to the needs of just one crop.

This raises concerns in terms of equity and fairness, especially when it comes to the use of water across the different sections of the sub-basin. Clearly, there is far more irrigation development in the downstream reaches of the sub-basin. The upper watersheds of the Bhima basin especially in the hilly regions of Junnar, Ambegaon and Khed talukas are largely rainfed. Most of the water use for irrigation is downstream of the Dimbhe dam on the Ghod river.

Photo Dimbhe dam reservoir. Credit: Barbara Willaarts

Irrigation canal in Dimbhe command area. Credit: Barbara Willaarts

3.2 Agricultural profile

In the Upper Bhima sub-basin, agriculture constitutes about 70% of the land use. The cropping systems in the sub-basin are mostly governed by rainfall, soil type and availability of water. The variation in rainfall from west to east (upper to lower catchment) is a prominent environmental gradient in the sub-basin. Table 7 provides decadal averages of annual rainfall received by different sections of the sub-basin.

Table 7: Decadal average annual rainfall in mm (2007-2017). Source: CGWB (2018)

Upper section	Middle section	Lower section
Maval (1760.51)	Pune City (788.02)	Daund (450.38)
Mulshi (1835.01)	Haveli (667.92)	Indapur (505.43)
Junnar (887.49)	Shirur (537.52)	
Ambegaon (774.51)	Khed (748.58)	

There are two main cropping seasons in the sub-basin viz. Kharif (monsoon or June–October) and Rabi (post-monsoon or November–March). The three main types of cropping systems observed in the basin are: rainfed agriculture, in which crops are grown only using rain water in the monsoon (no irrigation); irrigated short duration crops (100–120 days), with full or partial irrigation; long duration irrigated crops (two-seasonal or perennial). The spatial distribution of important crops and cropping systems in the Upper Bhima sub-basin is as follows:

1. Upper section – Although this western part of the sub-basin receives high rainfall, the physiographic conditions are not suitable for water storage and groundwater recharge. This is the upstream catchment of all major reservoirs. As a result, water from the existing irrigation projects is also not available. The cropping pattern here is mostly rainfed. The clayey soils are suitable for paddy, which is the most important Kharif crop in this region. Post-monsoon, there is only limited opportunity for a second crop of the year, depending on the level of moisture retained in the soil. These crops include chickpea, wheat, finger millet, little millet, etc.
2. Middle section – This is the richest part of the sub-basin in terms of availability of surface water as well as groundwater. Most of the middle section falls within the command area (the area around the dam/project, where the area gets benefits from the dam, mainly irrigation water) of the irrigation projects. Evidently, a variety of irrigated crops are cultivated in this area. One of the most important water intensive crops in the region is sugarcane. The region is also known for its vegetable cultivation. A large portion of the vegetable supply to Pune and Mumbai comes from this region. A variety of vegetables are cultivated in the post-monsoon season. Black soil several feet deep, found in Khed, Shirur and Daund, is suitable for Rabi crops such as wheat, jowar and legumes.
3. Lower section – This is the most dry, semi-arid section of the sub-basin with low rainfall. Also, these are the tail-end areas of most of the irrigation canals of existing projects. Consequently, rainfed

agriculture or partially irrigated crops are cultivated wherever groundwater is available. The most important crops include wheat, jowar, bajra, maize, groundnut, etc.

In the larger Upper Bhima sub-basin, the area under cereals is 47%, oil seeds contribute 14%, sugarcane 20% and pulses are grown in 15% of the area. Important fruit crops in the sub-basin include mango, guava, custard apple and pomegranate. Despite water scarcity (especially during the summer in the drier parts) in this region, a substantial area is under sugarcane cultivation which is a water intensive crop. As sugarcane cultivation is expanding, this is impacting the availability of water resources due to increased irrigation pressure. The Upper Bhima Basin has shown a substantial increase in irrigation water use for sugarcane and a marginal increase for other crops (Udmale et al., 2014).

3.3 Biodiversity profile

The head waters of the Bhima originate in the Western Ghats (WGs), one of the 34 Global Biodiversity Hotspots (Myers et al., 2000). The area is not only extraordinarily rich in biodiversity, but also supports the livelihoods of millions of people (approx. 245 million) residing in peninsular India, as most of the rivers supplying water to this region originate in the WG. The WG, in spite of covering less than 6% of the geographical area of India, harbour more than 30% of all plant, fish, herpetofauna, bird, and mammal species found in India (Bawa et al., 2007). The region is also home to charismatic large mammal species, such as the Indian Tiger and the Indian Elephant. Several areas within the WG with high biodiversity and conservation values have been protected and conserved as wildlife sanctuaries, tiger reserves, and national parks.
Pertaining to the physiographic and climatic gradient from west to east in the Upper Bhima sub-basin, the ecosystems and the biodiversity also varies significantly as one moves from the upper section to the lower section.

1. The upper section of the sub-basin is situated in the northern WG. It is an eco-region known for its species diversity, species endemism and unique habitats such as lateritic plateaus and rock outcrops. The hilly area in the upper section harbours tropical moist broadleaf forests. This is the most biodiversity rich area in the sub-basin. The forested areas at higher elevations have been protected under the Bhimashankar Wildlife Sanctuary, originally to protect the natural habitat of an endemic species, the Indian Giant Squirrel. The reserve also has a significant religious importance owing to the Bhimashankar Temple near the origin of Bhima, which attracts millions of pilgrims from all over the country, especially during the monsoon season. The forests are also rich in medicinal and wild edible plants, supporting traditional livelihoods of many local communities. Another wildlife sanctuary supported by the sub-basin is the Tamhini wildlife sanctuary towards its southwest boundary (see Fig. 2). These areas also harbour a large number of sacred groves. Sacred groves are patches of forests traditionally protected by local communities for their religious or cultural significance. Sacred groves are dedicated to particular deities. The protection of these groves and restrictions on resource extraction from the grove are all managed by the local communities. The basalt plateaus (e.g.,

the plateaus near the Ahupe and Nane Ghat) are unique non-forested habitats that support a variety of endemic smaller taxa e.g., *Cyathocline lutea* and *Nanothamnus sericeus.* In addition to their diverse flora and fauna, these areas also provide diverse Non-timber Forest Produce (NTFP) providing livelihood support for many tribal communities residing in these areas. Some of the important NTFPs include medicinal plants, notably seeds of *Terminalia chebula* (locally known as *Hirda*), honey, fuelwood and fodder. For some traditional practices such as *Rab* for growing rice seedlings, people depend on vegetation in the surrounding forested areas. In Rab, locally available biomass in the form of leaf litter, twigs, etc., is burnt on the farm in order to control weeds, eradicate diseases and to increase the vigour of seedlings. Collection of *Hirda* seeds is an important income generating activity for tribals in this sub-basin, especially during April–May for the young seeds, and November–December for older, fallen seeds. With limited agriculture and livelihood opportunities in these hilly regions, natural resources provide significant support for subsistence. In particular, Hirda seeds are a crucial source of income in the absence of a second crop, which is the case for most of this part of the Upper Bhima basin (as noted earlier).

The rivers also support a rich variety of fish species. As the Bhima and its tributaries continue to flow downstream to the base of the mountains, where valleys become wider and slopes are gentler, most of the rivers have been obstructed by major and minor dam projects. These dams have disrupted the ecological connectivity of aquatic species to a great extent (Kumar & Jayakumar, 2020). Yet, in addition to storage of surface water, the reservoirs also support a variety of fish which are fished by local populations. However, except for a few scanty studies from the upper Bhima sub-basin (Pawara Ravindra et al., 2014; Wagh & Ghate, 2003; Yazdani & Singh, 2002), detailed quantitative studies on freshwater biodiversity of this sub-basin are sorely missing.

2. The middle section is mostly agriculture dominated landscape. Agrobiodiversity surrounding the agricultural fields largely contributes to the overall biodiversity of the area. The non-cultivable areas supporting grasslands or shrublands also support different flora and fauna compared to the forested areas.
3. The lower section is also an agriculture dominated landscape. However, these areas also support dry, non-forested open natural ecosystems, often neglected as ‘wastelands’ (Madhusudan & Vanak, 2022). They are home to a variety of typical non-forested habitats including grasslands. These are important ecosystems for several habitat specific species such as wolves, blackbuck antelopes and other wild mammalian herbivores and carnivores as well as diverse floral species. These large carnivore populations are thought to play an important role in controlling herbivore populations that can otherwise raid crops. They also support the livelihoods of nomadic pastoralists and their livestock. Due to negligence and lack of knowledge about the role of these ecosystems, their conservation has been severely compromised. They continue to undergo changes and land conversions due to anthropogenic activities.

Sacred Grove near Aghane village

Forest and farmland ecosystems in the study area

Hirda (*Terminalia chebula*) tree

Credit: Bárbara Willaarts

3.4 Governance

Figure 5 describes the institutional framework in the context of governance and management of water, agriculture and biodiversity. The institutions function in a hierarchical manner, from the national to the local level. India being a federal country, jurisdictions of the centre and states are clearly defined in the Constitution or through subsequent constitutional amendments. As mentioned earlier, water is primarily a state subject except in the case of sharing of interstate rivers. Also, it is to be noted that water pollution is covered by the central act as many of the states agreed to this legislation. Agriculture is also a state subject. State subject means that the states can formulate policies and laws on that subject. Forest (proxy for biodiversity here) is under the concurrent list, meaning both the national and states can have jurisdictions. Though water and agriculture are under the state list, the centre does enact policies on them that can guide policy making by the states. Similarly, various ministries and departments/boards in the sectors of water, agriculture and forests at the national level are the apex bodies that formulate as well as administer rules and regulations in the respective sectors. Some see this as an effort to centralize governance.

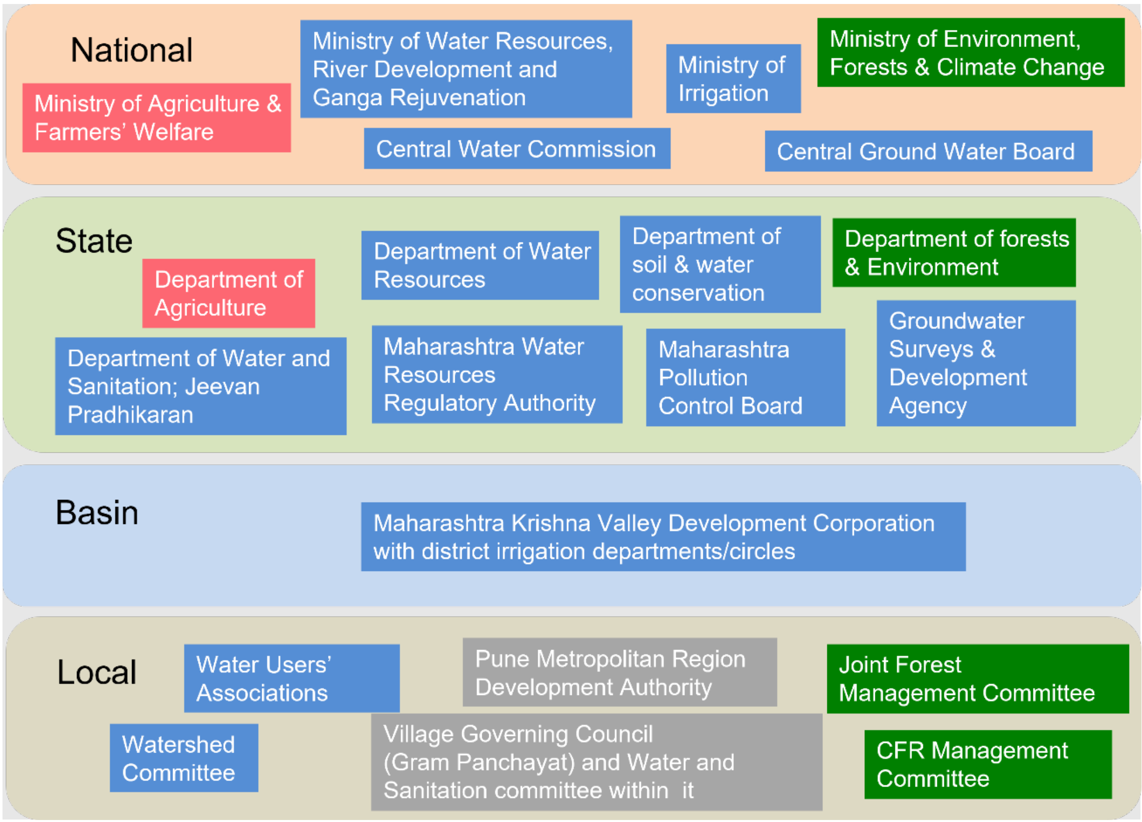

Figure 5: Upper Bhima basin Food-Water-Biodiversity governance organogram. (Blue- water sector, green – forest, red – agriculture, grey – General administration). Source: own elaboration

Within the state, various departments work as the regulatory and governing bodies. For example, the Department of Agriculture, Maharashtra is the authority for the formulation and implementation of policies and programmes aimed at achieving rapid agricultural growth through optimum utilization of land, water, soil and plant resources of the state. It also works towards the economics upliftment of the farming community through the implementation of beneficiary-oriented farming schemes. Similarly, the Maharashtra Forest Department is the governing body to manage, conserve and protect forest and wildlife resources in the state through afforestation and regeneration of degraded forest lands, forest protection as well as socio-economic upliftment of people in the forest fringe areas and sustainable management of forests and wildlife.

Within the water sector[7], there are many state institutions that perform specific functions to govern, manage and regulate the water resources within the state. The Maharashtra Water Resources Regulatory Authority (MWRRA), the first independent regulator in the water sector in the country, was set up to regulate water resources within the state of Maharashtra, facilitate and ensure judicious, equitable and sustainable management, allocation and utilisation of water resources, fix the rates for use of water for agriculture, industrial, drinking and other purposes ...' (GoM 2005; Joy and Kulkarni, 2010).[8] The Water Resources Department (WRD), Maharashtra is responsible for the management related to irrigation, flood control works, water management in rivers, dams, and reservoirs. In the case of groundwater management, the Groundwater Survey and Development Agency (GSDA) and MWRRA function as the state's groundwater authority. The role of GSDA is to develop and disseminate technologies, monitor and implement national and state policies for the scientific and sustainable development and management of groundwater resources. The state authority ensures protection of recharge areas, takes action against groundwater polluters, monitors compulsory registration of rig owners who operate in the state, regulates drilling of deep bore wells by issuing specific permissions, etc. The Maharashtra Industrial Development Corporation (MIDC) is the regulatory authority for water supply and drainage facilities to and around industrial areas. The Maharashtra Pollution Control Board (MPCB) implements various environmental legislations related to water quality. The MPCB functions under the administrative control of the Environment Department of the Government of Maharashtra.

Many national and state water policies mention river basin as an ideal unit for comprehensive planning and management and also highlight the need to set up River Basin Organizations/Agencies (RBO/As). However, there is not a single RBO in the country yet. In early 2000, Maharashtra constituted five irrigation development corporations for the different river basins primarily with the intention of borrowing money from the public through the issuance of bonds to implement various irrigation projects in the basins. One such corporation is the Maharashtra Krishna Valley Development Corporation (MKVDC), and the Upper Bhima sub-basin falls under its jurisdiction, being responsible for the planning and development of surface water schemes within the Krishna valley in Maharashtra[9].

Later, MKVDC was converted to an RBA mainly because there was a condition in the World Bank loan agreement for the Maharashtra Water Sector Improvement Project (MWSIP) in 2015 'to restructure the existing Maharashtra Krishna Valley Development Corporation (MKVDC) into the Maharashtra Krishna Valley Water Resources Corporation (MKVWRC) as a river basin agency' (IEG – ICR Review 2015)

At the local scale, the village governing bodies (Gram Panchayat) in rural areas and the municipal corporations in urban areas are the primary governing bodies that undertake diverse roles including the regulation and

[7] For a review of the water sector in Maharashtra, including the institutions involved, see Joy and Kulkarni (2010).
[8] The role of MWRRA to allocate water across different uses has been taken away from it and has been vested with the state cabinet through a subsequent amendment (in 2011).
[9] https://www.lawinsider.com/dictionary/maharashtra-krishna-valley-development-corporation

management related to agriculture, water and biodiversity. The Joint Forest Management Committee (JFMC)[10] and the Community Forest Rights Management Committee (CFRMC)[11] are the local institutions that manage forest resources at the village level. The Water Users' Associations (WUAs) formed in the command areas of public irrigation systems are responsible for the distribution of irrigation water, management and maintenance of irrigational canals, collection of water tariffs, resolution of water-related disputes among users, etc. The Village Watershed Committee (VWC) looks after activities related to micro-watershed development and the village water and sanitation committee, functioning under the village gram panchayat, manages the domestic water and sanitation in the village.

In the context of the institutional architecture around natural resource management in India, three issues stand out:

1) There is institutional fragmentation, and this is more pronounced in the case of water. There are different institutions to deal with different aspects of water and there is very little coordination amongst them. For example, the institutions that deal with surface water is different from the ones that deal with groundwater. This is mainly because surface water and groundwater are seen in silos (Committee on Restructuring the CWC and CGWB 2016).
2) The institutions are hierarchical and top down, with very little downward accountability by the supra-local institutions to the local ones (Joy and Paranjape, 2004).
3) There are many institutions at the macro scale (national and state) as well as at the micro level (village or micro watershed scale). However, there is an institutional vacuum at the meso scale such as sub-basins and basins where most of the allocational and management issues are played out. This is also confirmed by an earlier study of Tungabhadra basin (Nesheim et al., 2010).

[10] Joint Forest Management (JFM) is an approach and programme initiated in the context of the National Forest Policy of 1988 wherein state forest departments support local forest dwellings and forest fringe communities to protect and manage forests and share the costs and benefits from the forests with them. Communities organize themselves into a JFM Committee to protect and manage nearby forests, guided by locally prepared byelaws and micro plans.

[11] The Forest Rights Act (FRA), 2006 recognizes the rights of the forest dwelling tribal communities and other traditional forest dwellers to forest resources, on which these communities were dependent for a variety of needs, including livelihood, habitation and other socio-cultural needs.

Chapter 4 Water-Food-Biodiversity Nexus Challenges

This section describes the main nexus challenges that we have identified through the different stakeholder consultations and expert interviews. These include five interviews on food, water and biodiversity with experts having extensive knowledge on the Bhima basin. Likewise, we conducted several focus group discussions and interviews (including those with groups of farmers, both men and women, in the catchment and command areas of the Dimbhe dam in the Ghod sub-basin) during six field trips (May 2022 to January 2023). This assessment also reflects the perceptions of the stakeholders participating in a workshop held in January 2023 that was attended by researchers, civil society representatives, government officials and community members. Based on the stakeholder engagements, interviews with experts and the understanding gained during the field visits, some of the current challenges pertaining to the normative goals of equity, fairness and sustainability within the water-food-biodiversity nexus have been identified and will be discussed in this section.

Table 8 summarizes the challenges, their spatial relevance within the sub-basin and their nexus linkages. It was observed that the communities residing in the forest fringe areas in the upper section of the sub-basin, being closely associated with biodiversity-based livelihoods are evidently more vulnerable to the implications of the nexus between biodiversity-food and biodiversity-water. The upper section and the lower section of the sub-basin are mostly at the receiving end of the inequities related to water allocation and consumption. In the subsequent sections, we will describe the nexus challenges in detail.

Photos: Stakeholder workshop: Identification and mapping of challenges. Credit ISSER Pune

Photo: Engagement with a group of women at village Falode in Ambegaon

Photo: Collection of Hirda (*Terminalia chebula*) and other medicinal plants by tribals in the study area

Table 8 Nexus challenges pertaining to water, food and biodiversity in upper Bhima sub-basin

<table>
<tr><th>Challenge</th><th>WFB Nexus</th><th>Normative goals</th><th>Upper section</th><th>Middle section</th><th>Lower section</th><th>Urban</th></tr>
<tr><td>Livelihood security: Human-wildlife conflict</td><td>FB</td><td>Sustainability</td><td>Crop raiding by langur, wild boar in the upper section significantly affects agricultural yield and is also leading to changes in cropping pattern.
Leopard attacks on livestock and even on humans have also been reported, leading to loss of lives.</td><td></td><td>Crop damage by ungulates like sambar and spotted deer</td><td></td></tr>
<tr><td>Livelihood security: Hirda collection and selling</td><td>B</td><td>Sustainability
Fairness</td><td>Hirda collection and selling: Unfair market prices leads to uncertainty and inadequate monetary benefits to the local communities. Lack of knowledge about the sustainability of the NTFP harvest may lead to complete failure of this important livelihood practice in future.</td><td></td><td></td><td></td></tr>
<tr><td>Livelihood security: Fishing practices</td><td>WFB</td><td>Sustainability
Equity</td><td colspan="2">Building of dams and barrages obstructing the natural flows of rivers affects native fish diversity and populations, thereby impacting fishing practices of local communities.
Lack of regulatory mechanism on leasing out the fishing contracts often results in limited opportunity for local fishers or groups of fishers. Financially and politically dominant parties, sometimes even outsiders, bag the contract.</td><td></td><td></td></tr>
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<table>
<tr><th>Challenge</th><th>WFB Nexus</th><th>Normative goals</th><th>Upper section</th><th>Middle section</th><th>Lower section</th><th>Urban</th></tr>
<tr><td>Insufficiency of water for irrigation</td><td>WF</td><td>Equity
Fairness</td><td>Although a high rainfall area, the unfavorable topography presents limited water storage opportunities. As a result, only rainfed subsistence agriculture is practiced in this area</td><td></td><td>Being at the tail-end, users in the command area receive hardly any water from the canal irrigation project reaches in these areas. Even the sanctioned amount of water is not received as a large amount of water is utilized by the farmers in the middle section of the sub-basin.</td><td></td></tr>
<tr><td>Groundwater over abstraction</td><td>WF</td><td>Equity
Sustainability</td><td></td><td>Farmers in the middle section of the sub-basin have been overexploiting the groundwater resources for irrigation purposes.</td><td></td><td>Due to lack of infrastructure for the supply of water, the population in the peri-urban areas and industries depends excessively on groundwater for their requirements.</td></tr>
<tr><td>Land cover change</td><td>WFB</td><td>Sustainability
Fairness</td><td></td><td colspan="2">Rapid land cover changes in the past few decades have resulted in loss of forest cover and biodiversity, affected hydrological processes such as surface run-off, groundwater recharge, base flows and water availability in general.</td><td>Increase in built-up area and impervious paved surfaces results in increased surface run-off and decreased infiltration, which may lead to flash floods during heavy rains.</td></tr>
<tr><td>Changing cropping pattern</td><td>WF</td><td>Sustainability
Equity</td><td></td><td>Increasing cultivation of water intensive crops such as sugarcane puts extreme pressure on the surface and groundwater resources.</td><td></td><td></td></tr>
<tr><td>Diversion of water for non-agriculture use</td><td>WF</td><td>Fairness</td><td colspan="3">Diversion of water from irrigation to fulfil the requirements of growing urban population and of industries lead to conflicts over water allocations.</td><td></td></tr>
</table>

Challenge	WFB Nexus	Normative goals	Upper section	Middle section	Lower section	Urban
Loss of biodiversity	WB	Sustainability Fairness	Construction of dams has led to submergence of land, including forest land, and thereby loss of terrestrial biodiversity. Structural interventions like dams, barrages, weirs, etc. impede the natural flow of the rivers thus impacting the freshwater ecosystems. It may negatively affect fish diversity and fish community structure.			Due to encroachments around water bodies in Pune, the urban wetlands are increasingly facing anthropogenic pressures, threatening aquatic biodiversity.

4.1 Issues and challenges related to livelihoods of communities in the upper Bhima sub-basin

I) Human-wildlife conflict

Forests and biodiversity in the upper reaches of the Western Ghats have traditionally been protected by the local communities as well as formally by the state through a legal and policy structure governed by the state's forest department. These forests are a treasure trove of biodiversity and also play a critical role in achieving the sustainable development goals. Communities residing in the close proximity of these forests have been co-existing with the local biodiversity. Although it is ecologically and economically important to conserve biodiversity, the livelihoods of the local communities are also impacted by the wildlife with which they share ecological space. Our interactions with the stakeholders in the upper section of the sub-basin revealed that a recent increase in herbivore population in the wild has led to increased crop raids, mainly by wild boars, gray langurs and rarely by Gaurs (Indian bison). It was reported in one of the group discussions that about 10% of the crops are lost due to these raids. Changes in wildlife populations are also a likely cause for human-wildlife conflicts. For example, the recent decrease in carnivore (e.g., leopards and tigers) population is thought to have resulted in increased herbivore populations, which has, in turn, led to increased crop raids. Gray langurs and wild boars are among the most cited species responsible for raiding crops, in particular, finger millet. Finger millet used to be a very popular crop, yet its popularity among langurs has resulted in farmers either changing crops to avoid crop raids or giving up Rabi farming altogether. Increased leopard attacks on humans and livestock resulting in loss of lives is another key concern raised by the villagers. Women have observed leopards becoming less fearful of entering villages, which has led to the danger of facing attacks during fuelwood collection.

The main strategy employed to manage these conflicts is to simply watch crops, sometimes building structures to sleep on fields to watch them and deter wildlife. While farmers can get some meagre compensations for raided crops, the process for the same is lengthy and complex. Also, to avoid deliberations with the forest department about encroachment on the forest land, most of the crop raids are never reported by the villagers. As a preventive measure from leopard attacks, the forest department instructs people not to venture into the wild for NTFP collection or for grazing livestock. This in turn affects the livelihoods of local communities.

Normative goals: Sustainability, Equity and Fairness

The human-wildlife conflict is one of the critical sustainability challenges viz., protecting life on land and eliminating poverty and hunger (Braczkowski et al., 2023). Loss of livestock and changing crop pattern induced by wildlife attack have grave effects on food security, nutrition and health. Moreover, the losses place increased costs on the low-income rural communities residing in the forest fringes. Although protection of forests is a desirable outcome in the light of global climate change, the costs are heavily and unequally borne by the marginal communities.

II) Hirda (and other NTFP) collection

Non-timber forest products (NTFP) are a vital source of income and livelihood for the Basin's rural populations, especially in the upper section. Some of these NFTPs are direct or indirect food sources, such as wild edible plants, medicinal plants, wild honey, etc. One of the most economically relevant NTFP in the region is the seeds of Hirda trees (*Terminalia chebula),* a medicinal plant most commonly found in the north-western tip of the Basin. Hirda plays a vital role in sustaining local populations. It fetches a good price from the pharmaceutical companies as it is used in many Ayurvedic medicines. The Hirda seeds are collected by men and women in the households in two seasons per year. The premature seeds are harvested from the trees around the month of May and can fetch a price as high as Rs. 180–200/kg. The fallen, matured seeds are collected during October–November, which are sold, however, at a much lower price (Rs. 15–20/kg). It is one of primary source of income for many tribal villages in Ambegaon, Junnar and Khed Tehsils of Pune district and can account for as much as 50% of the total income of a household (Sarnaik et al., 2017). The cash earned from selling Hirda is utilized by people for weekly shopping for their daily requirements. Therefore, the dried Hirda seeds are typically sold as and when cash is required. However, the market supply chain for Hirda is very complex, with multiple players and scales. As a result, the small quantities sold by individual collectors cannot fetch a high price for the Hirda seeds (Haque et al., 2016). Moreover, the prices are not fixed, making the Hirda seed market very volatile, and without any regulatory mechanism.

Normative goals: Sustainability, Equity and Fairness

In the hilly terrain of the upper section of the sub-basin there are very few livelihood options apart from agriculture. Agriculture is also limited by the rugged terrain, where only rainfed subsistence farming is possible. Hirda seeds provide a vital source of income for local populations during substantial periods of the year (during March–May as well as November–December). There is also a risk of accidents and loss of lives involved in collecting *Bal Hirda* (premature seeds) from the Hirda trees. The communities become highly vulnerable due to the fluctuating prices of Hirda seeds.

Lack of studies on the sustainability of Hirda (and other NFTP) collection in the area are an important knowledge gap. Most Hirda trees are reportedly large and old, naturally recruited, while a few are small, which may indicate a low regeneration rate. The local villagers have not observed any decrease in Hirda yield per se, but fluctuations have been observed from year to year. Strong rainfall after flowering causes decreases in Hirda yield. Systematic scientific exploration is required to understand the growth parameters of the Hirda species, impacts of seed harvesting on regeneration and the availability of the resource in the future.

III) Fishing practices

As the Bhima Basin is home to many dams and reservoirs, these also support a variety of fish which are caught by local populations. Small-scale fishing in dam reservoirs is an important livelihood source.

Normative goals: Sustainability, Equity and Fairness

The construction of dams obstructing the natural flow of rivers has affected the native fish diversity and populations, thereby impacting the fishing practices of local communities. The current fishing practices in the dam reservoirs are regulated through government fishing contracts that are leased out annually. However, the lack of regulation in the pricing of these contracts often results in limited opportunities for local fishers or groups of fishers to obtain the contract. Financially and politically dominant parties, and sometimes even outsiders, bag the contract.

Detailed studies on freshwater diversity, impacts of introduction of exotic species on the local species, effects of dam construction, etc. are generally lacking.

Other Issues

Apart from these key concerns, there are other critical issues in the basin that are also relevant to the livelihoods of the local communities, but which do not really fit within the F-W-B nexus framework. For example, the allocation of individual and community forest rights is a central issue, particularly in the most biodiverse north western areas. The Forest Rights Act[12] (2006) deals with the re-attribution of historical land rights; however, the process is administratively complex and difficult to navigate for local communities.

In terms of pressures affecting biodiversity, several issues were raised. For example, the designation of critical wildlife habitats in the Bhimashankar landscape is a very sensitive topic. Villagers are living under a constant fear of displacement, while politically active groups are taking advantage of the situation for their own benefits.

The most biodiverse parts of the basin also coincide with some of the poorest areas, leading to an uneven wealth distribution, even if the downstream/upstream dichotomy does not fully apply in Bhimashankar and is more complex than that. Mostly, the latitudinal band surrounding Pune represents the area's wealthiest population, which seems to benefit most from biodiverse areas to the west.

4.2 Issues and challenges related to availability of water for irrigation

I) Insufficiency of water for irrigation: Inequitable impact of irrigation projects

Due to the climatic, topographic and geological conditions, water resources are unevenly distributed across the basin. The headwaters receive the largest amounts of rainfall, but due to the high slopes and basalt lithology, most of the rainfall drains downwards, limiting the water endowment. The middle sections of the upper Bhima are water rich, since they have access to surface water stored in the dams that span across this section of the basin, as well as groundwater resources. Semi-arid to arid conditions

[12] The Forest Rights Act (FRA) of 2006 recognizes the traditional rights of the forest dwelling communities. It encompasses granting Individual rights of self-cultivation and habitation as well as Community rights that include grazing, fishing and access to Water bodies in forests, access to biodiversity, community right to intellectual property and traditional knowledge, recognition of traditional customary rights and right to protect, regenerate or conserve or manage any community forest resource for sustainable use.

prevail in the lower part of the basin, and groundwater is the most important source of water in this part. Other than the longitudinal gradient from the wet west to the dry east part of the basin, there is also a clear latitudinal climate gradient that influences the availability of water resources. The southern part of the Upper Bhima receives higher amounts of rainfall than the northern part, and this also impacts the availability of water resources, although differences are less acute than the west to east gradient.

Normative goals: Sustainability, Equity and Fairness

Populations in the extreme upper part of the sub-basin have borne the impacts of irrigation projects in terms of displacement, loss of land and livelihoods. They still experience extreme water scarcity even for drinking and domestic purposes, especially in the summers. The rugged topography of the region also creates challenges for the implementation and success of watershed development programmes. Wells are also developed for rainwater harvesting, but these are not perennial. They dry up around December or January. Because of this, many villages privilege drinking/domestic water over irrigation as these villages have decided not to use wells anymore for irrigation, though these wells were initially built to secure water for agriculture during the Rabi period.

Farmers in the extreme upper and lower reaches of the sub-basin do not get water for irrigation, thus limiting farming opportunities for them. They practice only rainfed or partially irrigated farming wherever groundwater is available. They are the most affected in the event of extreme climatic events such as droughts or floods.

Other social problems also arise due to shortage of water— e.g., migration, reduction in the number of cattle, reduction in the production of eggs and milk—affecting the health of the society. Due to all these effects, farmers are forced to migrate to urban areas.

II) Overexploitation of groundwater

The upper, middle and lower sections in the upper Bhima sub-basin differ in their geology and hence vary in their potential for groundwater recharge. As one moves from the upstream to downstream in the sub-basin, the potential of aquifer storage goes on increasing. It varies from about 20 mm to 600 mm. The percentage of conversion of rainfall varies considerably between these sections. In the upstream, although rainfall is very high, not even 10% of the rainfall goes into the groundwater storage. In the middle and the lower sections, for example in the Ghod sub-basin, the potential storage of water in an aquifer system is high. Particularly in the section where there are alluvial aquifers, the potential storage is very high. The groundwater extraction is very high in the interim section before the command area really begins. Further downstream, there is water from canal irrigation, but they also have remarkably large potential of groundwater storage, almost of the order of 600 mm. Farmers in these areas also extract groundwater to a large extent for irrigation.

Normative goals: Sustainability, Equity and Fairness

Farmers in the middle section have been overexploiting the groundwater for a variety of water intensive crops such as sugarcane. As a result, the overall groundwater table in the region has gone down. Farmers who do not have canal water for irrigation and can afford high costs incurred for digging borewells continue to do so, tapping into deeper aquifers. The lack of any regulatory mechanism to monitor and control the use of groundwater raises a serious concern about fairness and equitable distribution of water as well as sustainability of groundwater usage. Overall, evaluating the sustainability of water use for different uses in the Upper Bhima requires an improved understanding of the status of groundwater aquifers. There is some scattered information (e.g., the Ghod basin study conducted by ACWADAM) but overall, there is still limited understanding on the hydrogeology of the basin, which prevents having an accurate picture of its dynamics and the sustainability of the relationship between demand and availability.

III) Changing cropping pattern

With the availability of abundant water from canal irrigation projects as well as groundwater storage, farmers in the middle section of the sub-basin have been growing a variety of crops including the water-intensive sugarcane. The Bhima basin is one of the major sugar-producing basins in India. Due to high political interests in the sugar industry, various policies such as price support and guaranteed sales to sugar mills, etc. have triggered expansion of land under sugarcane cultivation even in the arid areas (Lee et al., 2020).

Normative goals: Sustainability, Equity and Fairness

Increasing sugarcane cultivation has restricted the availability of water for downstream agriculture, invoking concerns about equity in resource distribution. Moreover, the expansion of sugarcane cultivation has reduced land under more nutritious food crops, challenging the sustainable development goals of food security. As water is available only in the middle and lower reaches of the sub-basin to practice water intensive cropping, it results in wealth accumulation in these areas.

Other challenges

Some of the other challenges that emerged during stakeholder interactions include the loss of biodiversity due to land cover changes in many parts of the sub-basin. Land cover changes are more prominent in and around growing urban centres and near dam reservoirs. The processes of urbanization and land cover changes have directly affected forest cover and biodiversity as well as hydrological processes such as surface run-off, groundwater recharge, base flows and water availability in general. Concerns were also raised over the allocation of irrigation water to satisfy increasing demands from the urban sector. Water from the Bhama Askhed reservoir has been allotted to meet the drinking and domestic water requirements of the population of Pimpri-Chinchwad. This raises fairness concerns in water allocation across sectors.

Chapter 5. Questions for research and next steps

5.1 Defining research questions

We attempted to review the current situation of the WFB in the upper sub-basin of the Bhima. Based on literature review, field research and stakeholder interactions, we identified critical WFB nexus challenges across the basin. The assessment revealed different parts of the basins and its local communities face diverse types of WFB challenges, and therefore a deeper assessment of resource availability, use and interlinkages across sectors is required to address these challenges.

The following questions emerge from our assessment that can be taken up by nexus research looking at linkages between WFB in the Upper Bhima basin, keeping in mind the normative goals of fairness, equity and sustainability.

1. What options exist for diversifying livelihood opportunities?
2. Given the present water use scenarios including e-flows in the basin, how much water would be available for agriculture-based livelihoods over time?
3. Can the vulnerability due to the uncertainties in Hirda market be reduced if there is assured water for irrigation and stabilized incomes from agriculture?
4. Given business as usual, what would be the impact on food and water in the next 20–30 years? What could be the alternate scenarios taking into account sustainability, equity and fairness?
5. Given business as usual, will *Hirda* collection be sustainable in the future? What interventions are needed to ensure sustainability and fair trading for non-timber forests products?
6. What priority actions/changes would help achieve equity and fairness in water allocation?
7. Should the relationship among FWB in the upper Bhima basin be framed as one of trade-offs or as synergies or something in-between (not so black and white)?

5.2 Next steps

The fairSTREAM project takes a transdisciplinary approach and is planning to continue investigating some of these key questions in further detail using a mixed approach that combines a modelling framework with stakeholder consultations and knowledge co-production to support further deliberation and strategic thinking around WFB nexus with basin stakeholders.

In particular the team intends to gain insights into the following question: *What water allocation strategies can contribute to secure household income through a diversified strategy that combines food production and Hirda collection?*

The modelling framework that will be used in the analysis integrates the coupled agent-based hydrological model Geographical, Environmental and Behavioural (GEB) (de Bruijn et al., 2023), and a plant species competition model called plantFATE (Joshi et al., 2022). This modelling framework will be used to explore a number of different 'what-if' scenarios (e.g., 'in- or decreasing subsidies for specific crops', 'changing prices for electricity/water', among other possibilities), to be developed with stakeholders and intended to support discussions among the Upper Bhima stakeholders on adaptative strategies to promote the sustainability, fairness and equity in the W-F-B nexus in the long run and taking into account global climate change scenarios.

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