CHAPTER 8: MEASUREMENTS OF SUSTAINABILITY

'The great challenge of the twenty-first century is to raise people everywhere to a decent standard of living while preserving as much of the rest of life as possible.'

-Edward O Wilson

The economic prosperity and well-being of any nation depends on the planet's capacity to provide resources and ecosystem services (Costanza et al., 1997). Signatures of environmental changes such as deforestation, falling fisheries, accumulation of carbon dioxide in the atmosphere are some of the indicatives suggest that the absorptive capacity of the biosphere is reducing. Demand for ecological services that are limitedly available as a natural resource for human consumption is increasing with rise in human population appears to be surpassing the regenerative and absorptive capacity of the biosphere (NFA, 2010). Humanity, thus, is expending greater than what nature can revitalize leading to shrinkage of natural capital stock of the globe. Thus, careful management of human interaction with the biosphere is essential to ensure sustainable future, wherein the need of systemic accounting tools arises for tracking the combined effects of the many pressures human beings that are posing on the planet (Galli et al., 2012).

Sustainable management of natural resources plays a significant role making optimum use of the existing natural resources. Sustainability for any region can be measured using various matrices like LCA, Footprints and Indexes that take into account environmental, social and economic domains; in individual as well as combined forms. The author has taken 02 such sustainability indicators to assess the level of sustainability (environmental stability) of the Kim River Basin viz. The Water Footprints and the Ecological Footprints.

WATER FOOTPRINTS

The volume of water on the earth by and large remains constant due to its dynamic nature, which is creating a circulation web of water from hydrosphere to lithosphere via atmosphere. Hydro-climatic processes play an important role in overall distribution pattern of water. Evapotranspiration increases the amount of water in the atmosphere, precipitation decreases; while the amount of water on land increases due to precipitation but decreases on account of evapotranspiration. Subsequently, the precipitation on land exceeds evapotranspiration as seasonal specific change, as a result there is always surplus water on land that either leads to surface run-off or to groundwater flow or both. Therefore, water in any state under hydro-climatic and geologic environment remains finite. We need this finite freshwater (surface as well as ground) resource available on land to fulfil human needs.

On account of growing population , increasing its sectorial demands and changing lifestyles, the freshwater consumption around the globe has increased almost seven folds in the past century (Galli et al., 2012) and this tempo of water withdrawal is expected to increase in the coming future (Liu et al., 2008). Thus, freshwater scarcity is a growing concern, placing considerable weightage on the accuracy of indicators that are used to characterize and map water scarcity worldwide. (Hoekstra et al., 2012).

Annually, human population need specific volume of water to meet their domestic, agricultural and industrial demands, which cannot exceed the annual replenishment rate of the available freshwater in a region. The Water

Footprint (WF) concept is an outline that acts as a framework for associating the human consumption and available freshwater globally (Hoekstra & Chapagain, 2008) .Water consumption is not the only reason for causing water scarcity; water pollution is equally responsible for it (UNDP, 2006). Therefore, WF computation serves as an important mean to estimate the actual water availability in a given area taking into account the freshwater withdrawals along with the pollution load. WF evaluation, thus expresses the human appropriation of freshwater in terms of volume of water consumed.

Types of Water Footprints:

For accurate analysis of global water availability and consumption, the WP accounts all the accessible freshwater that humans can withdraw as well as that can assimilate pollution. The Water Footprint Network splits the WF into three categories (Hoekstra & Mekonnen, 2011) viz.:

a) *The Blue Water Footprint*: The blue water footprint indicates the consumptive use of water (freshwater), where in 'consumptive water use' represents evaporation of water from water bodies or plants (combined with transpiration) and or water embedded in an product during its production; assuming that the water is lost and does not return back at the same time, same process or in the same form. Being a renewable resource, the water that recharges groundwater reserves and that flows through a river is always limited. Surface and groundwater is utilized for domestic, agricultural as well as industrial purposes and in any of these cases, in a given period of time, one cannot consume more water than its existence. Therefore, the blue WF quantifies the amount of available water that is consumed by the humans. The residual surface and groundwater that remains unutilized by humans, is assigned for ecosystem sustenance and surface water flows.

$$\mathbf{WF_{\mathit{Blue}} = BlueWater_{\mathit{Evaporation}} + BlueWater_{\mathit{Incorporation}} + Lost_{\mathit{Return\ flow}}}$$

$$\mathbf{[volume/time]}$$

Depending on the scope of the study, the calculations of Blue WF allow differentiating between sources of blue water, viz. surface and groundwater (Aldaya and Hoekstra, 2010). The water structures like dams and harvesting ponds are collection of rainwater that would have otherwise contributed to surface & sub-surface runoff. Since that water can be used for either domestic or irrigation purposes, it is considered in Blue WF for that specific consumptive use. The Blue WF is expressed in volume / time.

b) *Green Water Footprint:* The green water footprint measures the consumptive use of 'green water', a fraction of precipitation on land that neither contributes to runoff nor recharges the groundwater, instead is stored in the soil forming soil water. It is useful for crop growth and it leaves via evapotranspiration by plants or soil evaporation. The green water footprint in a process step is equal to:

$$\mathbf{WF}_{Green} = \mathbf{Green\ Water}_{Evaporation} + \mathbf{Green\ Water}_{Incorporation}\ \mathbf{[volume/time]}$$

Utilization of green water in agricultural sector can be estimated by crop models or with empirical formulas to estimate evapotranspiration. Differentiating the blue and green WF is advantageous when studying the hydrological and environmental impacts of irrigation types (canals, dams or rainwater) on the agricultural production of the area (Hoekstra and Chapagain, 2008).

c) *Grey Water Footprint:* It is the estimate of degree of freshwater pollution that can be associated with a particular commodity/process/sector. It is the volume of freshwater required to assimilate the pollution load of a water body depending on the background concentrations of dissolved constituents and water quality standards. In case of domestic consumptions, the grey water comprises the sewage load of the region, while for industrial sector, it is the total effluent that is generated in the industrial premises before it is subjected to treatment or disposal.

WATER FOOTPRINT OF THE KIM RIVER BASIN

The WF evaluation primarily depends on the scope and level at which the analysis is to be carried out. i.e entity of interest which can range from a product to consumer to a region or nation. For a comparative study, only global average estimates are sufficient but if the purpose is to identify the hotspots, a detailed accounting and assessment is pre-requisite to understand the environmental and socio-economic impacts of WF. (Water Footprint Network, 2011).

For understanding the freshwater consumption by human population with respect to the hydrological cycle, the author has implemented the river basin approach to quantify the WF as all the run-off from a river basin drains through a common outlet making it an independent system of study. The freshwater availability in a watershed stretch is given by the volume of precipitation on annual basis; where in the evaporative flow and the run-off are appropriated by the humans (Hoekstra, 2009). The blue water footprint is denoted by the consumptive use of the overland or groundwater flow and the green water footprint is implied by the human use of the evaporative flow from the land for agriculture and forests. Consumptive water use in a certain period in a certain river basin refers to water that after use is no longer available for other purposes, because it evaporated (Perry, 2007). Thus, for sustainability analysis of any area in terms of WF, a direct comparison should be viable in terms of water availability and water footprint. For this, a holistic approach is more suitable as compared to an individual study of product or consumer WF. Therefore, the author has considered the river basin as a basis for WF study where this direct comparison is possible.

There are no customary guidelines set for WF accounting; but the general rule is to include the WF of all processes within a production system that 'significantly' contribute to the overall WF of a product; and in case of a river basin, the WF comprises of all the sectors existing in that geographically bounded area. The evaluation methodology for the WF of a river basin follows analogous procedure to total WF of a nation/region but for a geographically delineated area (river basin in present case). The WF accounting of the Kim River basin, does not take into consideration whether the WF within the basin boundary is for the products consumed by the people living within the area or for making exported products. It purely measures the WF of different sectors (domestic, agriculture, livestock & industry) existing in the study area to acquire the overall Water Footprint of the basin area.

However, for a broader understanding of the association between the overall water use in the Kim watershed and the sustenance of the community inhabiting within, a through accounting of the water footprints (of all sectors) is made. An attempt is also been made to analyse the water dependency on the adjoining basins, especially for agricultural purposes because, it is estimated that 86% of WF of humanity is within the agricultural sector (Hoekstra and Chapagain, 2008). The calculation technique of the WF adopted hereby, includes, both the direct as well as virtual WF of the Kim River Basin.

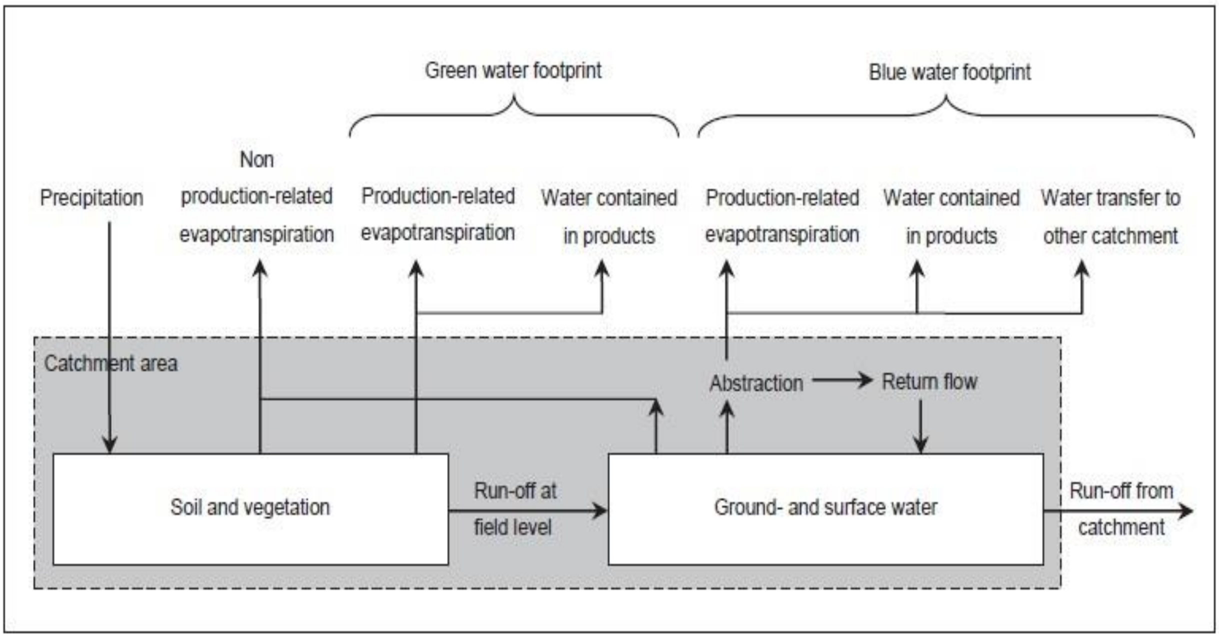

Figure 8. 1 The Green and Blue Water Footprints of a River Basin

It is a well-established fact that water is finite resource and its availability and demand varies within a year as well as across the years. Therefore, selection of period of data used for analysis of WF with respect to time thus plays a crucial role since it affects the outcome. Also, while computing the WF for a particular year, it is advisable to take into account the average climatic conditions prevailing over a prolonged period of time (preferably consecutive 30 years) in the area of interest (WF Assessment Manual, 2011). The author, though has calculated the WF scenarios for 1998, 2003, 2008 and 2013, she has taken into account the average climatic data inputs viz. Temperature, Rainfall, Relative Humidity, Wind Speed & Direction and Pan Evaporation for the past 30 consecutive years (1983-2013); and rest of the data inputs of that respective years. This accounting is based on the estimates of actual local water consumption and wastewater generation, with limited ground level verification.

The computation of WF of the Kim River Basin is based on the following rationales:

- For estimating the populations for the years 1998, 2003, 2008 & 2013, the annual population growth rate of 1.2%/annum is taken into account taking 1998 as base year(Census,2001 &2011).
- The floating population is assumed to be 5% of the total annual population of that respective year (Census, 2011).
- The domestic consumption of freshwater is considered as 80lpcd, which is assumed to stay uniform from 1998 to 2013 for the resident population that included rural as well as semi-urban; and 40 lcpd for the floating population (Town & Country Planning Organization, 2011).

  (The Drinking Water Mission, Government of India has considered water consumption @ 40 LCPD for rural population having no source of water. In the present case, this situation is rarely available. Hence, per capita water consumption for both, rural and semi-urban has been considered on par)
- For computing the Grey WF, 90% of the blue water consumed by the overall population in the study area is accounted as grey water volume generated annually.

- The livestock population is estimated using their population growth rate/annum according to the Livestock Census carried out timely (Livestock Census, 1997, 2002, 2007 & 2012).
- The per day water consumption of different livestock is considered based on the Indian Standards given by the Department of Animal Husbandry.
- The WF of production of various animal products (like milk, meat, etc) is not accounted since there is no statistical data available. Hence only their fodder and water requirements are considered.
- The livestock WF does not include poultry since it is a negligible consumer of water.
- The source for water for industrial consumption is considered to be groundwater only in the entire study area (GPCB,2013).
- The consumption of water and generation of wastewater is assumed to stay uniform for all the units established prior to 1998.
- The water consumption and wastewater generation of industrial units that have undergone expansion is not accounted.
- The blue water in case of village ponds and other water storage structures within the basin boundary is not computed since the rainfall is the only input in the study area.
- The evaporation from canal network and dams within the study area is ignored as these waters are used exclusively for irrigation, the evapotranspiration various crops has been computed individually.

A. Water Footprint of Domestic Sector:

The computation of domestic WF includes direct consumption of water by human population for various activities viz. drinking, washing, bathing, flushing, cleaning, etc. This does not include embedded or virtual water consumed in the production of products/ commodities/ agro-products required by humans on day-to-day basis. For Indian cities, since 2011, the optimum water that should be available per capita per day for small towns and cities (that lack closed sewerage system and STPs) is 80 lpcd (Town & Country Planning Organization, 2011). As a result, the water consumption and wastewater generation pattern are directly proportional. For calculating the total human demand of blue water in the study area, the resident (rural + semi-urban) as well as floating population water consumptions have been considered. Resident population comprises the permanent dwellers (who work as well as stay) in the study area, while the floating populations include travellers, seasonal migrants, factory workers (who stay outside the study area), etc. The source for drinking water in the upper part of the study area is majorly groundwater and rest of the demands are fulfilled by small streams; while in the central and downstream of the study area, water source is either groundwater through wells (depending on the quality) or through overhead tanks set up under Gram Panchayat Water Supply Schemes. The comparison of water consumption for domestic sector in the study area from 1998 to 2013 with an interval of 05 years is presented in Table 8.1.

Population	Year	1998	2003	2008	2013
RESIDENT (Rural + Semi-urban)	Population	339000	360507	382663	406180
	Water Consumption (lpcd)	80	80	80	80
	Annual Water Consumption(MCM)	09.90	10.52	11.17	11.86
	Annual Wastewater Generation(MCM)	08.91	09.47	10.06	10.67
FLOATING	Population	16950	18025	19133	20309
	Water Consumption (lpcd)	40	40	40	40
	Annual Water Consumption(MCM)	0.25	0.24	0.28	0.30
	Annual Wastewater Generation(MCM)	0.22	0.21	0.25	0.27
TOTAL (MCM)	Water Consumption/Annum	10.15	10.76	11.45	12.16
	Wastewater Generation/Annum	9.13	9.68	10.31	10.94
Total Domestic Water Footprint (MCM/Year)		**19.28**	**20.44**	**21.76**	**23.1**

Table 8. 1 Domestic Water Footprint of the Kim River Basin (1998-2013)

It is apparent from the data that the population increase from 1998 to 2013, has amplified the water consumption as well as wastewater generation. Virtually, 90% of the water used by a person per day for his daily activities is contributed as sewerage (Singh, 2006) and that adds to the grey water. Thus, greater part of the blue water used by humans form the grey water. The blue water footprint of the study area for the year 1998 is estimated to be 19.28 MCM and by 2013 it has increased to 23.1 MCM(20%). This gradual rise is attributed to the growth in urban sprawl in the study area in the 15 years interval (1998-2013).

B. Water Footprint of Industrial Sector:

The WF estimation of the industrial sector of the Kim River basin is based on the Blue water consumption (klpd) and Grey Water generation (klpd) from all the type of industrial units including the mining industries located in the study area is based on the data gathered from Gujarat pollution Control Board. As it has already been mentioned that the blue water source for all the industrial units located in the study area is groundwater, irrespective of its quality. The Annual Water Consumption and Wastewater generation of all the industrial units' existing in the study area, has been computed and given in Table 8.2.

Year	**1998**	**2003**	**2008**	**2013**
Water Consumption/Annum (MCM)	11.82	12.55	14.68	13.77
Wastewater Generation/Annum (MCM)	08.61	09.22	09.93	03.86
Total Industrial Water Footprint (MCM/Year)	**20.43**	**21.77**	**24.61**	**17.63**

Table 8. 2 Industrial Water Footprint of the Kim River Basin (1998-2013)

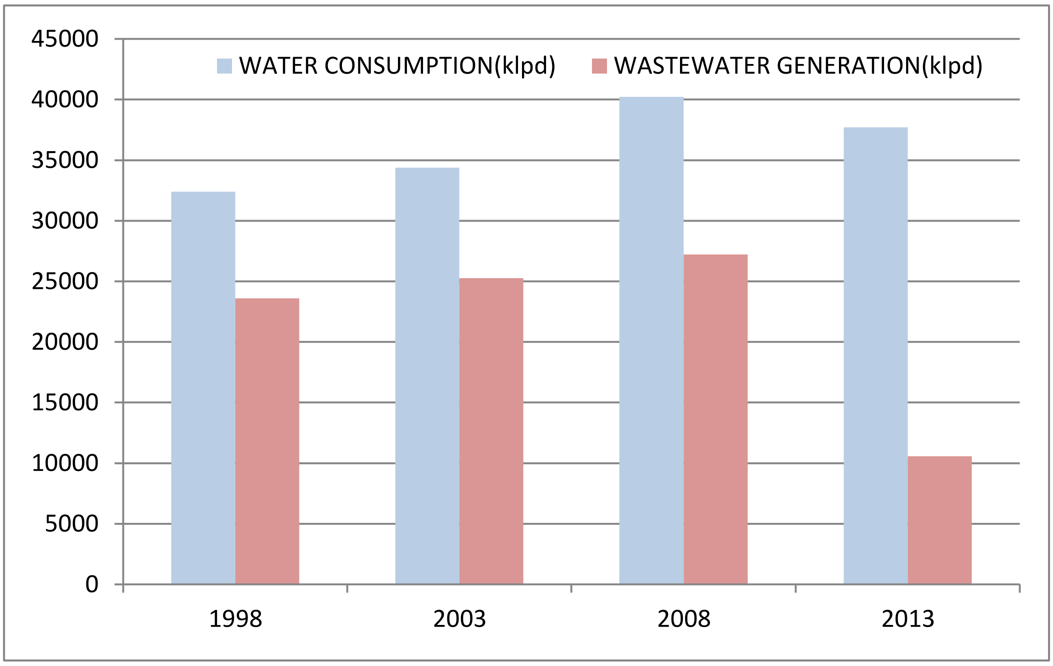

Figure 8. 2 Comparative Display of Water Consumption and Wastewater Generation in the Industrial Sector of the Kim River Basin

On account of industrial expansion in the study area, several new small and large scale industrial units have been established after 2000. This has increased the load on the available freshwater for this sector. Till 2008, there has been a gradual rise in water consumption, but, in spite of increasing number of industrial units after 2008, a decline is seen in the water consumption pattern (Fig 8.2). Also, the wastewater generation which was around 9.93 MCM till 2008, sharply dropped to 3.386 MCM in 2013. This is ascribed to adoption and implementation of better water management practices by industries like recycling and zero waste discharge technologies as well as upto certain extent products demand in the market. Highest WF for the industrial sector in the span of 15 years (1998-2013) was observed in 2008 (24.61) The reduction in the Blue and Grey water footprint in 2013, has led to decrease in the overall industrial Water Footprint of the study area, which stands at 17.63 MCM in 2013 as compared to 20.43 MCM in 1998. Thus, the overall study of the Blue and Grey water trends from 1998 to 2013 shows increasing water consumption and decreasing wastewater generation (Fig 8.2).

C. Water Footprint of Livestock:

The livestock population comprises buffalo's, cows, goats, poultry, camels, donkey, sheep, horses etc. Livestock production constitutes a very important component of the agricultural economy in India. As human population show an increasing trend, so does its demand for agricultural and animal resources. Hence, in the study area too, livestock population shows rapid rise to meet the growing population demands. The food and water requirements of these livestock populations is thus, accounted for water footprint calculations. Due to lack of availability of appropriate livestock population data at village level, the livestock population has been projected using annual growth rate of different livestock (19th Livestock Census, 2012).

Livestock Type	Livestock Census			
	1998	2003	2008	2013
Cows	45800	47200	51650	53000
Buffaloes	47380	49760	53330	55100
Goat	6900	8100	9700	10400
Sheep	1900	2680	3260	4000

**District Livestock Census 1997,2002,2007,2012*

Table 8. 3 Summary of Livestock Population in the Kim River Basin (1998-2013)

Livestock Type	Water Req./Day (litres)	Water Req./Annum (MCM)			
		1998	2003	2008	2013
Cows	140	2.34	2.41	2.64	2.71
Buffaloes	200	3.46	3.63	3.89	4.02
Goat	40	0.10	0.12	0.14	0.15
Sheep	40	0.03	0.04	0.05	0.06
Total Livestock Water Footprint (MCM)		**5.93**	**6.20**	**6.72**	**6.94**

Table 8. 4 Livestock Water Footprint of the Kim River Basin (1998-2013)

The livestock WF computation only takes into account the blue water consumption. With the increasing livestock population in the study area, the Blue Water Footprint (total) shows gradual increase from 5.93 MCM (1998) to 6.94 MCM (2013).

D. Water Footprint of Agriculture:

WF acts as a suitable indicator for optimum management of water resources, especially in the agricultural sector, which is known to consume 65% of freshwater resources around the globe (Hoekstra, 2008). WF accurately determines the volume and type of water actually used for growing crops and other vegetation. The WF of agricultural sector is the summation of all the 03 types of footprints viz. the blue, green as well as grey WF. The WF for this sector is calculated by computing the weighted average rainfall for a period of 30 years (1983-2013), effective runoff and evapotranspiration for different crops using the standard Crop Factor (K_c) and approach (Allen et al., 1998). For a comparative scenario, the WF of the study area is calculated for each crop type for 04 years at a period of 05 years interval (1998.2003, 2008 & 2013) over a period of 15 years.

The **WF*Blue*** is calculated separately for each crop type by considering the total quantity of water required by each crop type as per its growing season. This blue water can be surface or groundwater, internal or virtual in origin; is computed at a later stage. The **WF*Green*** is the consumptive use of water by plants which is the loss through evapotranspiration (mm/day) throughout the various growing stages of crops and is computed by considering the Kc (Crop Factor) for respective crop types (FAO,1998). The **WF*Grey*** is the excess of water applied in irrigation via canals that comprises agrochemicals and applied soil fertilizers. It leaves the agricultural field as either agricultural runoff or return irrigation seepage (Michael, 1983). As, it has already been stated that out of the total area under cultivation, ~60% of the study area covering middle and lower parts of the basin is irrigated using canal water that comes as a virtual water in the study area. Rest of the irrigation in the upper parts of the basin is done by river or groundwater as source and through the canal systems of Pingut and Baldeva reservoirs. The returned irrigation seepage finally forms the part of groundwater storage and thus the Grey water gets converted into blue water.

It is clearly visible from the cultivated crop area status (Table 8.4) that the total area under cultivation has gradually decreased from 1998 to 2013. Also the area under water intensive crops like sugarcane and paddy which has significantly increased during the post canal irrigation phase (after 1974) shows gradual decrease from 1998 to 2013. The author by following FAO's standard guidelines (FAO, 1977 & 1998) has computed crop specific quantity of water required for irrigation (Blue Water) and consumptive use (Green Water) by considering respective land area under cultivation (Table 8.5 & 8.6).

Crop Type	Growing Period (days)	Crop Factor (K_c)	Area Covered* (km^2)				Green Water (MCM)			
			1998	2003	2008	2013	1998	2003	2008	2013
Pulses	120	0.79	2.2	4.4	6.3	6.5	1.39	2.77	3.97	4.12
Sugarcane	330	1.1	614	596	487.3	414	1418.32	1180.16	1088.84	1002.56
Paddy	120	1.1	106.6	97.6	87.3	85.3	201.40	184.46	165.00	161.25
Groundnut	105	0.74	11.4	10.3	7.9	6.5	9.58	8.66	6.63	5.49
Cotton	160	0.82	7.6	6.0	5.8	1.2	7.93	6.28	6.09	1.21
Vegetables	90	0.8	15.0	20.1	10.9	14.0	11.04	14.80	8.00	10.28
Wheat	135	0.68	5.5	16.0	8.0	2.3	4.61	13.43	6.75	1.89
Jowar	100	0.71	18.8	6.2	6.4	4.2	13.78	4.56	4.70	3.08
Others	90	1.1	80.9	80.3	139.1	70.9	42.45	42.16	73.02	37.22
Plantains	300	1.1	3.2	7.1	2.3	1.9	6.70	14.91	4.75	4.03
Perennials	90	0.9	6.2	5.7	5.3	5.8	3.89	3.58	3.34	3.63
TOTAL			**871**	**765**	**751**	**633**	**1721.08**	**1475.76**	**1371.09**	**1234.77**

**Source: Irrigation Dept. GOG*

Table 8.5 Status of Blue Green Components of the Kim River Basin (1998-2013)

Crop Type	Water Requirement (m-hec/hec)	Area Covered* (km^2)				Blue Water (MCM)			
		1998	**2003**	**2008**	**2013**	**1998**	**2003**	**2008**	**2013**
Pulses	0.5	2.2	4.4	6.3	6.5	1.32	2.64	3.78	3.92
Sugarcane	2.2	614	596	487.3	414	1350.78	1123.96	1036.99	954.82
Paddy	1.8	106.6	97.6	87.3	85.3	191.81	175.68	157.14	153.58
Groundnut	0.6	11.4	10.3	7.9	6.5	9.12	8.25	6.31	5.23
Cotton	0.9	7.6	6.0	5.8	1.2	7.55	5.98	5.80	1.15
Vegetables	0.5	15.0	20.1	10.9	14.0	10.51	14.09	7.62	9.79
Wheat	0.6	5.5	16.0	8.0	2.3	4.39	12.79	6.43	1.80
Jowar	0.55	18.8	6.2	6.4	4.2	13.13	4.34	4.48	2.93
Others	0.5	80.9	80.3	139.1	70.9	40.43	40.15	69.54	35.45
Plantains	2	3.2	7.1	2.3	1.9	6.38	14.20	4.52	3.84
Perennials	0.4	6.2	5.7	5.3	5.8	3.71	3.41	3.18	3.46
TOTAL		**871**	**765**	**751**	**633**	**1639.13**	**1405.49**	**1305.80**	**1175.97**

**Source: Irrigation Dept. GOG*

Table 8.6 Status of Green Water Components of the Kim River Basin (1998-2013)

As the net area under agriculture has decreased over the period of 15 years (1998 to 2013), the WF has also reduced accordingly. As a result, the values of the Blue and Green components of agricultural sector clearly indicate that the water losses via evapotranspiration are more than the blue water consumption (Table 8.6). This may be ascribed to the extensive cultivation of water intensive crops like sugarcanes, paddy and plantains. Also, the imported canal water sustains a major part (~60%) of overall agriculture in the study area, since only rainfall and/or cannot support such extensive agricultural production.

E. Water Footprint of Forest:

The forests in the study area are restricted to the upper basin part of the study area and are characterized by mixed-deciduous type of plants. The WF computation of forests is similar to that of agricultural sector. The source of blue water for the trees, being the rainfall, the $\mathbf{WF}_{\mathbf{\mathit{Blue}}}$ is not accounted; while the $\mathbf{WF}_{\mathbf{\mathit{Green}}}$ is accounted as a part of evapotranspiration that varies seasonally. In case of deciduous trees when they shed their leaves in dry season, the rate of ET decreases and is computed by only the soil evaporation, while in the monsoon and spring seasons, when the foliage is dense, the ET is the sum of transpiration from trees and evaporation from the ground surface. The average K_c of Deciduous Trees having 70% canopy coverage is taken as 0.9 (FAO, Drainage Paper 24). By considering ET_o and the Crop factor (K_c) the ET_{Forest} has been estimated (Table 8.6).

Year	**1998**	**2003**	**2008**	**2013**
Deciduous Forest Cover (km^2)	262	213	213	196
ET_{Forest} (ET_o x K_c)		1.89		
Total Evapotranspiration (MCM/annum)	**495.2**	**402.6**	**402.6**	**370.0**

Table 8. 7 Water Footprint of Forest Cover in the Kim River Basin (1998-2013)

On comparing 05 yearly change in the **ET_{Forest}** (Table 8.6) it shows declining trends over a time period from 1998 to 2013 which is due to reduction in the forest cover in the study area. The summation of computed values of **ET_{Forest}** and **ET_{Crops}** for a particular year will contribute to the total evapotranspiration of the Kim River basin for that respective year.

Total Water Footprint:

The total WF of the Kim River basin can be expressed by the following equation-

$$WF_{Total} = WF_{Agriculture} + WF_{Domestic} + WF_{Forest} + WF_{Industry} + WF_{Livestock}$$

Water Footprint (MCM/Annum)	1998	2003	2008	2013
$WF_{Agriculture}$	3360	2881	2677	2411
$WF_{Domestic}$	19	20	22	23
WF_{Forest}	495	403	403	370
$WF_{Industry}$	20	22	25	18
$WF_{Livestock}$	6	6	7	7
WF_{Total}	**3901**	**3332**	**3133**	**2828**

Table 8. 8 Water Footprint of the Kim River Basin

It is clearly discern that the Total WF of the study area (Table 8.7) shows an overall decreasing trend from 3901MCM/ annum in 1998 to 2828 MCM/annum. This is mainly on account of decrease in the agriculture practices of the region. The agricultural sector is the largest consumption of blue water in the study area. The average blue water consumption of agriculture in the study area from 1998 to 2013 is approx. 85%; followed by forests (12%) and remaining sectors contribute at minor levels. Looking at the decreasing trend in the WF_{Total} of the study area, the per capita WF has increased from 19 MCM in 1998 to 23 MCM in 2013. This is attributed to population growth, change in lifestyle and thereby rising demands and growing pressure on the existing freshwater resources.

ECOLOGICAL FOOTPRINTS

The Ecological Footprint (EF) is a potential tool to measure the limits of resource consumption, the international distribution of the world's natural resources and means to achieve sustainability in terms of optimum resource utilization. Assessing current ecological supply and demand as well as historical trends provide a basis for setting goals, identifying options for action; and tracking progress toward stated goals for sustainable development. (WCED,1992). As the demands upon natural systems rapidly increase due to swelling global economy and the need to attain better standards of living, several studies suggest that many of the Earth's thresholds are being exceeded and the ability of biosphere to suffice the needs of humanity is reducing (Thomas et al., 2004; Haberl, 2006 and Moore et al., 2012).

The first systematic attempt to calculate the Ecological Footprint and biocapacity of nations' began in 1997 (Wackernagel et al. 1997). Ecological Footprint is defined as the total land and water area required to support a population with specific natural resources for an indefinite length of time (Rees & Wackernagel, 1994). Further, it is a matter of concern that along with the renewable and non-renewable resources, the ability of earth to assimilate the waste is also fading. The EF concept is developed after making multiple attempts to evaluate the burden of human population and its nature (Cohen, 1995).

Conceptualization of the EF is done on the basis of ground validation carried out globally in developing meticulous and narrative means to measure people's use of nature, viz. Life Cycle Assessments (LCA), energy analyses and energy-based lifestyle appraisals, etc. Noteworthy contribution on sustainability analysis has been received after the works credited to -Meadows et al, 1972, 1992; Borgstrom,1973; Holdrenand J. & Ehrlich P.1974; Whittaker, 1975; Vitousek et al, 1986; Hofstetter, 1991; Buitenkamp et al, 1993; Duchin and Lange, 1994; Pimentel et al, 1994; Schmidt-Bleek, 1994; Odum H.,1994; Krotscheck and Narodoslawsky, 1996 and Folke et al, 1997. Further, EF can also be used to scrutinize issues such as the limits of resource consumption, the international distribution of the world's natural resources and means to sustainably manage them at global level. This necessitates a prudent governance of human interaction with the biosphere to ensure future prosperity; and need for systemic accounting tools for tracking the combined effects of the many pressures human being is posing on the planet (Galli et al., 2012).

The biocapacity/ Ecological Capacity (EC) on the other hand is a measure of the amount of biologically productive land and sea area available to provide the ecosystem services that humanity consumes i.e.our ecological budget or nature's regenerative capacity.

Ecological Footprint and biocapacity values are expressed in mutually exclusive units of area necessary to annually regenerate such ecosystem services namely; cropland for the provision of plant-based food and fibre products; grazing land & cropland for animal products; fishing grounds (marine and inland); forests for timber and other forest products; land to accommodate for the absorption of anthropogenic carbon dioxide emissions; and built-up areas for shelter and other infrastructure. The consumption of these areas is converted into a single index: a land area that would be needed to sustain that population indefinitely.

Biological Productive Area = Arable land + Built up area + Forests for CO_2 absorption+ Pastures

Using the total Biological Productive Area available for a given year and population, The Biocapacity/Ecological Capacity (EC) can be computed as-

$$\text{Bio-capacity of an area} = \frac{\text{Total Biological Productive Area (Gha)}}{\text{Total Population of the Area}}$$

Therefore, the sustainability status of an area in terms of its prevailing ecological deficits or surpluses can be quantified; by comparing the land occupied by the population in a region with its available bio-capacity (Wackernagel, 1997).

Scenario	Condition	Remarks	Status
EC>EF	**Ecological surpluses**	Human pressures on ecosystem are within the scope of bio capacity	Sustainable
EC<EF	**Ecological Deficits**	Human pressures on ecosystem are exceeding the scope of bio capacity	Unsustainable

**EC=Ecological Capacity (Biocapacity), EF = Ecological Footprint*

The EF measures assumed biocapacity (EC) across five distinct land use types. Average bio productivity differs between various land use types, as well as between countries for any given land use types. Hence, for global comparison across different land use types in different countries, EF and EC are usually expressed in global hectares (gha). Global hectares provide more information than simply weight - which does not capture the extent of land and sea area used - or physical area - which does not capture how much ecological production is associated with that land. The use of global hectares allows for the addition of EF and EC values of different land use types into a single number: consumption-focused applications that have a global context and global sustainability studies aiming at comparing the EF and EC results of Nations benefit from the use of global hectares (Ferguson, 1999; Wackernagel et al., 2004).

As stated earlier, the productivity across different land use types shows variation which directly reflects the EF and EC of these land use categories. Thus, a coefficient is obligatory to obtain uniform platform for these calculations to obtain consistent and accurate results (Galli et al., 2007). For this, Equivalence Factors (EQFs) are used that convert the areas of different land use types, at their respective world average productivities, into their equivalent areas at global average bio productivity across all land use types. EQFs vary across different land use type as well as by year. The rationale behind EQF calculation is to value different land areas in terms of their inherent capacity to produce human-useful biological resources. The weighting criterion is not the actual quantity of biomass produced, but what each hectare would be able to inherently deliver. The Global Footprint Network (GFN) releases the calculated global EQFs annually in either their Guidebooks or Footprint Accounting Manuals (Footprint Network, 2014), which can be applied to compute the EF on annual basis.

Ecological Footprint of the Kim River Basin:

The Kim River basin, located in the Golden Corridor of industrial belt of Gujarat, shows various signs of urbanization and industrial growth. Moreover, being centred between two major cities of Bharuch (north) and Surat(south), evident growth in terms of infrastructural and residential development is distinctly visible from the land use maps (Fig 4.12-4.15) and analysed secondary data. The study area is bestowed with sufficient quantity of natural resources, mainly land and water, which are finite and support only a limited population demand. The humanity to meet its demands, can accept either of the two ways, i.e either it overexploits the available natural resources beyond the carrying capacity of the ecosystem or in the presented study ,it imports the products and services from outside to sustain itself. In both the cases, the biocapacity of the region is unsafe leading to unsustainable economic and social development.

The calculations for EF are centred on two basic facts : i) Keeping track of most of the resources consumed by the population along with the waste generated and ii) Converting the resources and waste flows to a biologically productive area necessary to provide these functions (Zhang Z. et al, 1999). Thus, EF indirectly quantifies how much nature a region uses.

The Ecological Footprint for the Kim River Basin is calculated for the period of 1998 to 2013 with an interval of 05 years using the following formula-

$$\textbf{EF of Kim River Basin} = \frac{(\text{Arable land x EQF}) + (\text{Built up area x EQF}) + (\text{Forests for } CO_2 \text{ absorption x EQF}) + (\text{Pastures x EQF})}{\text{Total Population of that Year}}$$

A rationale is framed for the EF calculations, which is as under-

i) For population estimation, base population of 1998 was considered and for further years, the population was estimated using the population growth rate of 1.2% for the study area. (Census 2001 & 2011).

ii) The area under various land use categories was estimated using land use data generated in Chapter-4 by the author.

iii) Only four different categories of land use were accounted for the EF and EC calculations viz. arable land, pasture land, built-up land and forest land {to absorb CO_2} since, the forest land for timber production and productive sea space being absent in the Kim River Watershed. These land use categories were assumed to be used for only one purpose specified. (NFA, 2014).

iv) Out of the total Bioproductive area available, 12% is assumed to be reserved for biodiversity (Wackernagel, 1998).

v) The Equivalence Factors (EQFs), (which are uniform for all the countries in a given year) for all the four years viz. 1998, 2003, 2008 and 2013 were acquired from published data and/or research papers to obtain all the land use categories on a global uniform platform (Wackernagel, 1998; 2005;2010;2014).

Year	Land-Use Category	Arable Land	Build up area	Forests	Pastures	Total
1998	**Equivalence Factor**	2.821	2.821	1.1387	0.541	
	Area (Hectares)	87020	3700	26200	4351	121271.00
	Total Population	339000				
	Per Capita	0.26	0.01	0.08	0.01	**0.36**
	Ecological Footprint	245483.42	10437.70	29833.94	2353.89	**0.85**
2003	**Equivalence Factor**	2.64	2.64	1.33	0.49	
	Area (Hectares)	78185.00	5500.00	21300.00	3909.25	108894.25
	Total Population	360507				
	Per Capita	0.22	0.02	0.06	0.01	**0.30**
	Ecological Footprint	206408.40	14520.00	28329.00	1915.53	**0.70**
2008	**Equivalence Factor**	2.51	2.51	1.26	0.46	
	Area (Hectares)	76617.50	10100.00	21300.00	3830.88	111848.38
	Total Population	382663				
	Per Capita	0.20	0.03	0.06	0.01	**0.29**
	Ecological Footprint	192309.93	25351.00	26838.00	1762.20	**0.64**
2013	**Equivalence Factor**	2.56	2.56	1.28	0.43	
	Area (Hectares)	66785.00	18500.00	19600.00	3339.25	108224.25
	Total Population	406180				
	Per Capita	0.16	0.05	0.05	0.01	**0.27**
	Ecological Footprint	170969.60	47360.00	25088.00	1435.88	**0.60**

Table 8. 9 Ecological Foootprint Summary of the Kim River Basin (1998-2013)

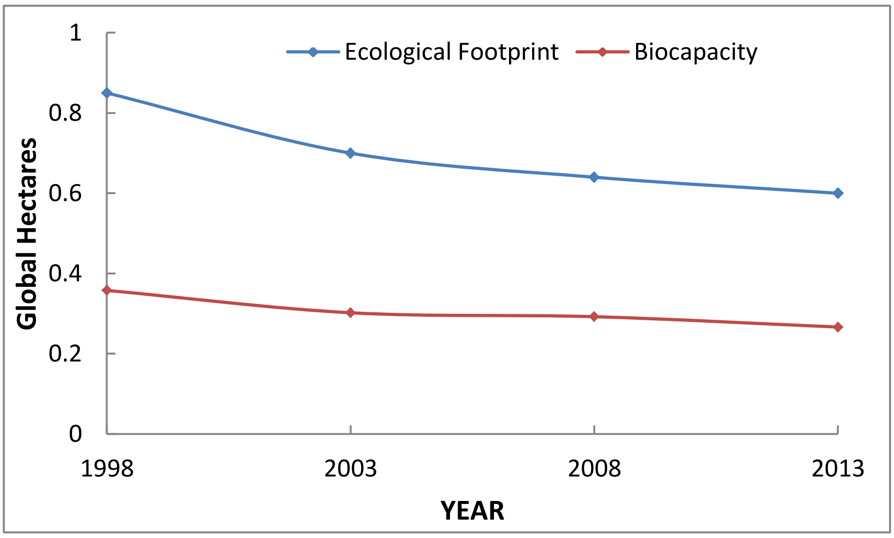

Figure 8. 3 A Comparative Chart Depicting the Changing Scenarios of EC and EF in the Kim River Basin (1998-2013)

The study area, like any other developing region, shows increasing trend in the population along with industrialization and infrastructural expansions. Thus, with availability of finite natural resources and growing humanity demands, a diminishing trend is observed in the Ecological Footprints and the limited Biocapacity (EC) of the study area (Fig. 8.2). In 1998, the EF of the study area was 0.85 gha/capita and EC was 0.30 gha/capita (Table 8.8) while after 15 years, i.e. in 2013, EF reduced to 0.60 gha/capita and EC was 0.27 gha/capita(Fig. 8.1). This shows that the population growth is directly exerting demand on the available natural resources of the study area. The relationship between EC and EF over the span of 15 years has also remained constant.

Thus, from the existing studies it is apparent that for all the four scenarios (1998-2013); the per capita EF and the EC of the Kim River Basin is less than the National/capita EF of India (0.9 Gha/cap) and National/capita biocapacity of India (0.5 Gha/cap) respectively. The results clearly indicate that EF > EC, that is the anthropogenic activities in the Kim River Basin are exerting continuous pressure on the ecosystem and therefore exceeding beyond the carrying capacity of the watershed region.

The suggested remediation measures for reducing the Ecological Footprint of the study area are discussed in the forthcoming chapter.