CHAPTER 6: HYDRO-METEROLOGY

'The water cycle and the life cycle are one.'
-Jacques Cousteau

Water is a substantial resource that occupies a distinctive place among other natural resources due to its vital role in both, the environment and human life. It is established fact that freshwater accounts for only 2.5% of the Earth's water, most of which is frozen in glaciers and ice caps. Pressure on freshwater resource is increasing due to industrialization and demographic growth (WWAP, 2012).

The hydrologic characteristics of any region are dependent largely on its geology and geography in which climate plays a dominant role. Amongst the meteorological processes, precipitation holds a very vital significance as source and distribution of water resource. Precipitation (Rainfall) is that part of atmospheric moisture which when reaches the earth's surface connects hydrology with geo-climatology. Precipitation initiates the water cycle which includes circulation of water in different systems under the influence of region specific meteorological attributes viz. evaporation, transpiration. Runoff and infiltration processes are solely governed by areas' geological environment. Understanding these dynamic processes in a closed system as a river basin facilitate in computing water balance and evolving management strategy to utilize existing surface and groundwater resources. Realizing this fact, the candidate has made an attempt to analyse various meteorological parameters and quantified the available water resources in the Kim River Basin at large. The following parameters have been emphasized.

METEOROLOGY

Temperature:

A temperature record of 10 years (2003-2013) was acquired from meteorological observatories located at Kim, Olpad, Valia and Amli in the study area. Average mean monthly minimum and maximum temperatures were computed for the study area. Temperature record shows a typical tropical behavioural pattern in temperature variations with characteristically hot and dry summers (Table 6.1).

Month	Monthly Average Temperature (^{0}C)		Relative Humidity (%)	Wind Speed (km/hr.)	Direction
	Minimum	Maximum			
January	10	24	53	0.9	NE
February	17	29	48	2.3	NE
March	20	33	52	1.5	NE-NW
April	22	38	48	3.4	WSW
May	25	41	50	12	SW
June	23	36	65	10	SW
July	21	31	79	7	SW
August	20	29	88	1.1	SWS-SW
September	20	30	81	0.6	SWS-SW
October	20	34	72	5.7	NE
November	17	31	63	2.9	NE
December	13	28	67	1.2	NE

Table 6. 1 Observed Average Monthly Temperatures, Relative Humidity and Wind records in the Kim River Basin

Relative Humidity:

Relative Humidity in the Kim River Basin and its neighbourhood is moderate to high and shows great variations in different parts of the study area. During the monsoon season, it reaches up to 85% and rest of the year; it fluctuates between 40-75% (Table 6.1).

Winds:

The winds in the Kim River Basin are light to moderate in speed and maximum wind velocity is observed during late summers and monsoon seasons (May end- September). Winds are normally strong in the lower parts of the basin that is due to its close proximity of sea. During June to September, the winds blow from SW to SWS direction, while during rest of the year, the prevailing wind direction is NE (Table 6.1).

Rainfall:

In any area, Rainfall (precipitation) is the principal source of all naturally available water. Precipitation data is a basic input for the study of any water resource system. Study on secular behaviour of rainfall of an area plays a significant role in crop planning as well as making suggestive predictions about crop-water requirements in different seasons, runoff & storage in reservoirs, groundwater recharge and flood conditions (Garg, 1998). It is also known fact that the rainfall intensity, its duration and distribution vary notable from area to area. These variations play a key role for hydrogeological investigations of an area.

The rainfall in the Kim River Basin is measured at number of weather stations viz. Kim, Kosamba, Tadkeshwar, Mangrol, Velachha, Pingut and Baldeva, while in the peripherial regions of the basin, it is measured at Olpad, Hansot, Valia, Uteva, Zankhvav and Amli(Fig 6.1). The study area receives its rainfall from the south-western monsoon, opening in mid- June and reaches to its maximum intensity during July. About 95% of rainfall occurs during July – September months

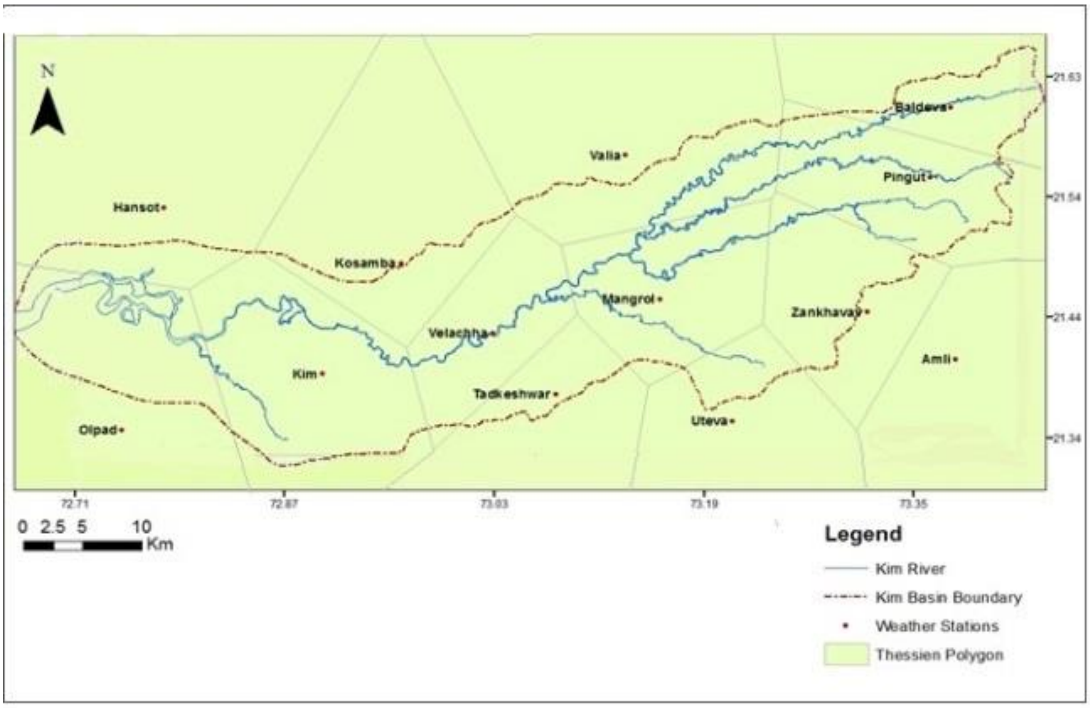

Figure 6. 1 Theissen's Polygon Method applied over the Kim River Basin

In water budget studies, it is necessary to know the average depth of precipitation over a drainage basin. Therefore, the Effective Uniform Depth (EUD) of precipitation over the study area was determined by using the Thessien polygon method. Theissen's Polygon is a graphical technique that attempts to allow for non-uniform distribution of rain gauge stations by providing a weighting factor for each station. In this method, the stations are plotted on a map, and inter-connecting lines are drawn. Perpendicular bisectors of these connecting lines form polygons around each station. The sides of each polygon falling within the basin area have been considered as the weighted area effective to precipitation of an individual station. Then for each polygon area, its percentage to total basin area has been computed. Thus weighted precipitation for an individual polygon has been derived by multiplying percentage of total area with observed rainfall input. Lastly, summation of weighted precipitation has provided an average precipitation of the basin at large.

Weighted average rainfall for the total basin area is then computed by multiplying the precipitation of each station by its assigned percentage of area and summation (Linsley et al, 1982). For this, the candidate as considered data of monthly precipitation for the period between 1983 and 2013 and calculated an average annual precipitation for an individual station to derive weighted rainfall for the study area(Table 6.2).

Sr. No.	Station	Rainfall (m)	Area of Polygon (km^2)	% of total Area	Weighted Precipitation (m)
1	Pingut	1.29	150.58	11.41	0.147606
2	Baldeva	1.34	41.48	3.14	0.041981
3	Zankhav	1.26	108.58	8.23	0.103311
4	Kim	0.98	237.18	17.97	0.175182
5	Kosamba	0.96	66.19	5.01	0.048186
6	Hansot	0.97	77.32	5.86	0.056933
7	Olpad	0.95	128.63	9.74	0.092376
8	Valia	1.13	115.73	8.77	0.098804
9	Mangrol	1.15	172.96	13.10	0.150547
10	Tadkeshwar	1.22	50.91	3.86	0.047127
11	Uteva	1.28	36.13	2.74	0.035143
12	Velachha	1.10	134.37	10.18	0.111563
	TOTAL		**1320**	**100**	**1.108759**

6. 2 Weighted Precipitation for Kim River Basin by Theissen's Method

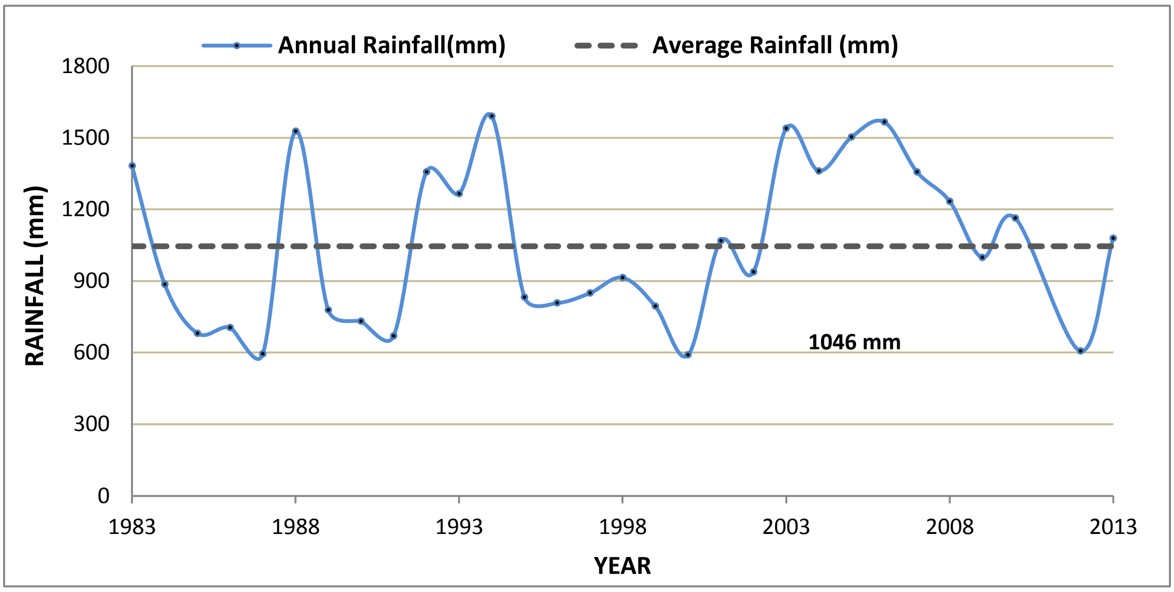

Figure 6. 2 Rainfall Time Series Curve for the Study Area (1983-2013)

Record of rainfall data from 1983-2013 (30 years) for relevant weather stations was collected from the State Water Data Centre, Gandhinagar. Average precipitation for the study area was then computed individually from 1983 to 2013 (30 years) and a rainfall time series curve for the study area was plotted (Fig. 6.2), which indicated high variability of rainfall in the study area. The mean annual rainfall in the study area is 1046 mm. On a closer observation it also indicates that the area has received above average rainfall for about 14 years, and the remaining years, it was below average. The lowest rainfall experienced in this area was in year 2000 (590 mm) and highest rainfall 1590 mm, experienced during the year 1994.

Evapotranspiration:

Evapotranspiration or consumptive use is the total amount of evaporation from a watershed, is taken as the sum of evaporation losses from the barren land and the plants (transpiration)[1]. Evapotranspiration is a function of three major processes (Manning, 1989) that return moisture to the atmosphere over the vegetated land area, that includes-

a) Evaporation of precipitation intercepted by plant surfaces.
b) Evaporation of moisture from plants through transpiration.
c) Evaporation of moisture from the soil surface.

'Potential Evapotranspiration' (PET) is the rate of evapotranspiration from a fully vegetated watershed when sufficient moisture is available to meet the requirements, while, 'Actual Evapotranspiration' (AET) occurs under normal field conditions (Thornthwaite, 1944).

Weather parameters affecting rate of evapotranspiration are radiation, air temperature, relative humidity and wind speed. ET_o is commonly computed using pan evaporation values (mm/day) obtained from the weather stations of a region. The pan evaporation is related to the reference evapotranspiration by an empirically derived pan coefficient:

$$\mathbf{ET_o = K_p \times E_{pan}}$$

Where, ET_o = Reference Evapotranspiration (mm/Day)

K_p = Pan Co-efficient = 0.70 (FAO,1977)

E_{pan} = Pan Evaporation (mm/Day)

The evaporation power of the atmosphere is expressed by the reference evapotranspiration (ET_o). Table 6.3 summarizes average monthly temperature, Relative Humidity and Pan Evaporation in the Kim River Basin for a period of 10 years (2003-2013).

Month	**Pan Evaporation**		**Evapotranspiration**(ET_o)	
	(mm/day)	(mm/month)	(mm/day)	(mm/month)
January	3.7	114.7	2.61	80.91
February	4.1	114.8	2.90	81.2
March	4.7	145.7	3.30	102.3
April	5.0	150	3.51	105.3
May	5.5	170.5	3.83	118.73
June	4.3	129	3.02	90.6
July	3.0	93	2.11	65.41
August	3.1	96.1	2.20	68.2
September	3.7	111	2.58	77.4
October	4.1	127.1	2.88	89.28
November	3.7	111	2.58	77.4
December	3.8	117.8	2.66	82.46
Total (mm/year)		**1480.7**		**1039.19**

Table 6.3 Decadal Average (2003-2013) Climatic Parameters in the Kim River Basin

The average water loss due to evaporation for the Kim River Basin stands at **1.480 m/year** and that due to evapotranspiration is **1.039m/year**. These computed values (Table 6.3) are further utilized in preceding chapter for calculating the consumptive use in the study area. For this purpose, the parameters like crop type, its variety, land cover and phenology have been considered. The computed AET for the study area has been further utilized in the estimation of the agricultural Water Footprint of the study area for different time periods.

SURFACE WATER HYDROLOGY

Surface water hydrology of any region is governed by a variety of attributes such as topography, soils, land use and climatic conditions and precipitation. Hydrology affects the development and character of surface water systems in a region. The surface water hydrology regimes of the study area comprises of Kim River, village lakes & ponds and irrigation reservoirs. Primary source of surface water in the study area is rainfall. Runoff from Kim River and its tributary streams forms the part of storage in the dams, tanks and ponds. The following table (Table 6.4) shows district wise decadal comparison of utilization of various water resources in the study area for irrigation purpose.

DISTRICT	TALUKA	YEAR	Irrigation Source and area (km^2)				
			Canals	River	Wells/ Tube Wells	Tanks/ Lakes/ Ponds	Total Irrigated Area by Sources
BHARUCH	Hansot	2003	70.7	1.6	0	0.3	73
		2013	73.6	0	4.4	0.2	78
	Valia	2003	12.3	5.4	38.5	0.2	56
		2013	11	40	36	17.3	104
SURAT	Mandvi	2003	21.2	2.5	4.7	1.2	30
		2013	27	0	7.3	0	34
	Mangrol	2003	110	6.6	35.2	2	154
		2013	92	3	23.4	0.3	119
	Olpad	2003	146.8	2.3	6.5	0.7	156
		2013	141.6	1.1	10.4	2.2	155
	Umarpada	2003	0	0	1	0	1
		2013	0	0	0.8	0.2	1

**Source: District Census Handbook,2001,2011*

Table 6.4 Decadal change in Various Water Sources for Irrigation in the Study Area

It is evident from Table 6.4 that in the study area canal irrigation predominates over other water sources. This is followed by groundwater as a source for irrigation, particularly practiced in the upper parts of the basin- the rocky upland region. Other water sources are meagre and localized in nature.

Village Lakes and Ponds:

Village ponds and lakes are the traditional rainwater harvesting structures, especially developed in the terrain characterized by the poor groundwater quality (Saline/ Brackish) and meagre quantity due to adverse geological environment.

In the study area, these structures are ubiquitously seen in the middle and lower parts of the basin, which is characterized by flat terrain i.e. coastal plain consisting muddy sediments with inherent salinity. In the study area, ponds are constructed across the remnants of palaeo-channel courses and every village situated within the coastal plain region has at least one such structure. These ponds during monsoon season get filled and freshwater starts recharging the shallow phreatic saline aquifers. Due to low density and weight of stored water, freshwater pushes the saline water from the pond and its peripheral region and create fresh groundwater mound subsurfacely (Fig 6.3). Such groundwater mounds sustain the water demand to the local inhabitants during the lean monsoon phase through a system of open dug wells located on the peripheral region of the pond (Plate 6.1). After the commencement of canal irrigation by and large, these ponds have been linked through the canals making them a structure for perennial storage.

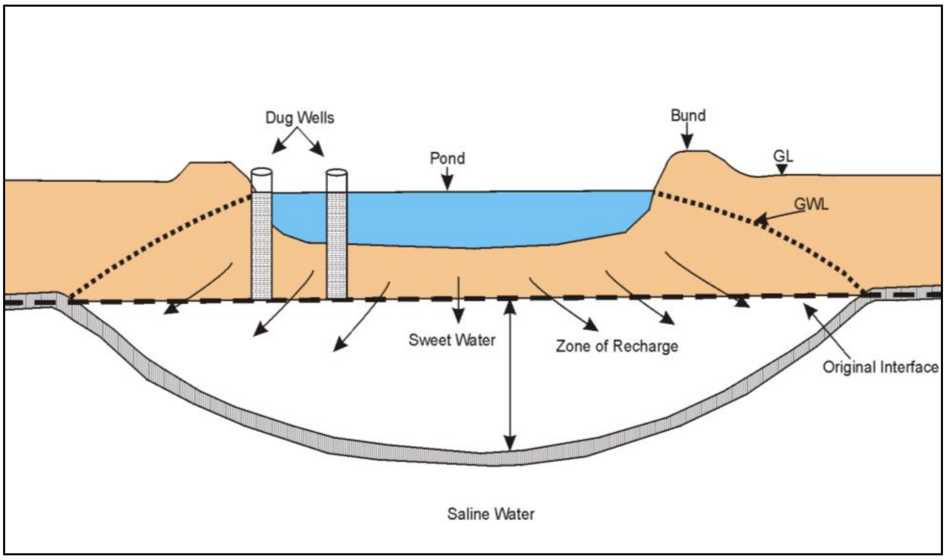

Figure 6. 3 A Schematic Cross Section of Village Pond Giving Details on Saline Water Interface and Creation of Potable Groundwater Mound along with Open Dug Wells for Groundwater Abstraction.

Plate 6.1 A view of Village Pond Inhibiting Open dug Well at the Peripheral Region. (Loc. Kantiyajal)

Dams & Reservoirs:

The study area has two minor irrigation schemes viz. the Pingut and Baldeva Irrigation Schemes constructed on Tokri River, a tributary of the Kim River. Details of both the schemes are highlighted in Table 6.5.

The upper part of the Kim River watershed is rocky and hilly therefore, witnesses high surface run-off. The groundwater potential is also poor due to basaltic rocky aquifers characterized by high order of seasonal water table fluctuations. The Irrigation Schemes of Pingut (Plate 6.2) and Baldeva were thus setup on the tributary of the Kim River as a continuous source for fresh water, primarily for irrigation purpose.

Irrigation Scheme Details:	**PINGUT**	**BALDEVA**
Taluka	Valia	Valia
Village	Khambhi	Baldeva
River	Tokri	Tokri
Location:	21^{o} 30’ N 73^{o} 24’ E	21^{o} 36’ N 73^{o} 21’ E
Catchment Area	21.25 km^2	29.56 km^2
Purpose	Irrigation	Irrigation
C.C.A	14.06 km^2	22.40 km^2
Nature of Catchment	Hilly - Forested Area	Hilly - Forested Area
Ave. Annual Rainfall	2000mm	1216 mm
Max. Flood Discharge	15100 Cusecs	24650 Cusecs
Dam Details:		
Type	Earthen	Earthen
Length	1345 metres	1193 metres
Canal Details:		
L.B.M.C	6.4 km	2.7 km
R.B.M.C.	4.6 km	5.6 km
Type of Canal	Lined	Lined
No of villages benefitted	6	13

Table 6.5 Salient Features of the Baldeva and Pingut Irrigation Schemes in the Study Area

Plate 6.2 A View of Pingut Dam and Reservoir (Loc. Khambi Village Tal.Rajpipla)

The data on rainfall, storage capacity along with accrued irrigation benefit for the past 10 years (2003 – 2013) of both the Pingut and Baldeva irrigation schemes are given in Table 6.6.

Year	PINGUT			BALDEVA		
	Rainfall (mm)	Live Storage (MCM)	Total Irrigated Area (hecs)	Rainfall (mm)	Live Storage (MCM)	Total Irrigated Area (hecs)
2003	1682	8.04	989	1492	7.84	594
2004	1278	7.55	786	1602	7.84	686
2005	995	7.40	965	1314	7.84	574
2006	1339	7.50	719	1801	7.84	492
2007	1574	7.56	733	1768	7.84	495
2008	1400	7.50	619	1438	7.84	583
2009	811	7.13	659	1395	7.84	741
2010	895	6.22	442	1023	7.84	687
2011	968	7.22	494	1124	7.84	807
2012	1467	5.28	176	1929	7.84	19
2013	746	7.27	328	1050	7.84	521

**Source: Superintendent Engineer Office, Baldeva & Pingut Irrigation Schemes, Rajpipla*

Table 6.6 Decadal Status of Hydrologic Storage and Irrigation Inputs of Pingut and Baldeva Irrigation Schemes

It is clearly discernible from the data (Table 6.6) that for the past two decades, these irrigation schemes have substantially supported the irrigation in their respective command area on sustainable basis.

Canal System:

In the study area, irrigation is predominantly carried out through canal water of various irrigation schemes (Table 6.3). In the upper parts of the Kim River Basin, there exists two canal systems viz. the Pingut which is 11 km long and the Baldeva which is 9.3 km (Fig 6.4).

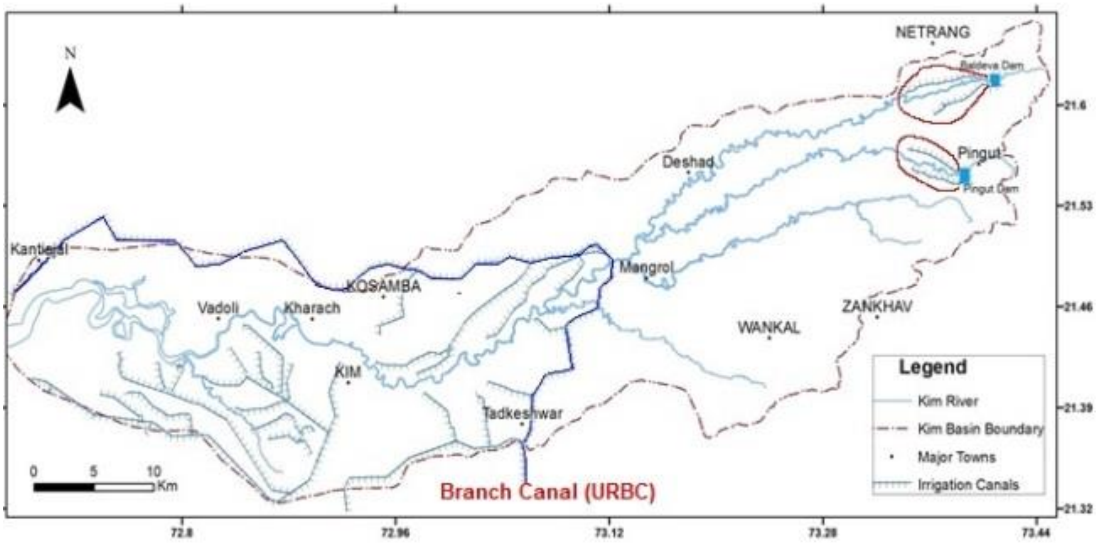

Figure 6.4 Map Showing Network of Various Branch and Distributary Canals in the Study Area

Further, the canal command area is also restricted within the basin limits. But the major part of the basin, particularly the middle and lower, has a canal network that belongs to the Ukai Right Bank Canal (URBC) and the Kakrapar Right Bank Canal (KRBC), a major irrigation projects developed from Tapi River, which is an adjacent basin in south of the study area. These two canal systems together form a network of almost 270 km with their main and distributary canals' (Figure 6.4). The entire Pingut, Baldeva and KRBC Schemes have the lined canals, while the main canal of URBC is unlined (Plate 6.3).

Plate 6.3 A View of unlined Warethi Distributary of the URBC (Loc. Warethi. Kim-Mandvi Highway)

The details of the crops sown in the study area in each cropping season and applied irrigation water through the existing canal schemes, for the past 10 years (2003-2013) is given in Annexure 5 as a data input to compute the agricultural Water Footprint of the study area.

Kim River:

The Kim is a perennial river originating from the hill ranges of Bharuch District in the east. It flows in the south-west direction covering a total length of 107 km and covers an area of 1320 km^2. In terms of water potential, Kim holds adequate water throughout the year. The river in its upper rocky upland part is dry in the summer, while in the lower reaches the river has sluggish flow on perennial basis. Further, during post-monsoon season, the river on comparing with water table position offer gaining (Affluent) stream condition till the middle segment of the basin, whereas, the lower segment of the basin at places, show losing(Influent) nature. As a result river channel has numerous water pools that subsists the irrigation and domestic water demands to the bank area population.

The River Discharge and Flow rate of the Kim River are monitored at Daheli River Gauge Station (21^0 33’40” N, 73^0 12’14’’E) on daily basis. However, the candidate for her need has adopted, these data (2003-2013) on annual basis (Table 6.7)

YEAR	Maximum Discharge (Cusecs)	Month	Average Rainfall (mm)	Average Annual Flow (Cumecs)
2003	140.58	July	836	50.671
2004	1535.46	October	1470	88.458
2005	246.67	October	1283	50.77
2006	417.52	July	1482	77.11
2007	954.5	October	1388	35.668
2008	512.85	July	1050	39.115
2009	266.64	August	1136	42
2010	191	July	634	14.518
2011	206	July	740	38
2012	88	October	159	8.2
2013	120	July	597	27

**Source: State Water Data Centre, Gandhinagar*

Table 6.7 A Summary of Annual Discharge of Kim River as Monitored at Daheli

Although the river discharge is a function of rainfall input and watershed characteristics, there is a glaring disparity trends in the river discharge and rainfall (Table 6.7). this rainfall and river discharge data incongruity is attributed to the presence of two irrigation reservoirs, viz. the Pingut and Baldeva. Delimiting the river discharge, the plotted river discharge hydrograph (Fig 6.5) shows annual discharge during the year 2004 as the highest, that progressively shows decreasing trend till the year 2013. Considering the available data sets (SWDC,2014), the mean annual discharge of the Kim River at Daheli River Gauge station stands at ~ 425 cusecs.

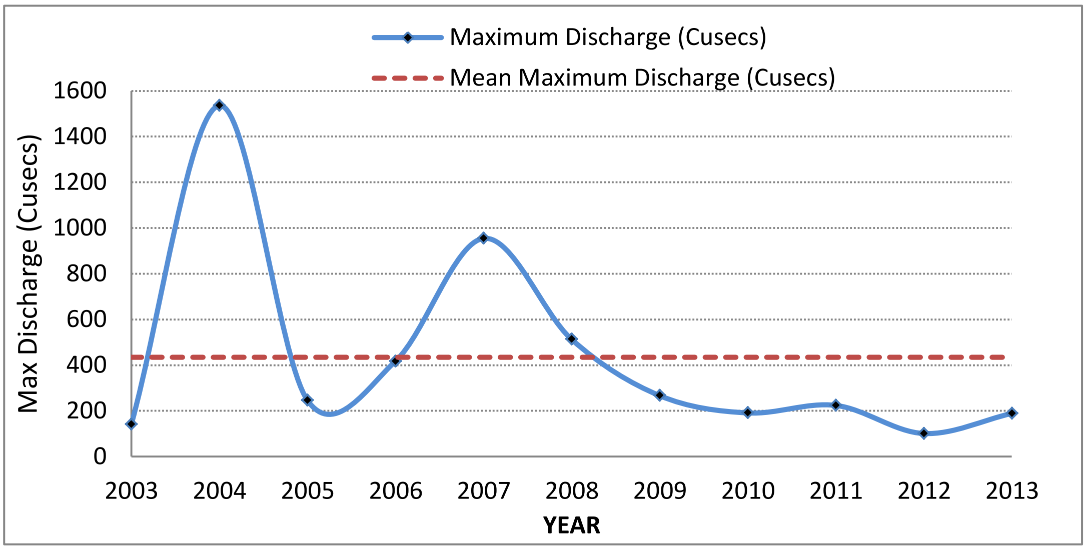

Figure 6.5 Annual Discharge Hydrograph of Kim River as Observed at Daheli

In terms of water quality, the Kim River shows a diverse scenario. In the upper reaches, due to hilly terrain and less human settlements, the river has maintained its pristine nature and show good water quality. In the central alluvium plains, the dendritic river channels flow through places of human settlements where its water is used for various domestic purposes that leads to slight deterioration in its quality. Further downstream of the NH-8, i.e. towns of Kim & Kosamba, the water quality is polluted due to disposal of sewage and industrial effluents.

Plate 6.4 Pollution in the Kim River due to Domestic Activities. Loc. NH-Bridge at Kosamba

Location	Kambodiya Bridge 21^0 36'N and 73^0 21'E (Upstream)		Vadoli Bridge 21^0 25'N and 72^0 49'E (Downstream)	
Parameters	**Pre-monsoon**	**Post-monsoon**	**Pre-monsoon**	**Post-monsoon**
pH	8.2	7.9	8.1	8.1
DO (mg/l)	8.5	8.4	4.3	3.8
Nitrates (mg/l)	48	30	54	32
Phosphates (mg/l)	0.34	0.18	1.6	0.25
Sulphates (mg/l)	1.1	1.3	1.9	1.8
TDS(mg/l)	420	1000	1100	1140
TSS (mg/l)	10	32	45	80

**Source: GES,2013*

Table 6.8 Kim Water Quality as monitored in the U/S and D/S of the river

A comparative account on the water quality deterioration based on the chemical analysis of water samples collected from different upstream and downstream locations (Table 6.8) points to that during the post monsoon period-

i) Dissolved Oxygen (DO) tends to decrease from 8.5 to 4.3 mg/l.

ii) Nitrate (NO_3^{-2}) tends to increase from 48 to 54mg/l.

iii) Phosphate (PO_4^{-2}) tends to increase from 0.34 to 1.6 mg/l.

iv) Total Dissolved Soilds(TDS) tends to increase from 420 to1100 mg/l and

v) TSS shows marked increase from 10 to 45 mg/l.

Owing to the obvious limitations offered by the river discharge data that are available for a very limited area, for the water balance study, the candidate has computed the surface run-off in the study area using theoretical approaches.

SURFACE RUN-OFF

Surface runoff is that fraction of precipitation and other drainage water of a watershed, which moves over the natural land surface and then through a network of channels into the main stream as surface flow (Batra, 2001). Rainfall intensity & duration, area of the drainage basin, basin geology, drainage pattern, vegetation, soil type, slope and water table are few notable factors that control the surface runoff in an watershed (Taylor and Schwatz, 1952).

Due to lack of appropriate runoff data availability for the Kim River Basin, the author has estimated reliable runoff using standard Empirical Approaches like Binnie's Runoff Percentages (1870) and Barlow's Method (1912).

Binnie's Runoff Percentage:

Sir Alexander Binnie (1872) measured the runoff for more than 40 catchments in India and developed curves of cumulative runoff against cumulative rainfall and found them to be similar and he had derived the percentage of runoff accordingly. (Table 6.9)

Annual Rainfall (mm)	500	600	700	800	900	1000	1100
Annual Runoff %	15	21	25	29	34	38	40

Table 6.9 Binnie's Annual Runoff Percentages

In the study area, the Average Annual Precipitation is 1108mm (Table 6.2). Applying the Binnie's Runoff Percentage (Table 6.9), the annual runoff for the Kim River Basin is 40% of the total precipitation which is evaluated as **440 mm/year**, i.e. 580.8 MCM/year.

Barlow's Method:

Barlow (1912), on the basis of his extensive studies on small catchments (~130km^2), characterized by different land-use patterns, in Uttar Pradesh, proposed the following equation to calculate the runoff-

$$R = kP$$

Where, *R*- Runoff; *P*-Precipitation, *k*- Percentage Coefficient

Further, he had categorized watersheds into five categories and suggested their values of respective coefficients applicable for rainfall input as, light (<25 mm/day), medium (25-75 mm/day) and continuous down pour (>75 mm/day).Using these two factors, values of co-efficients for different catchment types and rainfall nature has been suggested (Table 6.10).

Nature of Rainfall	Catchment Types				
	A	B	C	D	E
Light rain (<25mm/day)	7	12	16	28	36
Medium rainfall (25-75mm/day)	10	15	20	35	45
Continuous downpour (>75mm/day)	15	18	32	60	81

A: flat cultivated and black cotton soil, B: flat, partly cultivated soil,
C. average catchment, D: hills and plains with little cultivation,
E: hilly and steep regions with hardly any cultivation

Table 6.10(A) Percentage Coefficients (k) for Surface Runoff Computation (Barlow,1912)

To compute the annual runoff in the Kim River Basin, the candidate has adopted the Theissen's polygons as weighted catchment units, used for rainfall calculation and applied Medium Rainfall as input along with appropriate applicable catchment types, viz. A, C & D.

Catchment Type	Area of Polygon (km^2)	Weighted Precipitation (m)	Total Rainfall Received (MCM)	Percent Coefficient (*k*)	Runoff Total Runoff (MCM)
D	300.639	1.11	333.709	**35**	117
C	1019.42		1131.09	**20**	226
Total	1320.00	-	**1465**	**-**	**343**

Table 6.10(B) Annual Surface Runoff for the Kim Watershed (Barlow's Method)

The annual runoff calculated (Table 6.10), calculated by Barlow's method, thus, stands at 343 MCM/year.

Runoff calculations using both the methods signify that there is great variation in the obtained runoff values. The runoff calculated using Barlow's co-efficient is more accurate as compared to the Binnie's method, since the previous technique takes into account the classification of catchment areas based on their physical and topographical attributes while the later method has a general runoff percentage factor which stands for any type of catchment. Hence, for all further calculations like water balance studies etc., the Barlow's approach is taken into consideration.