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ASSESSMENT OF ENVIRONMENTAL FLOWS REQUIREMENTS OF VISHWAMITRI RIVER USING HYDROLOGICAL METHODS

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ABSTRACT

In the present research work, efforts are made to assess the Environmental Flows Requirements (EFRs) for water deficient and highly urbanized & industrialized zone-2 of Vishwamitri River i.e. downstream to confluence point of Surya tributary with Vishwamitri River. EFRs are extracted in terms of % natural Mean Annual Flow (MAF) for High Flow Season (HFS) and Low Flow Season (LFS). The average daily discharge data available during 2003-2015was analysed to estimate the total annual flow available at upstream of Zone-2. The MAF was estimated 73.00 MCM for Vishwamitri River. According to Tennant method, Zone-2 of Vishwamitri River would remain in outstanding habitat conditions with 60% of MAF during HFS and 40% of MAF during LFS. According to Tessman method, outstanding habitat conditions can be derived if flow varies from minimum of1.19 m^3/s during LFS to maximum 7.10 m^3/s during HFS. The preliminary estimate of EFR is also derived using Flow Duration Curve (FDC) Shifting Method by Global Environmental Flow Calculator (GEFC) software and accordingly the EFR should be 33 to 60% of MAF to maintain slightly modified to natural ecological conditions. The result derived by FDC Shifting Method validates the results derived through Tennant and Tessman methods.

Keywords: *Environmental Flows, Habitat Conditions, Tennant Method, Tessman method, FDC Shifting Method, GEFC.*

INTRODUCTION

Globally the importance of maintaining sustainable river basins, by reserving some water along the river, is growing. “Environmental flows (E-Flows) describe the quantity, quality and timing of water flows required to sustain freshwater & estuarine ecosystem, the human livelihoods and well-being that depend on these ecosystems (The Brisbane Declaration, 2007)”.Environmental flow requirements are often described in terms of flow discharges of certain magnitude, timing, frequency and duration (Smakhtin and Anputhas, 2006). These flows ensure the capability of river regime to sustain biodiversified aquatic habitats and various ecosystem processes. Certain amount of flow is to be purposefully left into an aquatic ecosystem to maintain it in a good habitat condition. Study of the nature of rivers as ecosystems is quite essential as the ecological integrity depends upon their physical, chemical and biological characteristics. Flow in river controls the the physical characteristics and ecosystems of rivers.Recently in India, the awareness of the need to reserve some water along a river has been increased. Environmental Flows Assessments (EFAs) is a new research field in India.Tharme (2003) reviewed more than 200 various EFA methods.The majority of these methods can be grouped into following distinct categories.

- Hydrological Methods
- Hydraulic Rating methods
- Habitat Simulation Methods
- Holistic Methods

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1. The main driving issues for the choice of method for assessment of E-flows are scoping, basin scale planning, impact assessment and river restoration (Acreman and Dunbar, 2004). Some studies have been reported on estimation of environmental flows using hydrological index methods for the selected stretches of Narmada and Cauvery Rivers, respectively (Dubey, et al. 2013; Durbude, et al. 2014). For the assessments of many river basins at national level, rapid hydrological methods would be most suitable.

HYDROLOGICAL METHODS

In these methods, the past hydrological data series records of the river flows (discharge as m^3/s) are used for recommending E-flows for maintaining river health at designated level. These methodologies are widely used in both developed and developing countries at initial planning level.

Tennant method (Tennant 1975, 1976 a, b) is also known as Montana method, widely used hydrological method which addresses E-flows for fishes and wildlife, recreation and other related environmental resources. Tennant method proposes the value of minimum and optimum environmental flows to be releasedfor availing desired habitat conditions in river. The percentage allocation of MAF reduces with degradation in habitat condition. Tessman (1980) had modified Tennant method by considering natural variations in flow on a monthly basis.

River Zoning

Vishwamitri River stretch can be classified into two major zones as follows based on Water Quality Status (WQS) (Bhangaonkar and Patel, 2018).
Zone-1: Stretch of Vishwamitri from origin to NH-8 bridge

Water quality of this stretch of Vishwamitri has represented Water Quality Index (WQI) values ranging from 50 to 75.

Zone-1 is rich with DO. It can support good ecology if restored in perennial behavior. Zone-2: Stretch of Vishwamitri from NH-8 bridge upto confluence of Vishwamitri with Dhadhar River

Water quality of this stretch has replicated WQI values more than 75. Zone-2 is more polluted than Zone-1.

DESCRIPTION OF STUDY AREA

Zone-2 contains high BOD and less DO. Zone-2 also polluted due to higher concentration of hardness, chloride, sulphate and alkalinity. This downstream water of Vishwamitri is also used for irrigation purpose by the adjoining farms (Sharma, 2016). Thus, zone 2 requires more attention in qualitative and restoration aspects. Figure 1 represents study area of Vishwamitri along with river zoning.

Table 1: Tennant (1976) Method for Estimating E-Flows as % of MAF

Description of Flow	April to September	October to March
Flushing flow (from 48 – 96 hours)	200% MAF	Not Applicable
Optimum range of flow	60 - 100% MAF	60 - 100% MAF
Outstanding habitat	60% MAF	40% MAF
Excellent habitat	50% MAF	30% MAF
Good habitat	40% MAF	20% MAF
Fair or degrading habitat	30% MAF	10% MAF
Poor or minimum habitat	10% MAF	10% MAF
Severe degradation	<10% MAF	<10% MAF

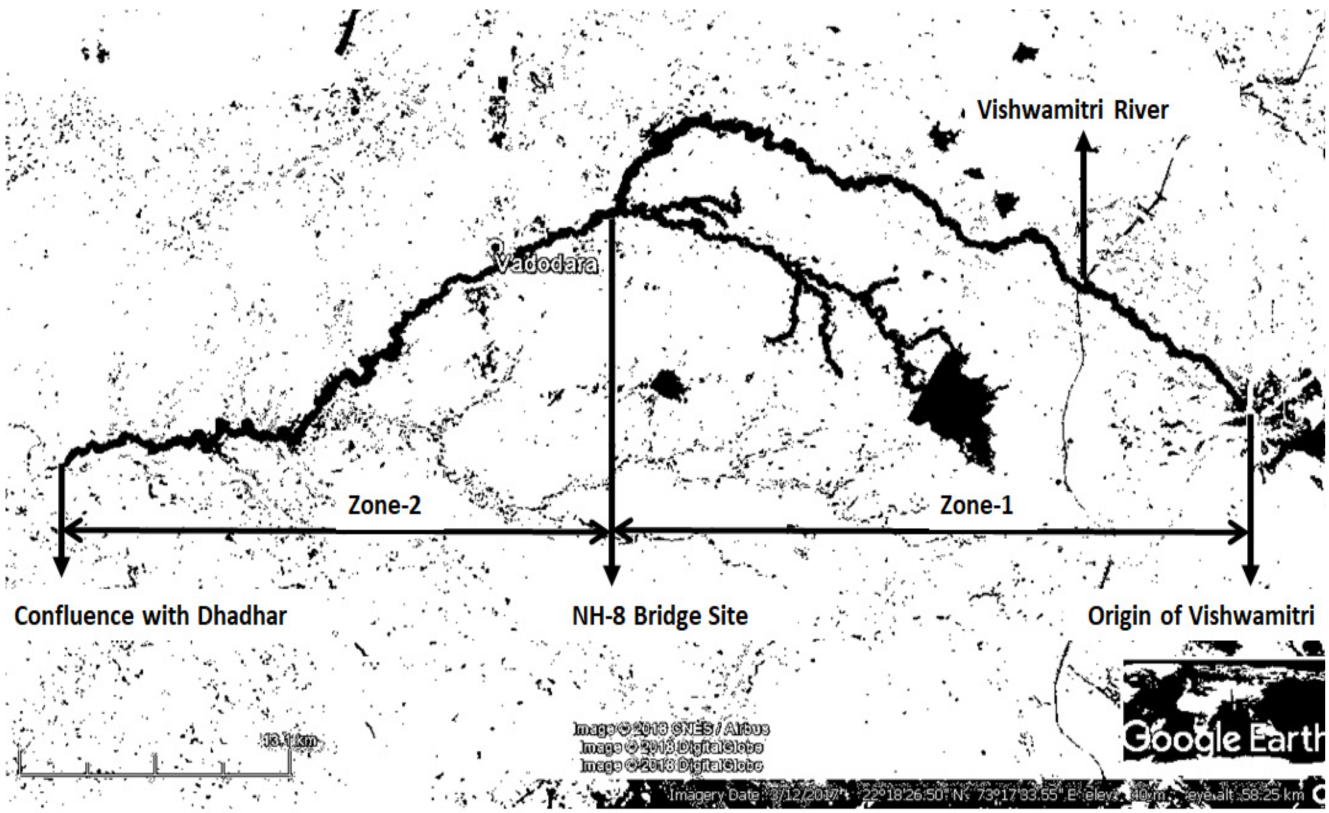

Fig.1: Depiction of Vishwamitri along with Zones

METHODOLOGY

In the present study “Tennant Method” is adopted, wherein environmental flow regimes are prescribed on the basis of the mean daily discharge or the Mean Annual Flow (MAF). Tennant (1976) proposed that certain flow can achieve the maintenance of particular state of habitat as given below in Table 1.

Tessman (1980) adopted Tennant seasonal flow recommendations to calibrate the percentage of Mean Annual flow (MAF) including monthly variability.These recommendations are based on Mean Monthly Flows (MMFs) as well as Mean Annual Flows (MAF).As per Modified Tenant method, the conditioned represented in Table 2are formulated to determine magnitude of monthly E-flows in the river.

Table 2: Conditions by Tessman to Formulate Monthly E-flows

Condition	Monthly E-flows
If MMF < 40% of MAF	Monthly minimum E-flows equals to the Mean Monthly Flow (MMF)
If MMF > 40% MAF	Monthly minimum E-flows equals to the 40% MAF
If 40% MMF > 40% MAF	Monthly minimum E-flows equals to the 40% MMF
Flushing Flows	For two weeks period 200% of MAF is required as flushing flow on an annual basis during the month of highest runoff

The mean daily discharge data availed from State Water Data Center (Gandhinagar, Gujarat) at Pilol river gauging station on Vishwamitri and volume of water released in Surya River, a major tributary of Vishwamitri, through Ajwa weir (operated at Ajwa reservoir by Vadodara Mahanagar Seva Sadan (VMSS), Vadodara) are used to estimate the total annual flow available at upstream of the Zone-2. Table 3 represents sample daily discharge data and monthly flow at Pilol river gauging station on Vishwamitri River for duration 2013-2015. River mainly flows during four months i.e. June, July, August and September. Table 4 represents volume of water released during 2003-2015 from Ajwa weir in Surya River. Annual flow of water available at upstream of Zone-2 for last thirteen years duration i.e. 2003-2015 at confluence of Vishwamitri and Surya is represented in Table 5. The Mean Annual Flow (MAF) is estimated to be 73.00 MCM. Table 6 represents the Environmental Flow Requirements (EFRs) of Vishwamitri River during High Flow Season (HFS: From June to September) and Low Flow Season (LFS: From October to May) using Tennant Method.

Mean monthly flows, expressed in terms of % inflows of Vishwamitri, were used to derive month wise distribution. The mean monthly flow distribution during August month was estimated as 30.47 MCM (i.e. 41.73% of MAF) which is more than 29.20 MCM (i.e. 40% of MAF) and hence minimum of 40% MAF has been considered to derive monthly E-flows during same month. In order to reduce mean monthly flows during August, the excess inflows in Vishwamitri during this month are to be restored or harvested. The mean monthly flow distribution during June, July, September and October was estimated and it was found that mean monthly flows were less than 29.20 MCM (i.e. 40% of MAF) and hence for these months actual % MMF were considered to derive monthly E-flows distribution.The percentage distributions of monthly E-flows for the duration from November to May were assumed uniform to impart perennial behavior to Vishwamitri. The estimated Environmental flowallocations for Zone-2 using Tessman method are represented in Table 7.

Table 3:Daily Discharge Data and Monthly Flow at Pilol Gauge Station

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Month	Monthly Flow (in MCM)												
June	---	---	31.76	---	---	---	---	---	---	---	2.81	---	---
July	4.43	6.67	28.65	13.63	6.00	---	2.96	1.01	9.95	---	46.23	42.76	0.38
Aug	7.78	46.76	2.30	40.87	6.88	13.25	0.29	28.74	84.20	29.23	49.09	22.81	0.09
Sept	3.00	---	28.25	3.91	13.23	4.77	0.091	44.01	16.79	11.11	78.14	61.79	---
Oct	---	---	0.23	1.38	1.06	---	---	0.05	1.15	---	8.08	6.74	---
Total	15.21	53.43	91.21	59.79	27.17	18.02	3.34	73.81	112.09	40.34	184.35	134.10	0.47

Source: Derived through runoff data availed from State Water Data Centre (SWDC) Gandhinagar

Table 4: Volume of Water Released from Ajwa Weir

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AnnualFlow (in MCM)	8.81	98.28	---	---	0.11	---	---	6.11	2.71	0.11	2.26	16.01	---

Source: Derived through runoff data from Vadodara Mahanagar Seva Sadan (VMSS), Vadodara

Table 5:Annual Flow of Water Available at U/s of Zone-2

Year	Annual Flow (in MCM)		
	Vishwamitri River(Gauged at Pilol)	Surya River(Gauged at Ajwa)	Total Annual Flow
2003	15.21	8.81	24.03
2004	53.43	98.28	151.71
2005	91.21	0.00	91.21
2006	59.79	0.00	59.79
2007	27.17	0.11	27.28
2008	18.02	0.00	18.02
2009	3.35	0.00	3.35
2010	73.83	6.11	79.94
2011	112.11	2.71	114.82
2012	40.46	0.11	40.57
2013	184.37	2.26	186.63
2014	134.12	16.01	150.13
2015	0.48	0.00	0.48
Mean Annual Flow in MCM (Duration: 2003-2015)			73.00

Table 6:Estimated Environmental Flow Allocation for Zone-2 using Tennant Method

Site Name	MAF (In MCM)	Flow Requirements(as % of MAF)	HFS (In MCM)	LFS (In MCM)
Downstream to NH-8 bridge (Zone-2: i.e. S-8 to S-16)	73.00	Flushing flow (200%)	146	Not Applicable
		Optimum range (60-100%)	44-73	44-73
		Outstanding (60% at HFS, 40% at LFS)	43.80	29.20
		Excellent (50% at HFS, 30% at LFS)	36.50	21.90
		Good (40% at HFS, 20% at LFS)	29.20	14.60
		Fair or degrading (30% at HFS, 10% at LFS)	21.90	7.30
		Poor (10%)	7.30	7.30
		Severe degradation (<10%)	<7.30	<7.30

MAF= Mean Annual Flow derived from Daily Discharge Data for Period 2003-2015, MCM= Million Cubic Meters, HFS= High Flow Season (June-Sept), LFS=Low Flow Season (Oct-May)

Table 7: Estimated Environmental Flow Allocation for Zone-2 of Vishwamitri River Using Tessman's Method

Month	% Distribution	Poor: 10% MAF*		Fair: 40% MAF		Good: 60% MAF		Excellent: 80% MAF		Outstanding: 100% MAF	
		MCM	m^3/s	MCM	m^3/s	MCM	m^3/s	MCM	m^3/s	MCM	m^3/s
June	2.83	0.22	0.08	0.65	0.31	0.87	0.33	1.08	0.42	1.30	0.50
July	27.25	2.09	0.81	6.27	3.02	8.36	3.22	10.45	4.03	12.54	4.84
August	40.00	3.07	1.18	9.20	4.44	12.27	4.73	15.33	5.92	18.40	7.10
September	25.12	1.93	0.74	5.78	2.79	7.71	2.97	9.63	3.72	11..56	4.46
October	1.26	1.92	0.74	1.9	0.92	3.83	1.48	5.75	2.22	7.67	2.96
November	0.51	0.77	0.30	0.8	0.37	1.54	0.59	2.31	0.89	3.08	1.19
December	0.51	0.77	0.30	0.8	0.37	1.54	0.59	2.31	0.89	3.08	1.19
January	0.51	0.77	0.30	0.8	0.37	1.54	0.59	2.31	0.89	3.08	1.19
February	0.51	0.77	0.30	0.8	0.37	1.54	0.59	2.31	0.89	3.08	1.19
March	0.51	0.77	0.30	0.8	0.37	1.54	0.59	2.31	0.89	3.08	1.19
April	0.51	0.77	0.30	0.8	0.37	1.54	0.59	2.31	0.89	3.08	1.19
May	0.51	0.77	0.30	0.8	0.37	1.54	0.59	2.31	0.89	3.08	1.19
Total	100.00	14.60	---	29.20	---	43.80	---	58.39	---	73.00	---

*Both During HFS and LFS

FDC Shifting Method

For basin scale planning of the Vishwamitri River, the environmental flow assessment can be initiated using Global Flow Environmental Flow Calculator (GEFC). GEFC is a software package for desktop rapid assessment of Environmental Flows. The software is developed by International Water Management Institute (IWMI), Sri Lanka. GEFC has facilities to zoom on arrive basin, calculate a variety of hydrological characteristics, define or select any category of ecosystem protection, calculate the associated environmental flow duration curves (FDCs) and time series and display both. The EF estimation technique in GEFC is using monthly time step series reflecting "natural" / unregulated flow conditions and its corresponding FDC- a cumulative distribution function of flows. The FDC is represented by 17 percentage points on the probability (X) axis. The purpose of Environmental Flow is to maintain the ecosystem in some prescribed or negotiated condition, also referred as desired future state, Environmental Management Classes (EMCs), a level of environmental protection. Six EMCs are incorporated in GEFC, ranging from "Unmodified" to "Critically Modified" as shown in Table 8.

Table 8: Environmental Management Classes (EMCs) used in FDC Shifting Method

EMC	Most Likely Ecological Condition
A	Natural Rivers with minor modification
B	Slightly Modified
C	Moderately Modified. The habitats and dynamics of the biota have been disturbed
D	Largely modified. A large loss of natural habitat, biotas and basic ecosystem functions has occurred.
E	Seriously Modified. The losses of the natural habitats, biotas and basic ecosystem functions are extensive
F	Critically Modified. Modification has reached a critical level and the ecosystem has been completely modified. In the worst case, the basic ecosystem functions have been destroyed and the changes are irreversible.

This software works on concept of shifting of reference FDC along the probability axis and thereby reducing the frequency of flow for desired EMC. The difference between the default shifts of the reference FDC for different EMCs is set to be one percentage point. The analysis can be carried out either using default (simulated) global flow data,

Table 9: Estimate of % Natural MAF and long term EF-volumes (MCM) using FDC Shifting Method

Vishwamitri Watershed		EF-Volumes (MCM)					
% Natural MAF		60.6	33	17.1	8.8	4.6	2.5
Environmental Management Class		A	B	C	D	E	F
% Probability	REF						
0.01	3152.000	3049.000	2131.000	1204.000	891.000	417.000	200.000
0.1	3049.000	2131.000	1204.000	891.000	417.000	200.000	109.000
1	2131.000	1204.000	891.000	417.000	200.000	109.000	57.500
5	1204.000	891.000	417.000	200.000	109.000	57.500	30.600
10	891.000	417.000	200.000	109.000	57.500	30.600	17.000
20	417.000	200.000	109.000	57.500	30.600	17.000	9.310
30	200.000	109.000	57.500	30.600	17.000	9.310	4.240
40	109.000	57.500	30.600	17.000	9.310	4.240	2.120
50	57.500	30.600	17.000	9.310	4.240	2.120	0.412
60	30.600	17.000	9.310	4.240	2.120	0.412	0.247
70	17.000	9.310	4.240	2.120	0.412	0.247	0.235
80	9.310	4.240	2.120	0.412	0.247	0.235	0.223
90	4.240	2.120	0.412	0.247	0.235	0.223	0.212
95	2.120	0.412	0.247	0.235	0.223	0.212	0.201
99	0.412	0.247	0.235	0.223	0.212	0.201	0.191
99.9	0.247	0.235	0.223	0.212	0.201	0.191	0.182
99.99	0.235	0.223	0.212	0.201	0.191	0.182	0.172

with a spatial resolution of 0.5 degree, or a user-defined file. A preliminary estimate of % Natural Mean Annual Flow (MAF) as well as long term EF-volumes (MCM) required for different EMCs derived from the "Global Flow Database" in the form of monthly discharges (in m^3/s) available for duration 1901-2000 for location of Vishwamitri watershed and result is represented in Table 9.

RESULTS AND DISCUSSION

Environmental flows regimes are prescribed on the basis of the average daily discharge or the Mean Annual Flow (MAF) for both High Flow Season (HFS) and Low flow season (LFS). Results derived using Tennant method shows that Zone-2 of Vishwamitri River would remain severely degraded if flows less than 10% of MAF i.e. less than 7.30 MCM; poor or surviving habitat can be observed if flows 10% of MAF i.e. 7.30 MCM in both HFS and LFS whereas outstanding habitat conditions can be observed with 60% of MAF i.e. 43.80 MCM during HFS and 40% of MAF i.e. 29.20 MCM during LFS. Results derived from Tessman method represent the monthly E-flows that can be implemented to restore Vishwamitri in designated habitat. According to Tessman method, poor or surviving habitat can be observed in Zone-2if flow varies from minimum of 0.30 m^3/s during LFS to maximum 1.18 m^3/s during HFS whereas outstanding habitat conditions can be derived if it varies from minimum of 1.19 m^3/s during LFS to maximum 7.10 m^3/s during HFS. In LFS, minimum flows are to be maintained during November to May months while in HFS, maximum flow is to beobserved during August.

From the Global Database of GEFC it is derived that for maintaining the slightly modified to natural ecological conditions in the river at the source site, the EFR should be 33 to 60% of Mean Annual Flow (MAF). Such flows have again 50% of probability of exceedence. The results obtained by FDC Shifting Method validate the results of Tennant and Tessman methods for subsidizing fair to good habitat conditions.

CONCLUSION

Present state of pollution of Vishwamitrireveals the need of releasing environmental flows to restore river into its excellent to outstanding habitat. Water resource planners and authorities can implement the E-flow requirements of Vishwamitri by releasing water through reservoirs, harvesting available surface runoff or off taking flows from Narmada Main Canal (NMC) whichcrosses Vishwamitri River at its upstream stretch in order to restore river in its perennial state. Construction of development of flood plains on downstream side, increasing the storage capacity of existing reservoirs and constructing new storage reservoirs to harvest the annual inflow of the river will not only control the flood but also help later on to maintain environmental flow requirements of the river without compromising the water demands from different sectors. Gated weir or barrage can be constructed on Vishwamitri at suitable downstream location to regulate required E-flows in river. However, measures to control pollution of river at different locations and thereby enhancing the water quality of available surface water resources are equally important.

It is to be noted that Vishwamitri can be a wide source of surface water if properly restored and harvested with its environmental flow requirements. Action plan is required to control the pollution through various point and diffused sources prevailing in Vishwamitri watershed. Besides this, the strong social movement and general interest of community in the restoration of Vishwamitri are of vital importance for solving many of fundamental problems prevailing in watershed. Training and awareness programmes can be conducted for citizens, communities, policy and decision makers, government officials and other stakeholders to recognize the importance regarding need of environmental flows. Multidisciplinaryenvironmental flows regulating team can be set up to enhance the functioning of all components of the river ecosystem.

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