Assessment and Implementation of Environmental Flows to Restore River Gomti- a Tributary of Ganga, India

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Abstract— Environmental flows in rivers are essential to maintain their natural regime, purify themselves, sustain aquatic life and vegetation, recharge groundwater and support livelihoods. Rivers play their role in people's cultural and spiritual lives. These functions are possible with a suitable e-flow regime. This paper aims to quantify E-Flows for alluvial river Gomti- a tributary of river Ganga, at upstream and downstream of Lucknow City, at Sultanpur and at Jaunpur. These E-flow sites were chosen on the basis of homozonation study of Gomti Basin. Two methods- Hydrological consideration and holistic approach: Building Block Methodology has been employed for assessing the E-flows at four sites falling in middle and lower zone of the Gomti Basin.

The two set of E-Flows obtained have been compared with observed flows and virgin flows limits to visualize the implications of implementation plan for normal maintenance year and drought year. Considering Gomti basin water plan for 2045 while trying to meet future sectoral water demand and managing e-flows minimum allocation, the paper argues for e-flows implementation by participatory wetland conservation and improvise agricultural water use efficiency. Summary of investment plan in Gomti Basin to manage demand and supply of water optimally including minimum e-flows in Gomti river. Freed water from agriculture may be diverted into river Gomti from irrigation canal systems, off-taking from Sharda and Ghaghara rivers passing through the Gomti basin.

It is found that recommended monthly E-flows for Mehndighat is higher than the observed flows and even more than virgin flow volume except in the month of July. At Fuslauna site E-flows are higher than estimated virgin and observed flow for the months of January to June and for rest of the months July to December, E-flows values are within virgin/observed flow volume limits. Hence to implement E-flows in Gomti river at Fuslauna site, additional water from Sharda Sahayak Feeder, through Gomti escape has to be released for lean flow months January to June. Augmentation of flows in Gomti river is recommended by increasing base flows contribution particularly during lean flow months.

For Sultanpur and Jaunpur sites required e-flows are almost twice higher than the present day flows in Gomti river. E-flows for Gomti river at Jaunpur is higher than the virgin flow for the month of January to June, estimated at Maighat - a d/s CWC site below Jaunpur.

Alternatively, based on MOWR guidelines (as issued in case of Ganga river) considering only hydraulic perspective, minimum E-Flows for Gomti river at Lucknow, Sultanpur, Jaunpur and Maighat has been calculated. E-Flow estimates for Lucknow comes to 15.02 m³/s, 7.70 m³/s and 3.41m³/s during monsoon (June to Sep.), non lean flow month (Oct & Nov.) and lean flow months Dec to May respectively. For Sultanpur site 42.70 m³/s, 23.73 m³/s and 10.26m³/s and for Jaunpur site 44.94 m³/s, 29.22 m³/s and 11.28m³/s has been obtained for the same period.

E-flows assessed applying BBM, monthly discharge ranges are for Mehndighat 40-415 m³/s, Aqueduct site 40-58 m³/s, Sultanpur 92-950 m³/s and for Jaunpur site 100-795 m³/s. During wet months flushing requirement for two weeks period is 310 m³/s at Lucknow, 1370 m³/s at Sultanpur and 2450 m³/s for Jaunpur. This peak flow appears possible at Lucknow due to barrage but difficult to implement at Sultanpur and Jaunpur. Although ever maximum discharge observed had been at Lucknow 916.97m³/s, at Sultanpur 1373.68 m³/s at Jaunpur 2991.82 m³/s and at Maighat 3521.53 m³/s but on average and 75% dependability level these flow becomes very low.

It is suggested that E-Flows assessed for Gomti river using BBM may be refined on the basis of more research carried out with informed hydrology, biodiversity habitat conditions and parameters of geomorphology.

Keywords— Environmental flows, river conservation, basin plan, water use efficiency, Building Block Methodology.

I. INTRODUCTION

The responses to ecological degradations are likely to be a priority for river conservation and management [Vaughan et al, 2008]. Rivers attain a stable regime over thousands of years through adjustment of slope and cross section according to the volume of water and sediment carried over time. A modification of the flow regime and obstruction in river water-way will definitely result in sediment transport dynamics and to the channel change in long run. In most of alluvial rivers like Gomti, river bed has come up about 2 m above 1960 bottom level, changed the slope and hence sluggishness in flow, visible by once a highly sinuous river is now turned in moderately sinuous.

Gomti river plan form dynamics is entirely changed due to low flow and no-connect to her flood plain around the city reaches.

Flows necessary for maintenance of channel form and specific morphological units based on water level could be predicted. Similarly, biological habitats and socio-economic flow requirements could be estimated [WWF-India, 2020]. A holistic approach- Building Block Methodology would be employed to assess environmental flows requirement of a river [Kings et al, 2008]. In general, geo-morphological requirement of flows are often higher over biological or social demands. Recommended E-flows of a river system are site specific and depend upon what people want to see their rivers should look like.

River Gomti faces floodplains encroachment in upper stretch, while the middle and lower stretches face pressure from pollution and excessive groundwater abstraction. To restore Gomti river from aquatic biodiversity perspective for which it is well known, the key concern was proliferation of invasive and hardy species in the river and their main consideration was around providing conducive hydraulic habitat for Indian Major Corps (IMCs). Fluvial geomorphology looks for lateral and longitudinal connectivity. Socio-cultural concern of people is water quality and quantity in time and space. Over all river health may be considered while recommending suitable e-flows in the river.

The Gomti river was jacketed to save the Lucknow city from flood damages by constructing embankments 250-450 m apart on both the banks of the river, post 1960- 1971 peak floods (3564 m³/s & 3085 m³/s, respectively at Hanuman setu) and a British weir of 1911 and later in 1965 Gomti barrage was constructed to raise water level for municipal water supply at Gaughat to feed Water Works at Aishbagh (265 MLD) and Balaganj (200 MLD). The III WW at Gomtinagar (80MLD) is fed from S.S. Feeder Canal. There are 71 Minor Lift irrigation canals in Gomti Basin, having total capacity to draw 1458 cusecs (41.29 m³/s) and CCA of 35445 ha.

Under Gomti river front development (2014-17) around the Lucknow City, the river has been engineered by controlling its width, digging bed and shaped linear to reclaim saved land by constructing RCC diaphragm wall on both the banks distancing 110 to 125 m apart in 16 km city stretch followed by parallel drains along the river on both banks to divert sewage drains and a rubber dam was constructed across the river downstream Gomti barrage near La Martinier College to raise water level for navigation around the city stretch.

Beautification, electrification, fountains, construction of road, Amphity Theater and many more plans were under the project.

In case of embankments on both banks of the river, the spacing between the embankments should not be less than 3 times Lacey wetted parameter for the design flood discharge (Q) corresponding to 100 years [GFCC, 2004] with clear waterway equal to $4.75Q^{1/2}$. Lacey clear waterway for Gomti river corresponding to discharge of 3140 m³/s comes to 266 m. River width restricted to 240 m and clear waterway 110-125 m only to reclaim land out of 450 m wide flood plain at places upstream of Gomti barrage. Assuming economic development will shape ecology of the river by taking pollution abatement measures and ensuring ecological flows from existing irrigation canal system off-taking from Sharda and Ghaghara rivers.

Behavior and training of Gomti river near bridges and barrages (16 in numbers in 30 km reach between Lucknow-Sitapur bypass road bridge to Shaheed path) around capital city Lucknow-post river front development has been studied by the authour and found that built in cross section could take highest peak flood of 3564 m³/s at Gomti barrage and afflux created due to presence of many rail and road bridges [Ravindra, 2019]. Impact of river channelization and river front development on fluvial ecology was studied by [Dutta et al, 2018] and reported that fish habitat have been destroyed. The Gomti river water quality has been studied by many researchers [Dutta et al, 2011] and reported that barrage down stretch is most polluted as sewage of Gomtinager and waste water discharge from nearby STP is poured into the river [Alam, et al, 2020]. On the other hand, Gomti river basin plan for future water need has been prepared by TAHAL Consulting Engineers Israel/India for State Water Resources Government of Uttar Pradesh [SWARA 2020].

Recently, WWF-India in association with UPWamReC, SWaRA and Partners have initiated assessment of environmental flows for major rivers of Uttar Pradesh [WWF-India, Oct. 2020]. These E-Flow sites are shown in Figure-1 and the location of E-F sites for Gomti river is given in Table-1.

This paper discusses the E-flows quantification and its implementation plan for Gomti river, considering the constraints of water availability in Gomti Basin and argues for flows augmentation by transferring water from Sharda and Ghaghara rivers through Lucknow branch of Sharda canal and Sharda Sahayak Feeder.

The Gomti basin setting showing canal system and related control structure on rivers is shown in Figure-1. Homozonation of basin on the basis of slope on which ground E-flows sites have been selected is shown in Figure 2.

Figure-1 (A.) E-Flow Site On Major Rivers Of Uttar Pradesh, (B.) Mehndighat, (C.) Aqueduct, (D.) Sultanpur, (E.) Jaunpur

**Table-1
E-Flow Sites Selected On Gomti River**

Site	Location	Reason
Mehndi ghat, u/s Lucknow city	80°56'47.82"E, 26°51'38.599"N	Abundance of aquatic biodiversity, CWC site
Indira Aqueduct, Fuslauna	81°4'5.411"E, 26°49'41.17"N	Polluted stretch d/s Gominagar, Lucknow
Sultanpur, under bridge	82°4'27.903"E, 26°16'46.487"N	CWC site
Jaunpur, u/s Shahi	82°39'50.772"E	CWC site

II. GOMTI RIVER GEOMORPHOLOGY

A number of meander scars and ox-bow lakes d/s of Lucknow city are drying up over the years (1991-2019). Most of older floodplain is occupied by urban settlements employing poor lateral connectivity.

Once upon a time highly sinuous (meandering length 200 km up to Lucknow in 490 km stretch), Gomti river is now moderately sinuous and does not show any plan form dynamics as has remained fixed its position for the last four decades. The mapping of channel shift and thalweg also confirms the lack of any dynamics apparently due to lack of sufficient flow. Gomti River around Lucknow lacks any sign of natural geomorphic activity due to insufficient flow 6 m³/s in May (2000-04).

Figure 1 Canals And Related Structures On Rivers.

Figure 2 Elevation Map Of Gomti Basin

Sediment load at Lucknow site (1991-92 to 2013-14) is 1584 tonnes per day (0.58 million tonnes/year or 0.42 million m³/year) for 10503 km² i.e. 0.15 tonnes per day per km². This corresponds to a catchment denudation rate of 0.04 mm/year. In low flow years the sediment load is low while the high flow years have high sediment load, maximum in the month of September.

At Sultanpur most of the geomorphic features within the valley margin have been obliterated by the anthropogenic interventions, mostly in the form of agriculture and settlement. The river is characterized by very tight meanders but very few meander scars are mapped. The river has shifted 800 m from sinuous bend to nearly straight course. At Jaunpur the channel is symmetrical, stable and representative of single channel as Sultanpur. The cross section maximum width 949 m and depth 14 m is in main central cross section whereas downstream section is relatively shallower [Sinha, 2020].

Sediment load at Maighat site (1985-86 to 2015-16) is 6995 tonnes per day (2.55 million tonnes/year or 1.83 million m³/year) for 30042 km² i.e. 0.23 tonnes per day per km². This corresponds to a catchment denudation rate of 0.06 mm/year. In low flow years the sediment load is low while the high flow years have high sediment load, maximum in the month of September.

III. BIODIVERSITY SURVEY

Alteration in the natural flow regime of the rivers have affected the habitat and the abundance of aquatic species. A total of 81 species belong to 53 genera 24 families and 7 orders were recorded in Gomti river.

Among these, 72 are native and 7 are exotic ones. Gomti river IUCN Red list data for 2000-01 is shown in Figure-3.

Figure-3 Biodiversity Survey For Gomti River

Source: Starter Document on biodiversity survey (WWF-India Report)

Hydrological and basic water quality observed at E-flow sites in Gomti River is given in Table-2.

IV. SOCIO- CULTURAL PERSPECTIVE

Present and desired Gomti river health category at each E-flow sites have been agreed to be degraded to moderately modified category.

TABLE-2. HYDROLOGICAL AND BASIC WATER QUALITY OBSERVED AT E-FLOWSITES IN GOMTI RIVER

E-Flow Sites	Lucknow-Mehndighat U/S Hanuman Setu		Lucknow Aqueduct		Sultanpur under bridge		Jaunpur u/s Shahi pul	
River depth/width in m	Summer	Monsoon	Summer	Monsoon	Summer	Monsoon	Summer	Monsoon
Av. depth (Min, Max)	2.15 (0.76 -3.35)	1.14 (0.76 -2.62)	Survey not conducted as site was decided later	4.33 (2.5-5.9)	Survey not conducted as site was decided later	4.54 (2.5 -8.0)	4.84 (3.7 -6.10)	5.96 (2.7 -8.2)
River width	80	90		100		50	50	50
Average flow Velocity (m/sec)	0.100	0.060		0.08		0.47	0.133	0.070
Water Quality basic parameters								
Colour	Clear	Greenish	Survey not conducted as site was decided later	Black	Survey not conducted as site was decided later	Black	Greenish	Greenish
pH	8.9	9.2		8.2		9.4	8.3	9.4
Temp (°C)	32.4	22.6		23.5		23.1	35	23.1
DO (mg/l)	7.5	7		4		3.8	6.8	7
TDS (mg/l)	195	225		405		361	240	361

Water quality and quantity are the main concern of bank's community. Imperial gazetteers inform that in ancient period Gomti was a dynamic sinuous and biodiversity rich river with sluggish flow. River width in upper stretch was limited to 100-200 m, in middle around Lucknow 200-400 m and in lower stretches 400-600 m. Today flood plains are encroached for settlement and agricultural use. Dense Namish Aranya (forests) are lean and Shiva temples dotted all along its bank. Oozing groundwater is seen in some of religious places along Gomti River.

V. E-FLOWS MOTIVATION METHODOLOGY

Two target conditions are considered, one for normal maintenance year which is neither wet nor dry hydraulic year, and second is for drought year. Flushing needs of higher order discharge for two weeks is also taken into account. The river health category targeted is from degraded to moderately modified. The flow motivations for different thematic groups are listed in Table 3.

TABLE-3 E-FLOWS MOTIVATION METHODOLOGY

Thematic Group	Motivation for Normal Maintenance	Motivation for Drought year
Biodiversity	The size and weight of fish are significantly affected by lower depth. In summer (dry season) to maintain congenial thermal profile for the fish, to maintain desired DO; The recommended wet season depth is suitable for Temperature variation, Oxygen, plankton production etc.	Minimum required water depth to maintain fish base around the site. The recommended wet season minimum water depth to have pool connectivity, which are useful for nutrient flow and growth of food chain.
Geomorphology	The aim is to maintain lateral and longitudinal connectivity in the river during dry and wet seasons and would sustain some geomorphic activity in the form of sediment disposal. Additional requirement of flow to completely inundate the channel belt and some portion of floodplain for two weeks duration.	Minimum water depth to maintain longitudinal connectivity and partial lateral connectivity.
Socio-cultural	The recommended water depth is corresponding to people memories of historic flows, and this will also improve the soil moisture and fishing based livelihoods.	Present day flow acceptable to perform rituals and livelihood activity carried out though with difficulty..

VI. E-FLOW ESTIMATION PROCESSES

1. LUCKNOW

TABLE-4
E-FLOWS RECOMMENDED FOR MEHNDIGHAT SITE U/S
LUCKNOW CITY, GOMTI RIVER

e-flows	Normal Maintenance Year			Drought year		
	Leanest month Jan.	Wet month , Aug.	Flushing in wettest (Sep)	Dries t month Jan.	Wet month, Aug	Flushing in wettest (Sep)
Water level in m,	3.5 RL(105.65)	5.5 RL (107.65)	6.0 RL(108.15)	2.5 RL (104.65)	5 RL (107.15)	5.5 (107.65)
Discharge in m3/s	183.72	415	600	129	406	415

(i). For Mehndighat **site**, the water depths and corresponding likely flows recommended has been given in Table-4. On the cross section various water depth requirements for normal maintenance and dry year is shown in Figure 4.

Figure 4. Recommended E-Flow For Mehndighat, U/S Lucknow Barrage

TABLE 5 : AVERAGE MONTHLY VIRGIN, OBSERVED AND SUGGESTED E-FLOWS FOR GOMTI RIVER AT MEHNDIGHAT, LUCKNOW

Flow Volume* in MCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Virgin	95.86	58.38	34.00	20.40	14.81	62.94	544.54	856.07	805.93	489.58	251.04	152.55	3386.10
Observed	85.63	68.46	72.08	62.23	59.30	71.95	171.61	312.89	465.63	282.81	123.79	102.93	1879.31
E-Flows	492.37	352.30	415.02	340.64	338.80	396.08	516.65	1112.2	1554	847.01	356.48	304.93	7026.48

*Note: Virgin flow for Upper Gomti Basin has been estimated by TAHAL and the same is modified for Lucknow site in area proportion. CWC observed data for Hanuman Setu 1985-2015 and E-flows value of WWF-India considered

For Gomti river at Lucknow Average monthly virgin, observed and recommended E-Flows is given in Table-5 and shown in Figure 5. It is found that average annual virgin flow volume (1961-2015) is 3386.10 MCM, observed average annual flow volume (1985-2015) is 1879.31MCM whereas recommended annual E-flows volume is 7026.48 MCM for Mehndighat. Recommended monthly E-flows for Mehndighat is higher than the observed flows and even more than virgin flow volume except in the month of July. Hence WWF-India E-flows recommendation for Mehndighat is not acceptable.

Figure 5: Average Monthly Virgin, Observed And Suggested E-Flows For Gomti River At Mehndighat, Lucknow

**Table-6
E-Flows Recommended For Fuslauna E-F Site, Aqueduct D/S
Gomtinagar, Lucknow**

E-flows	Normal Maintenance Year			Drought year		
	Leanest month Jan.	Wet month, Aug.	Flushing in wettest Sep	Driest month Jan.	Wet month, Aug.	Flushing in wettest, Sep.
Water level in m,	3 RL(101.5)	5.3 RL (103.8)	6 RL(104.5)	2.25 RL 100.75)	3.5 RL (102)	5 (103.5)
Discharge in m3/s	58	111	170	29	42	65

On the cross section various water depth requirements for normal maintenance and drought year is shown in Figure 6.

E-flows hydrograph for maintenance year and drought year has been plotted and shown in Figure 7 and Figure 8.

Figure 6 Gomti River Cross Section At Fuslauna, Downstream Indira Aqueduct, Gomtinagar, Lucknow

Figure 7 Recommended E-Flows In Gomti River At Aqueduct Site For Maintenance Year

Figure 8 Recommended E-Flows In Gomti River At Aqueduct Site For Drought Year

It is found from Figure 7 that recommended E-Flows are almost double of the average observed flows in Gomti river at Gomtinagar. Perusal of Figure 8 shows that recommended e-flows for drought year is not available in the Gomti river, as minimum observed flows are almost half of required E-flows. Augmentation of minimum flows in Gomti river d/s Lucknow during 15th Feb to 15th June from Sharda Sahayak Feeder Canal through Gomti escape to outfall upstream of Indira Aqueduct is recommended through Gomti escape of S.S.Feeder.

To check that whether e-flows are within the limits of virgin flow at Indira Aqueduct or not, figure 9 has been plotted. In this figure virgin flow corresponding to Upper Gomti Basin estimate and observed flow corresponding to CWC Hanuman Setu has been considered without any modification rather assuming the same.

Perusal of Figure 9 informs that recommended e-flows are higher than estimated virgin and observed flow for the months of Jan to June and for rest of the months July to Dec, e-flows values are within virgin/observed flow volume limits.

Figure 9 Virgin Flow Vs E-Flows At Fuslauna, Aqueduct, D/S Gomtinagar, Lucknow

2. SULTANPUR E-F SITE

For Sultanpur site, the water depths and corresponding likely flows recommended has been given in Table -7.

On the cross section various water depth requirements for normal maintenance and drought year is shown in Figure 10.

**Table-7
E-Flows Recommended For Sultanpur**

E-flows	Normal Maintenance Year			Drought year		
	Leanest month Jan.	Wet month h, Aug.	Flushing in wettest Sep	Dries t month h Jan.	Wet month h, Aug	Flushing in wettest, Sep.
Water level in m,	2.25 RL(80.75)	7.5 RL (86.0)	9 RL(87.5)	2 RL (80.5)	3.5 RL (81.5)	5 (83.5)
Discharge in m ³ /s	137	618	950	90	150	230

Figure 10 Gomti River Cross Section At Sultanpur

E-flows hydrograph for maintenance year and drought year has been plotted and shown in Figure 11 and Figure 12.

Figure 11 Recommended E-Flows In Gomti River At Sultanpur Site For Maintenance Year

Figure 12 Recommended E-Flows In Gomti River At Sultanpur Site For Drought Year

Perusal of Figure 11 and Figure 12 suggest that recommended EF values are far higher than the observed flows at Sultanpur.

3. JAUNPUR E-F SITE U/S SHAHI PUL

For Jaunpur site, the water depths and corresponding likely flows recommended has been given in Table -8.

**Table- 8
E-Flows Recommended For Jaunpur**

E-flows	Normal Maintenance Year			Drought year		
	Leane st month Jan.	Wet mont h , Aug.	Flushi ng in wettest Sep	Dries t month h Jan.	Wet mont h, Aug	Flushi ng in wettest , Sep.
Water level in m,	3 RL(69)	7 RL (73)	11 RL(77)	2 RL (68)	3.6 RL (69.6)	5 (71)
Dischar ge in m3/s	144	517	795	108	137	210

On the cross section various water depth requirements for normal maintenance and drought year is shown in Figure 13.

Figure 13 Gomti River Cross Section At Jaunpur

E-flows hydrograph for maintenance year and drought year has been plotted and shown in Figure 14 and Figure 15.

Figure 14 Recommended E-Flows In Gomti River At Jaunpur Site For Maintenance Year

Figure 15 Recommended E-Flows In Gomti River At Jaunpur Site For Drought Year

It is found that required e-flows are almost double higher than the present day flows in Gomti river at Jaunpur. To check the e-flows value whether they are within virgin flow limits or not, let us consider the virgin flow at Maighat which is CWC gauge site d/s Jaunpur. The virgin flow is estimated at Maighat based on 1961-2015 rainfall data series.

Average annual virgin flow volume at Gomti Basin end is 9889.34 MCM. Hydrograph is shown in Figure 16 and discharge is given in Table 9.

Figure 16. Virgine, Observed And E-Flows For Gomti River At Maighat, Jaunpur (In M3/S)

It is evident from Figure 16 that recommended E-flows values for Gomti river at Jaunpur is higher than the virgin flow for the month of January to June, hence unpracticable. Augmentation of flows in Gomti river is recommended by increasing base flows contribution particularly during lean flow months.

VII. E-FLOWS ESTIMATION CONSIDERING HYDRAULIC PERSPECTIVES

Alternatively, low order e-flows based on MOWR guidelines considering hydraulic perspective only for Gomti river at Lucknow, Sultanpur, Jaunpur and Maighat is calculated based on 1985-2015 CWC flow data on 75% dependability and given in Table-10. E-flow estimates for Lucknow comes to 15.02 m³/s, 7.70 m³/s and 3.41m³/s during monsoon (June to Sep.), non lean flow month (Oct & Nov.) and lean flow months Dec to May respectively.

TABLE-9.
AVERAGE MONTHLY VIRGIN, OBSERVED AND E-FLOWS IN M3/S FOR GOMTI RIVER AT MAIGHAT, JAUNPUR D/S EF SITE

Flows in m3/s	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Virgin	103.38	72.43	39.88	67.80	18.65	70.72	605.20	957.00	919.69	496.87	269.51	160.74
Observed	134.81	107.72	33.18	63.11	44.19	81.39	290.73	493.5	592.35	420.16	181.83	144.22
E-flows	144	128	122	108	100	150	284	517	796	467	211	159

Table 10

E-Flows Estimates For Gomti River At Lucknow, Sultanpur ,Jaunpur And Maighat Considering Hydrological Perspective Only

E-. Flow Requirement	@30% of Monsoon month average flow	@25% of Oct. & Nov	@20% of average discharge for lean flow months
Lucknow	15.02	7.70	3.41
Sultanpur	42.70	23.73	10.26
Jaunpur	44.94	29.22	11.28
Maighat	78.09	40.01	13.92

Perusal of Table-10 and Table 11 suggests that E-Flows estimate using Hydrological perspective gives a very conservative figure whereas consideration of biodiversity and geo-morphological perspective using BBM shows higher value of flows (refer column 5 in Table 11.) The reason of this great difference is that one is based on average regulated flows whereas the second mimics the natural (virgin) flow of the river, indicating that E-flows should not be estimated by hydrological consideration. It will not solve the ecological degradation and loss of goods and services provided by a river. Now the question is where from E-flows may be implemented. For this water resources availability is estimated and allocation of e-flows has been assessed.

TABLE 11 E-FLOWS ASSESSMENT FOR GOMTI RIVER AT LUCKNOW, SULTANPUR , JAUNPUR USING BBM

EF sites	Target Normal Maintenance Year		Flushing for 15 days in m	Average Monthly discharge range	Duration of not fulfillment of EF as compared to observed hydrology
	water depth in m				
1	2	3	4	5	6
Gomti River	Summer season	Wet season	/ (m3/s)	m3/s	Refer graphs
Mehndighat Lucknow u/s Barrage	3.5	5.5	6.3 (600)	184-415	Jan to May (5 months)
Indira Aqueduct, Lucknow d/s Gomtinagar	3	5.3	6.8 (310)	40-58	Ian to Jun (6 months)
Sultanpur	2.25	7.5	9 (1370)	92-950	Jan to Dec (12 months)
Jaunpur	3	7	11 (2450)	100-795	Jan to Dec (12 months)

VIII. AVAILABLE WATER RESOURCES IN GOMTI BASIN

(i). RAINWATER

Rainfall average(1961-2015) is 872.67 MCM and trend analysis shows no appreciable change in Gomti basin. Monthly average annual rainfall water on basin area of 31433.67 km² is 27431.2 MCM with monsoon availability of 25022.8 MCM(796.1 mm) and non-monsoon availability of 2408.4 MCM (76.6 mm).

Virgin Flow Volume

Virgin flow volume series has been generated for Gomti Basin and its sub basins from 1961 to 2015 rainfall data. The annual virgin flow volume for Upper Gomti sub basin (13586.12 km²), Sai Sub basin(12188.39 km²), lower Gomti sub basin (5659.16km²) is estimated at 4397.53 MCM, 3423.01 MCM, 2068.74 MCM and 9889.29 MCM respectively.

(ii) Dynamic Groundwater Resource

Using Groundwater Estimation Methodology of 2015, dynamic annual replenish able groundwater resource in the Gomti basin has been estimated as 10,283.00 MCM and annual groundwater draft as on 3/2015 is 9512.00 MCM giving stage of groundwater extraction 92.50%, i.e. in critical category.

Total Water Resources available in Gomti Basin

Some of local surface water (generated within basin due to rainfall runoff), imported canal water from Banbasa barrage through Sharda Canal system and from Lower Sharda barrage (including inflow from Girja barrage on Ghaghara river) and dynamic groundwater resource comes to 35210.34 MCM at 90% dependability as given in Table 12

Utilizable Water Resources in Gomti Basin

a) Generated within Gomti basin: At outfall of Gomti basin, availability of observed flow in Gomti river at 75% dependability is 3305.5 MCM annually, with only 542.1 MCM during non-monsoon season, that includes rainfall runoff, field irrigation runoff and base flows.

b) Imported water from other river basin to Gomti basin at 75% dependability

Diversion from Sharda river 2487.6 MCM

Diversion from Ghaghara river 7091.7 MCM

c) Groundwater availability

Annual replenishable groundwater resource 10283 MCM

Hence presently, total utilizable water resources in Gomti basin is 23167.8 MCM,(a+b+c) against total water resources availability in Gomti basin 38647.51 MCM at 75% dependability.

Table 12
Total Available Water Resources In Gomti Basin

Property	Dependability Level				
	Mean	25%	50%	75%	90%
Local Surface Water (generated within basin), Mm ³ /yr	9,889.29	11,851.19	9,654.05	7,485.66	6,036.94
Imported from Banbasa Barrage, Mm ³ /yr	8,251.03	9,592.78	7,506.29	7,120.26	6,529.54
Imported from Lower Sharda Barrage (including inflow from Girija Barrage), Mm ³ /yr	20,347.31	24,104.53	16,416.1	13,758.6	12,360.8
Dynamic Groundwater, Mm ³ /yr	10,283.00	10,283.00	10,283.0	10,283.0	10,283.0
Total Available Water, Mm ³ /yr	48,770.63	55,831.50	43,859.5	38,647.5	35,210.3

TABLE 13 AVERAGE AND 75% DEPENDABLE VIRGIN, OBSERVED AND E- FLOWS IN GOMTI RIVER AT MAIGHAT

Flow Volume, MCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Virgin Flow Average	277.07	175.27	106.89	67.80	49.99	183.16	1621.93	2564.75	2382.00	1331.61	698.04	430.78	9889.29
Observed Flow Average	361.29	260.68	230.29	163.45	118.43	210.80	779.16	1322.58	1534.19	1126.03	470.94	386.51	6964.35
E-flows as at Jaunpur	386	310	327	280	268	388.5	761.12	1385.56	2061.64	1251.56	546	426.12	8391.35
Virgin Flow @75% depend	209.73	103.67	80.91	51.32	37.84	138.64	1227.71	1941.38	1803.05	1007.96	528.38	326.08	7,485.66
Observed Flow @ 75% depend	280.9	200.8	177.8	125	89.2	137.5	393.2	640.5	1023.7	568.5	279.4	264	3305.5

The average monthly and 75% dependable virgin flow, observed flow and recommended e-flow (as at Jaunpur) has been tabulated in Table 13 for Gomti Basin at Maighat. The annual E-flow volume is 8391.35 MCM which is 84.85% of average virgin flow, 120.53% of average observed flow. E-flows volume is respectively 112.09% of virgin flow and 253.86% of observed flow at 75% dependability. E-flows as compared with average and at 75% dependable flow are shown in Figure 17.

Figure 17. Virgin, Observed And E-Flows Volume For Gomti River At Maighat D/S Jaunpur- Av. Vs 75% Dependability

It is clear from Figure 17 that recommended e-flows for Jaunpur site is even higher than virgin and observed flow volume at Maighat, a site downstream of Jaunpur the last one on Gomti river prior it merges into Ganga. For the rest of the months e-flows are within average virgin flow volume. It is suggested that relook in e-flows numbers require more study.

IX. TOWARDS E-FLOWS IMPLEMENTATION – NEXT STEPS

In comparison to E-Flows assessment, the E-Flows implementation has always been a much more complex, challenging and time-intensive task; this phenomena gets even more cumbersome in case of committed river systems (whose water resources are committed/allocated to various uses, including – irrigation, domestic supplies and industrial use).

The surface water of Gomti Basin is used as raw source for domestic water supply for major urban centers and for irrigation through minor irrigation schemes. To meet the growing demand of water of Lucknow city, Gomti river waters are being used. During summer months, river is almost dried up. Therefore, to meet the domestic water supply of Lucknow city, 150 cusec of water is made available from Lucknow branch of Sharda canal system through Mahdoiya escape in to Gomti River during May and June. A pumping station is built at Gaughat on Gomti River to lift this water for supply to old city area. For trans-Gomti area of Lucknow city, 50 cusec of water is pumped from Sharda Sahayak feeder to Kathauta Jheel. From here, water is supplied to this area.

Besides Lucknow, Gomti River supplies domestic water to Sultanpur and Jaunpur town. Further, there are 71 minor lift irrigation schemes in Gomti basin, 25 on Gomti river, 23 on Sai river, 9 on Sarayan river, 6 on Kathna river, 5 on Kalyani river and 3 on Pirai river having total capacity of 1458 cusecs and CCA of 35,445 ha. But their running capacity has dropped to 50%, due to non-availability of sufficient power and water. In Gomti basin, domestic and industrial water supplies are mainly dependent on ground water.

Gomti Basin is water short and unable to meet present and future water demand of 15068 MCM (2015), 16823 MCM (2025), 18442 MCM (2035) and 18468MCM (2045). Non-agricultural Water demand in Gomti Basin is given in Table 14 and Figure.17. Growth of Non-agricultural water demand from 16% of water use in 2015 to 23% in 2025, to 29% in 2035 and to 32% in 2045 as shown in Figure 18[TAHAL, 2020].

Table 14
Non-Agricultural Demands, MCM

Water Demand	2014-15	2024-25	2034-35	2044-45
Urban Domestic	357.62	457.74	511.87	548.36
Rural Domestic	388.66	607.76	889.66	997.57
Livestock	163.62	179.53	197.01	214.49
Industrial	33.67	63.75	93.83	123.92
Total Non-Agricultural	943.57	1308.78	1692.37	1884.34

Figure 17 Non-Agricultural Demands, MCM

Figure 18 Non-Agricultural Demand Growth, %

Agricultural Water Demands

Considering three agricultural scenario given below as AGP-1, AGP-2 and AGP-3 Agricultural water demand estimated is given in Table-15 and is shown in Figure 19.

- **AGP-1:** Projected Crop Areas as per the prevailing Trend (BAU)
- **AGP-2:** Proposed Crop Areas as per past Trend for increasing crops(replacing paddy by SRI gradually and keeping other decreasing crops constant
- **AGP-3:** Proposed Crop Areas, a shift in Rice area from traditional method to SRI method by 20%, 30% and 40% in year 2025, 2035 and 2045, respectively has been considered. Also conversion of 10% area to micro-irrigation has been considered.

Table 15 Agricultural Water Demand In Gomti Basin

Agricultural Demand	2014-15	2024-25	2034-35	2044-45
AGP-1	14,123.54	15,514.41	16,750.31	17,584.00
AGP-2	14,123.54	15,373.71	16,253.64	16,280.45
AGP-3	14,123.54	14,332.88	14,298.48	14,104.85

Figure 19 Agricultural Water Demands In Gomti Basin (Mcm) By 2015, 2025, 2035 & 2045

It is evident from Figure 19 that agriculture water use share in overall water use is decreasing from 94% in 2015 to 88% by 2045 in the Gomti Basin. The total sector oral water demand is shown in Figure 20.

Figure 20 Sectoral Water Demands In Gomti Basin (Mcm) By 2015, 2025, 2035 & 2045

Figure 21 Gomti Basin Population, Per Capita Water, Unmet Agri Demand & Stage Of Gw Extraction BAU

As shown in Figure 21, in Gomti Basin per capita water availability is 780 m³/person, this means water scarcity situation prevails in the basin due to population density (882 person/sq. km) being more than 3 times of the India (382 person/sq.km). This is the situation while inter basin water transfer is meeting the most of command irrigation since nineteenth century.

River Gomti has been one of the most critical rivers, when it comes to E-Flows implementation, primarily because this one is a groundwater fed river, with no real storage (except one at Lucknow, but that is a barrage only) on it. This means that, any additional flows requirement in wake of E-Flows recommendations will have to take into account fairly complex and tough decisions.

The implementation of E-Flows will have to take into account the concerns and issues of the water resources institutions – as they are the ones who deal with water resources planning, allocation, distribution and use. Therefore, these E-Flows recommendations are required to be deliberated upon with various stakeholders, especially the water resources managers. This will facilitate the buy-in from them and therefore, aid in E-Flows implementation.

The storages and diversions alone are not the answer to maintaining E-Flows regime in such river systems; the heavy reliance on groundwater and therefore unregulated groundwater exploitation is another critical issue that needs to be tackled, if E-Flows, are to be maintained in the river systems in a sustainable manner.

Assessment of human interventions and its impacts on hydrological regime of river Gomti by the author [Ravindra, et al. 2015] informs that,

- Drainage congestion and encroachment in the upper segment:** The upper stretch of the river is heavily encroached by agricultural fields and has sluggish flow condition. As per revenue records, encroachment into the river and its floodplain has left limited fields in the name of Gomti river in each village in the upper stretches. The upper and middle segment of the river is severely affected by flooding during monsoon due to drainage congestion. Deforestation along the banks has also led to run-off depositing silt in the stream bed leading to low channel capacity.
- Extensive exploration of groundwater:** The unregulated groundwater exploitation has contributed significantly to reduction of flows in river Gomti. As part of the water cycle, groundwater is a major contributor to Gomti river's flow and its tributaries. The precipitation during the monsoon season is the dominant source of water for groundwater recharge in the GRB. If extent of extraction is lowered to river bed depth, the maintenance of ecological flow becomes difficult in that reach.
- Reduction in forest cover and wetlands:** There has been severe reduction in forest cover and wetlands in the entire Gomti basin due to rapid land-use change and increasing demand of land for urbanization. This has affected the flow of water in Gomti river, as most of the tributaries originate from water bodies or forests and reduction in their density has caused reduction in water availability in the river. Except Pilibhit and Kheri districts, all the districts falling under the basin are deficient in forest cover. LANDSAT satellite data of 1978 and IRS-1C/LISS III sensor data of 2008 shows that, built-up area has increased while the forest and plantation area including water bodies has decreased. There is no flow in the initial 57 km stretch of the river with wide encroachment of active floodplains.

In another study conducted by author 'impact of river channelization and riverfront development on fluvial ecology: evidence from Gomti river' authors made assessment of the loss of river process and ecosystems under changed hydraulic regimes post RFD.

They observed eight types of habitat in the undisturbed segments of the Gomti river, while only two habitat types were present in the channelized segments. The paper argues that, due to heavy channel engineering led river front development and other related morphometric changes, there would be decline in freshwater species and water quality, lowering of groundwater tables in the city reach resulting from diminishing base flow and flooding of the downstream areas. "The reduction in flow, in the absence of water augmentation measures, will further impact the minimum environmental flows required to maintain the healthy ecosystems in the river broadening the area of ecological disturbances."

Maintaining E-Flows in Gomti river would be a complex proposition. Nevertheless, it is a lifeline for the cities, towns and villages through which it passes; therefore, for a larger cause, the health of Gomti river needs to be improved.

The present day flows at all the location (except first location, i.e. Mehndi Ghat and that is mainly because of the barrage at downstream of this site) on Gomti river does not meet E-Flows requirements due to the reasons discussed above. The E-Flows maintenance in Gomti river would therefore require massive interventions in regard to catchment area treatment, ground-water regulation through promoting water use efficiency across all water-using sectors, including – irrigation. Whilst the barrage at Lucknow, will play some role in maintaining E-Flows in first two E-Flows sites around Lucknow city; but the groundwater management will hold the key.

Urban water demand by Lucknow city is envisaged total 1281 MLD by 2040 for the projected population of 5.6 million. The existing 3 water works (Aishbag, Balaganj & Gomtinagar) use 575 MLD surface water (from Gomti 475 MLD and 80 MLD from SS Feeder Canal). Shifting groundwater supply (from existing 47.90% to 25%) to surface water supply (increased from existing 52.10% to 75% use) means demand of 1001 MLD from current 575 MLD that a gap of 426 MLD has to come from augmenting Gomti river flows by near by irrigation canal systems in an attempt to guarantee the water availability of 500 MLD in all seasons..

The merit and demerit of various options to augment Gomti river flows namely- (i) lifting of water from Ganga river at Lava-Kush barrage Kanpur, 80 km away; (ii) pumping water from Ghaghara river at Elgin bridge Barabanki, 60 km away; (iii) lifting water from Sharda Sahayak Feeder at km 65 to Kheri branch (11km pipe) through Munderi escape to Gond –Sarayan (tributaries) to Gomti river, (iv) lifting water from SS Feeder km 104.0 (27 km pipe) connecting Ateria escape of Kheri branch to Gomti river; and (v) by gravity flow connecting SSF km 140.78 by 20km pipe line directly to Gomti river, near bridge at Lucknow-Sitapur Ring Road and has been studied and reported by author [Ravindra, 2019].

It has been agreed that gravity flow option is economically feasible by connecting SSF at 140.78 km directly to Gomti river) and UP Jal Nigam have been directed to prepare DPR for upcoming Water Works at Alambagh and Indira Nagar.

It is recommended to augment Gomti river flows from Sharda Shayak canal system, off taking from Ghaghara river by gravity flow through 20 km pipeline from chain age 140.78 km to outfall 2 km upstream of Gaughat near Lucknow-Sitapur Road bridge, as shown in bottom of Figure 23.

Figure 23 Sarda Sahayak Feeder Link To Gomti River From Chainage 140.78 Km . Figure 24 Gomti Escape Link

Figure 24 Ssfeeder Link Through Gomti Escape To Gomti River U/S Aqueduct

Augmentation of minimum flows in Gomti river d/s Lucknow during 15th Jan to 15th June diversion of surface water from Sharda Sahayak Feeder Canal through Gomti escape to outfall upstream of Indira Aqueduct is recommended through Gomti escape of S.S. Feeder as shown in Figure 24.

Gomti Flows Augmentation at Origin:

Government of Uttar Pradesh has plan further to augment Gomti river flows at Origin (Fulhar Jheel / Gomat Taal through Devipur minor of Madhotanda distributary of Sharda canal), 450 km away from Lucknow (Figure 25) ensuring longitudinal connectivity in Gomti river by providing environmental flows requirement and towards development for navigation around Lucknow

Figure-25 Linking Devipur Minor Of Madho Tandra Dy To Fulhar Jheel (Gomat Tal)- The Origin Of Gomti River

Base Flows Augmentation: Recharge from Water Harvesting in Gomti Basin

Watershed and Wetlands development and Rooftop rainwater harvesting could recharge 100 MCM at conservative estimate as detailed in Table-16.

TABLE 16 GROUNDWATER RECHARGE AUGMENTATION.IN GOMTI BASIN DURING 15 YEARS TIME SPAN							
S. N	Activity	Cost. in Cr. Rs.	Area	Unit	Rates in Rs.	Recharge in MCM	Remarks
1	Watershed Development	269.2	53844	ha	5000	9.69	Area with 2% additional rainfall recharge
2	Wetland Development	1646.6	44263	ha	5000	74.36	On 60% area, 1.4 mm per day for 200 days
3	Roof Top Harvesting	1120.6	22870000	m ²	490	16.01	Limited to five major cities in 10% roof areas.
Total		3036.4				100.06	

X. INVESTMENT SUMMARY FOR GOMTI BASIN

Gomti River is water short at times in quantity and quality, its flows has to be augmented by water transfer from other river basins such as Sharda/Ghaghara. Water transfer from Ganga River is not cost effective and sustainable. Ensuring groundwater recharge to enhance base flows and environmental flows of Gomti River is required for sustainability of the water resources and good health of the river. The investment to be made in Gomti Basin for improvement in water use efficiency in Agriculture sector and recharging groundwater is of the order of INR10,396.23 Crores. Formation and strengthening of WUAs 240.69 cr, removing canal system deficiencies 1,245.06 cr, removing drainage system deficiencies 1,546.42 cr, shallow tubewell Installations 309.10 cr, watershed development 269.22cr, sodic land reclamation 471.51 cr, wetland development 1,646.57cr, waste water treatment 710.26 cr, roof top harvesting 1,372.70 cr, micro irrigation 1,045.07 cr, CAD&WM works 1,045.07 cr, and miscellaneous @5% INR 495.06 cr.

XI. CONCLUSIONS

E-Flows assessment, like any other robust E-Flows assessment process, has been a socio-technical and scientific process, but considering all practical natural boundaries (in terms of possibilities of flows) of a given river. While e-flows assessment for Gomti River has been preliminary estimated at four sites (i) two sites around Lucknow city, one upstream of Gomti Barrage and another d/s of Gominagar, (ii) Sultanpur and (iii) Jaunpur. Recommended E-flows are compared with virgin and observed flow at e-f sites. It is concluded that some refinement is required in future studies. Implementation issues of E-flow has been discussed in length. It is suggested that to implement e-Flows, backup efforts have to be made so that water could be freed from irrigation sector and let a minimum allocation of E-flows mandated in Gomti river and then move to required E-flows as estimated by experts and agreed by stakeholders. Water harvesting, conservation and sub surface storage by ensuring base flows to sustain river flows during lean flow months. This is very important for groundwater fed river like Gomti. A summary of investment over 15 years span has been given to recover 100 MCM rainwater at cost of INR 10,000 crores

Flows augmentation at origin of Gomti river is one good response of UP government and community in Pilibhit. River corridor has been demarked in government records and river cross section released in Pilibhit and Shahjahanpur district dovetailing MANREGA funds.

To Augment flows in Gomti River around Lucknow City, gravity flow option is economically feasible by connecting S.S. Feeder Canal off- taking from Girja barrage on Ghaghara river, from 140.78 km by underground 20 km pipeline to Gomti river, near upstream of Lucknow- Sitapur road bridge.

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