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Revival of Mathura's ailing Yamuna river

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Abstract The quality restoration of any river, especially of the Yamuna at Mathura, a religious center in India, is a very complex and interdisciplinary endeavor. River pollution cannot be minimized merely by diverting the routes of drains carrying wastewaters and/or establishing sewage treatment plants. The required strategy for pollution control should not only be a multi-line approach but also be fool proof. The various sources of pollution in the Yamuna river and possible strategies to restore this ailing river to its pristine status are presented in this paper.

On the importance of the Yamuna at Mathura

The river Yamuna has been acclaimed as a holy river (next to Ganga) in Indian mythology. Yamuna *aachaman* (rinsing the mouth with holy water) at *Vishram ghat* (bathing platform) is considered the surest way of salvation, and pilgrims from as far off a place as Gujrat carry its holy water in sealed vessels for religious functions. Yamuna *poojan* (worship) is considered a must for candidates contesting elections in Mathura (HT, 2004a). On all auspicious festivals, pilgrims first take a ritualistic dip at ghats before paying obeisance to the deities in temples. Despite such importance, most ghats however are ruined or near extinction (HT, 2004c).

The Yamuna originates from the Yamnotri glacier in the Lower Himalaya at an elevation of about 6380 m above sea level. The river with its total flow length of 1376 km travels through a number of historical, religious and large cities, viz. Delhi, Fariadabad, Vrindaban, Mathura, Agra, Kalpi and Allahabad where it merges into the Ganga. Yamuna's water quality in the Himalayan segment and in the segment after confluence with the Chambal river is relatively good (Bhargava, 1983b, 1985c). However, because of the removal of large volumes of water and discharge of pollutants into the river system the water quality in the Delhi segment and next highly eutrophicated segment is critical. At Delhi, heavy discharges of untreated domestic sewage and non-availability of dilution, has degraded the quality in the downstream stretch of the river. The Yamuna is used for surface water supply of Delhi, Mathura, Vrindavan and Agra. For Mathura (on the right bank of the Yamuna), the water is removed at Gokul barrage, some 8 km downstream of Mathura, where the water is highly polluted, while most of the city's wastewater is discharged upstream of Mathura. It should be the other way round. One can only pity the Ganga Pollution Control Unit of Mathura and the Uttar Pradesh state's *Jal Nigam* (an environmental engineering department) which is considered to be one of the world's biggest departments of its kind.

Mathura (latitude 27°35′N, longitude 75°E), 55 km upstream of Agra and 150 km downstream of Delhi, the historic city and birth place of Lord Krishna, each year attracts a large number of devotees/pilgrims for taking a holy bath in the Yamuna at Brij Bhumi (Mathura) during different festivals and religious occasions. River water quality at Mathura stretch (see Fig. 1) is therefore very important but, unfortunately, is characterized (see Table 1) by offensive odour and ugly look. At some points, the river water is jet black, with a thick layer of waste scum on the surface (HT, 2004d), flooding of the city's main market to a depth of about one metre, with stinking sewage, floating dead animals, high load of organic and inorganic material, significant oxygen depletion, excessive presence of pathogens and periodic mass killing of fish and other aquatic life. A religious organization in Mathura, viz. the 'Vishwa Sanatan Dharm Raksha Dal' while

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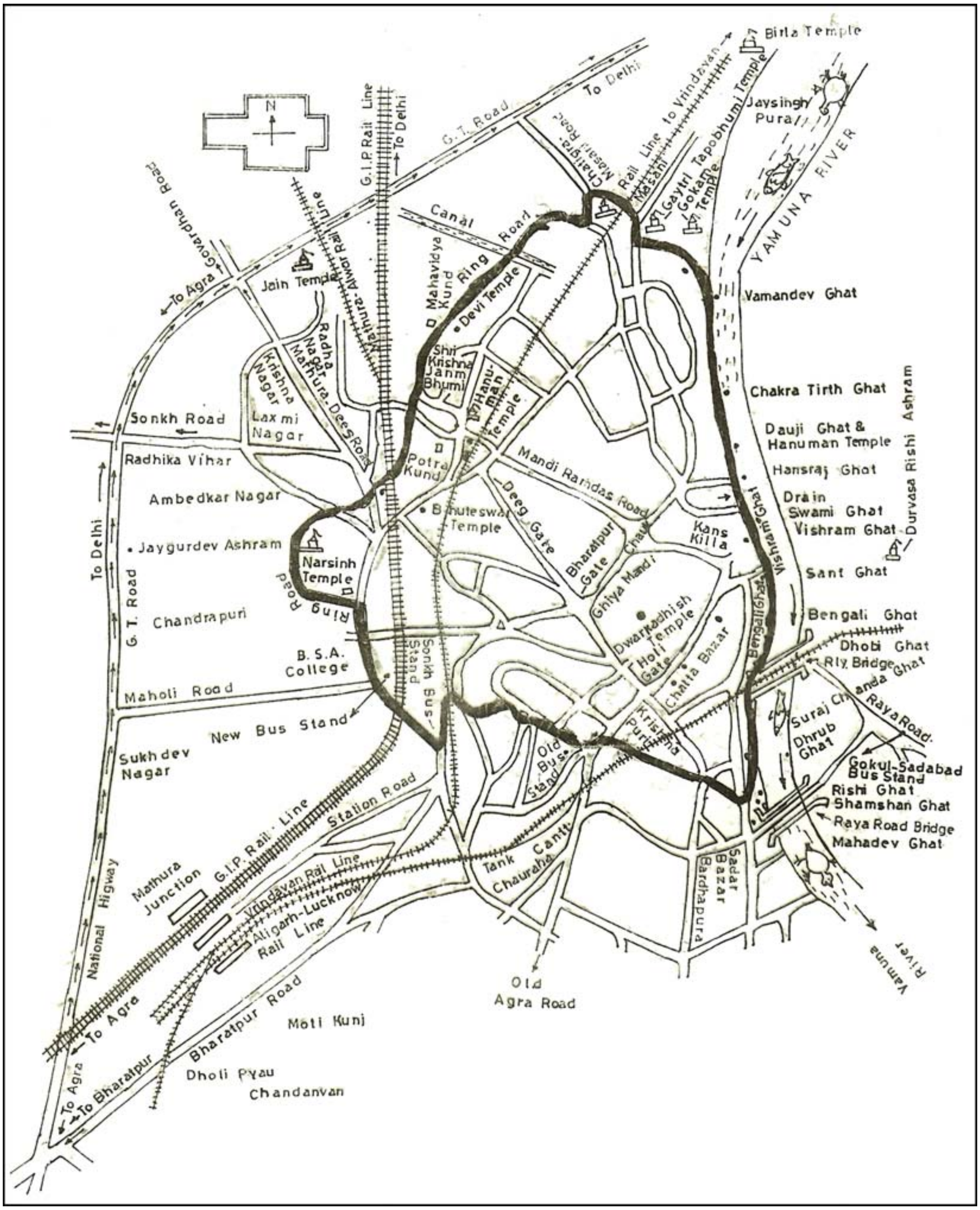

Fig. 1 Map of Yamuna river and Mathura city

organizing a *dharna* (sit-up) for their many demands related to the Yamuna pollution say that despite chrores (1 crore = 10 million and one US dollar equals 48 rupees) of rupees aid from Japan, nothing has improved (HT, 2004b). A UNESCO report (HT, 2004f) by experts has sounded the alarm for the clean up of the Yamuna river as it also forms an integral part of the great monument, the Taj, which attracts millions of people to Agra. Apart from the numerous law suits under the Water (Prevention and Control of Pollution) Act 1974, the State Pollution Control Board keeps sending warnings to the polluters but has no courage to proceed against them (HT, 2004d).

1. Water quality status at Yamuna ghats at Mathura

Many Indian rivers (including the Yamuna) have been surveyed comprehensively, analysed and reported on for their water quality and suitability for various beneficial uses [Bhargava (1983a, 1994), CPCB (2000, 2002) and HT (2004a,d,g)]. The Yamuna at Mathura presents the most unaesthetic scene (see Fig. 2), leaving apart its poor quality as summarized in Table 2 from Delhi to Agra [Bhargava (1985c), Kumar (2004) and CPCB (2000) for the 1996 to 1998 data]. The water quality as expressed by Bhargava's

Table 1 Visual observations of the Yamuna river (Source: Kumar, 2004)

Sl. No	Location in Mathura	Visual observations
1	Upstream of Gaytri tapobhumi (upstream of Mathura)	Very little floating matter and odour (in the afternoon time). The light penetration depth (transparency) remains only 0.2 m.
2.	Kans Killa (At right bank of Yamuna river in Mathura)	A major drain (carrying large amounts of solid wastes along with sewage from the main city) outfalls into the river. Some minor drains also out fall directly into the river. The river turns dark grey with lot of floating matter and very bad odor.
3.	Swami ghat (Downstream of Kans Killa	An out door bathing ghat where the river contains large amounts of floating matter from the municipal wastes along with huge quantities of the poly bags and the river looks blackish imparted with objectionable odor in the day time in particular.
4.	Vishram ghat (On the right bank of river Yamuna and downstream of swami ghat)	This most important ghat for a holy dip and out door bathing at Mathura is less than 1 km downstream of the major sewer outfall. A minor sewage drain outfalls into the river directly at this ghat. The river at this ghat of high religious significance is infested with lot of solids of all kinds. Large amounts of solids get deposited on the river banks. The river having dark grey has a transparency of only about 0.2 m. The colonies near the river banks are infested with a serious mosquito problem.
5.	From old Railway bridge to Raya road bridge with Suraj Chanda Ghat and Dhruv ghat (Right bank of Yamuna river)	At these ghats, thick layers of floating matter cover almost one third of the river width on its right bank, and apart from almost zero transparency highly objectionable floating dead animals giving foul odour are seen on the river's bank which is also used as a bathing ghat.
6.	Pumping stations (On this Right bank of river Yamuna)	Over flowing of waste water from these pumping stations and from side drains near the pumping stations are very frequent.
7.	Hansganj to Old Railway bridge (Left bank of river Yamuna)	Basin of river mostly used for agricultural purpose. This Bank has high erosion and the water is mostly used for agriculture. Only few large trees are seen in this whole stretch.
8.	Other Location	Regular dumping of holy materials in the river apart from heaped solid wastes on the right bank of the river. Several drains out fall into the river resulting in periodic mass killing of fish due to higher pollution of river.

water quality index (WQI), a number (ranging from 0 for highly/extremely polluted to 100 for absolutely unpolluted water) representing the integrated effect of the pollutional parameters relevant to a particular beneficial use, is also presented in Table 2. The WQI includes the effect of weight of each variable (pollution parameter) in the sensitivity function values of the various pollution variables relevant to a particular use (Bhargava, 1985a,c). The sensitivity function of all variables for a given use would thus have equal weight. The simplified model (Bhargava, 1983c) for WQI is represented as:

$$\mathrm{WQI} = \left[\mathrm{II}_{\mathrm{I}=1}^{\mathrm{n}} \mathrm{f_i(Pi)}\right]^{1/n} \times 100\ ,$$

in which n = number of variables considered more relevant to the use, $\mathrm{f_i(P_i)}$ = sensitivity function of the ith variable, which includes the effect of weighting of the ith variable in the use.

The geometric mean would permit an adequate depression in the WQI value when a significantly relevant parameter's sensitivity function value is sufficiently lowered by the unacceptable level of the parameter's value.

As seen from Table 2, the water quality of the Yamuna river at Mathura, particularly in the summer months, when the river has maximum utility for the devotees and tourists, is close to unacceptable levels of below a WQI of 10 for bathing, etc. and around an overall WQI of 20. The WQI for bathing, swimming, etc. comes down from a low value of 35 to extremely low values touching around 6 as the river flows along the various ghats of Mathura. The biochemical oxygen demand (BOD) values rise to as high values as 14

Table 2. Water Quality of the Yamuna River at and around Mathura

City		Year	Temperature of River water °C		Velocity m/s		Depth of Light Penetration cm		pH		Dissolved Oxygen mg/L		Biochemical Oxygen Demand mg/L		Chemical Oxygen Demand mg/L		Chlorides mg/L		Conductivity in m mhos/cm		Hardness mg/L		Coliform No./ 100 ml		Ammonia Nitrogen mg/L		WQI Swimming etc.		WQI Public Water Supply		WQI Agriculture		WQI Industry		WQI Fish Culture		Overall WQI	
			S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W
Delhi	u/s		30 (31)	20 (19)	0.1	0.1	27	28			7.5	8.5	5.2	2.9			4.5	30	196	260	104	140	70	170		0.4	57	63	69	70	93	75	58	55	72	90	70	71
	d/s		32	20	0.02	0.01	36	47			8.0	2.2	10	4.5			32.5	63.3	364	344	184	172	2400	2400		0.8	27	28	42	35	74	53	55	62	55	45	51	45
Mathura	u/s		30 (30)	18 (18)	0.3	0.25	28	30			7.5	5.6	7	3			87	200	658	613	204	214	2400	920		0.6	35	56	47	58	28	8	45	46	65	81	44	50
		1996	(29)				50				7.1		5				128		926		228		204000		1.34		23		25		6		41		66		32	
		1997	(31)				50				12.5		2				30		1366		278		15000		1.27		31		31		52		14		67		39	
		1998	(35.5)				50				5.1		3				144		426		130		11500		1.07		23		23		9		75		53		36.5	
	u/s Hansra ni Ghat 0 Km	2004	15 (March)	12 (Jan.)					7.42 (March)	7.40 (Jan.)	4.4 (Mar)	4.8 (Jan.)	14.0 3day 27ºC (March)	18.0 3day 27ºC (Jan.)	50 (Mar)	70 (Jan.)	162 (Mar)	219 (Jan.)	966 (Mar.)	1050 (Jan.)							7	7.7	15.5	15	7.8	6.3	60	40	43	23.5	26.5	18.5
	Drain 0.1 Km	2004	19 (March)	16 (Jan.)					6.82 (March)	6.80 (Jan.)			24.5 3day 27ºC (March)	25.0 3day 27ºC (Jan.)	480 (Mar)	490 (Jan.)																						
	Swami Ghat 0.4 Km.	2004	16.2 (March)	12.5 (Jan.)					7.3 (March)	7.3 (Jan.)	3.0 (Mar)	2.6 (Jan.)	18.0 3day 27ºC (March)	18.4 3day 27ºC (Jan.)	70 (Mar)	85 (Jan.)	205 (Mar)	240 (Jan.)	922 (Jan.)	1030 (Jan.)							5.5	3.5	12	8	7.5	6.3	56	40	20	2.7	20.2	12.1
	Vishra m Ghat 1.0 Km	2004	16 (March)	12 (Jan.)					7.48 (March)	7.36 (Jan.)	3.4 (Mar)	2.8 (Jan.)	16.0 3day 27ºC (March)	18.2 3day 27ºC (Jan.)	70 (Mar)	80 (Jan.)	196 (Mar)	233 (Jan.)	930 (Jan.)	1020 (Jan.)							5.7	4	12.5	8.2	7.5	6.3	56	40	20	2.6	20.3	12.2
	Bridge road d/s 2.8 Km	2004	16 (March)	12 (Jan.)					7.52 (March)	7.48 (Jan.)	3.9 (Mar)	4.6 (Jan.)	16.8 3day 27ºC (March)	17.5 3day 27ºC (Jan.)	80 (Mar)	70 (Jan.)	200 (Mar)	220 (Jan.)	943 (Jan.)	1250 (Jan.)							6.3	7.5	13.5	15	7.6	6.3	57	45	21.5	23.5	21.2	19.5
	d/s Gokul Barrag e 8 Km.	2004	15 (March)	12 (Jan.)					7.5 (March)	7.45 (Jan.)	4.2 (March)	5.8 (Jan.)	18.0 3day 27ºC (March)	16.4 3day 27ºC (Jan.)	70 (Mar)	70 (Jan.)	156 (Mar)	208 (Jan.)	958 (Jan.)	1180 (Jan.)							7	8.5	15.4	17	7.7	6.3	60	42	24	26.5	22.8	20
	d/s		30	15 (18)	0.22	0.6	23	31			7.4	9.2	12	6.1			89	203	660	615	204	216	2400	84		0.6	14	64	23	62	25	8	43	46	50	75	31	50
		1996	(40)				20				2.1		5				146		1001		238		20500		1.29		8		8		6		37		23		16.5	
		1997	(33)				20				6.8		2				214		1466		296		230000		0.85		26		25		6		9		56		24.5	
		1998	(34)				20				5.1		5				70		460		150		17000		1.04		21		23		54		59		54		44	
Agra	u/s		28 (29)	17 (18)	0.25	0.5	43	44			7.1	9.2	12	6			115	304	700	666	204	216	2400	84		0.8	23	59	32	55	8	5	49	51	51	69	31	50
	d/s		29	20	0.22	0.6	31	41			5.7	5.3	14	5			67	285	770	670	232	223	540	280		1.0	11	44	21	47	43	5	41	49	35	65	33	49

u/s = upstream; d/s= downstream; S= Summer; W= Winter; WQI = Water Quality Index; Ambient Temperature is shown within parenthesis.
AWQI of > 89 represents class I (Excellent); 65-89 represents class II (Good); 35-64 represents class III (Satisfactory); 11-34 represents class IV (Poor); <11 represents class V (Unacceptable)(Unacceptable)

Sources : Bhargava, 1985c; Kumar, 2004 and CPCB, 2000

Fig. 2 Scene near Vishram Ghat

to 18 mg/L at the ghats from a 7 mg/L value when the river enters Mathura. The dissolved oxygen is maintained only at about 3 to 4 mg/L at the various ghats of Mathura where the coliform count reaches a value of even 204,000 per 100 ml.

The water quality at Mathura has been varying over the years due to some action plans which were not, however, be effective for various reasons (Bhargava, 1992, 2000). Despite expenditures running into crores of rupees, the Yamuna water quality at Mathura could not manifest any improvement (HT, 2004a, b, d, e, f, g). Considering the significance of Mathura as a religious center for the Hindus, it is high time that serious efforts be undertaken towards restoring the quality of the Yamuna.

Large amounts of untreated/partially treated domestic wastewater, solid waste, industrial waste, enter into the Yamuna river between Delhi and Mathura. This quality degradation is further aggrevated by the low flow conditions of the Yamuna. The Kans Kila to Dhrubghat (Raya Mathura Road Bridge) stretch is heavily polluted and a large area of the river (from the old railway bridge to the road bridge of Raya-Mathura Road) is covered by a thick layer of floating masses. A major drain carrying the city's wastewater outfalls in the Yamuna just upstream of the series of bathing ghats (the main bathing ghat, the *Vishram ghat,* is only about 1 km downstream of this major drain). Apart from harmful chemicals, the ammonia concentration reaches as high as 30 times the permissible level (HT, 2004d). For Mathuraites, it had only been a remote expectation to see their Yamuna river ever meeting the basic requirements of mass bathing .

As per the water quality criteria of the Central Pollution Control Board (CPCB, 2002), the water quality of the Yamuna at Mathura is of class-D level (some times, even class-E). As per the biomapping water quality criteria, it belongs to class-C level (river in eutrophication stage). The dissolved oxygen (DO) level at Mathura (downstream) comes down to very low values, resulting in periodic mass killing of fish and other aquatic life. During November 2004, dead floating fish were observed at least three times in Mathura

(HT, 2004e). The water quality of the Yamuna river in regard to total and faecal coliform is alarming in its Mathura stretch (coliform counts vary between 7.0×10^4 to 2.8×10^6 Nos/100 ml). The polluted suspended materials (organic, inorganic and toxic) tend to settle (forming sludge) in the river /drain bed during the dry season. The dissolved materials, like heavy metals and pesticides, are adsorbed on the surface of these suspended materials settling in the river bed. The settled materials redistribute themselves in the river during the flood season, and these toxic substances get de-adsorbed to harm the aquatic life.

2. Sources of pollution of the Yamuna river

Pollution (pollutionem in Latin means defilement) manifests too much of any contaminant which may render the receiving environment (air, water or land) unsuitable for its desired use (s). For a biologist, it is a change that often brings about a reduction in the diversity of species and imbalance in diversity and abundance. For a chemist, it is the presence of non-permissible or objectionable substances (solids, liquids or gasses). The environmental engineer/technologist regards it as the presence of any foreign substance which tends to degrade the environmental quality, such that a hazard is constituted or the usefulness of the environment is impaired. Therefore, when it comes to water, all pollutants are not detrimental to all uses. For example, dissolved oxygen (DO) is a parameter of highest significance for the fish culturist but not so for an agriculturist. Likewise, temperature of water has great relevance for industrial cooling but not for many other uses. The dissolved salts are treated as pollutants for agricultural uses and coliform bacteria are most undesirable for drinking water. Invariably, one must specify the use when talking of pollution.

At Mathura along the Yamuna river, natural sources of water pollution are almost absent; the man made sources include the following.

1. *Domestic waste water*
   Mathura city [population : over 3 lac (0.3 million)] is spread mostly along the river, and the city's natural slope is towards the river. Hardly 50% of the city area is sewered. Total wastewater generation in Mathura city is about 43 mld (million litres a day). Nineteen drains (Kumar, 2004) collect a high portion of this wastewater and discharge it into the Yamuna. But despite these drains having been tapped (under the "Yamuna action plan") for pumping the sewage through 5 pumping stations to the sewage treatment plants of a total capacity of 28 mld (oxidation pond type), a major portion of the town's wastewater reaches the river directly due to overload, shock loads, rains, power cuts, chocking of drains, failure of pumps, mis-management, etc. Typical of India (also of some other under developed countries), *jhuggi-jhompries* (cluster of make-shift type of huts) without any access to sewers, constitute a large source of wastewater that flows directly into the river. Further, in many highly populated narrow lanes of cities along the river, deep sewers can not be laid without causing structural hazards to the buildings. The wastewater from such areas is bound to reach the river untapped. The city's groundwater (polluted for ages) also seeps into the river.
2. *Industrial wastes*
   A number of small and big industries such as saree printing, metallic works (brass, copper and silver mouldings) located between Mathura and Vrindavan release harmful and nonbiodegradable toxic chemicals, dyes, detergents, etc. into the Yamuna with or without prior treatment. Some residents carry on mini industrial activities such as electroplating in their private homes. As a result, toxic wastes flow into the open drains towards the river while polluting the groundwater as well through seepage.
3. *Pollutants from agricultural activites*
   In the Mathura region, the left side catchment areas of the river are mainly used for agricultural purposes. Ignorant and/or greedy farmers use excessive quantities of chemical fertilizers, pesticides, etc. in the hope of a greater yield and of better quality. A large quantity of commercial fertilizers and pesticides applied for agriculture is thus washed down into the river.
4. *Solid wastes*
   In Mathura, the problem of solid waste disposal (both domestic and industrial) has become very acute because of insufficient disposal facilities. Solid waste is heaped up everywhere in the city, which also prevents the flow of wastewaters into the drains. The drains, therefore, overflow and the overflowing wastewaters join the river directly instead of going to the treatment plants. Solid waste is also often dumped on the river banks and even on the bathing ghats. This uncontrolled dumping of solid waste creates ugly, unaesthetic scenes, and the storm water takes along all the solid wastes into the river. The per capita generation of solid waste in the region ranges from 0.15 kg/day to 0.35 kg/day (Chatterjee,1987), and about 0.225 kg/day (72 tons/day approximately) for Mathura city. The indiscriminate use and disposal of polythenes not only choke the drainage system to cause flooding of streets but also manifest ugly sites.
5. *Dumping of holy materials*
   The Yamuna at Mathura is well known for its holy status. Poly bags filled with different kinds of holy material viz. defiled photos, flowers, *puja* (worship) *samagree* (material) etc. is immersed into the river by the devotees thus increasing the suspended and floating materials (organic, inorganic and toxic) to add to the ugliness.

6. *Mass bathing by devotees*
Mass bathing at Mathura (on the Yamuna's right bank) at the time of different festivals and other religious occasions is very common all through the year. Unfortunately, the needed sanitary facilities are not available along the banks of the river. Therefore, a major part of the floating population utilizes river catchment areas for open defecation. Thus, contributed pathogenic and organic contaminants in the river catchments are regularly washed down into the river through the overflow of drains, sudden releases of water from upstream side or rains.
7. *Other sources*
Direct disposal of half-burnt and/or un-burnt dead bodies of humans and animals which are mauled and scattered all over by stray dogs and birds cause more aesthetic problems, continuous unabated problems of siltation and bank erosion, pollution load from upper segment which is highly polluted; over-exploitation of fresh water from the river and thus non availability of proper dilution.

3. Strategies for restoring river quality of the Yamuna

The water quality of the Yamuna river has been continuously degraded all along its Mathura stretch. The strategies that could restore the Yamuna water quality to its pristine status in the Mathura reach of the river, include the defensive approach (reducing the concentration of the pollutants) and the pro-active approach (augmenting the river's ability to assimilate higher amounts of the pollutants at higher rates), as are detailed in the following.

3.1. Defensive approaches

1. *Improving the sewerage system*
The entire area of Mathura, particularly the one which slopes towards the Yamuna river, should invariably be sewered. The wastewaters thus collected should be sent (through pumps if necessary) to a distance of about 3-5 km downstream of the city for treatment and disposal. This would ensure that the wastewater of the city would not enter into the river.
2. *Wastewater treatment and management*
The entire wastewater generated and collected in Mathura should be subjected to conventional (i.e. primary as well as secondary) sewage treatment before its final disposal on land and/or in the Yamuna river at some 3 to 5 km downstream. For efficient wastewater management, the strategies should include the following aspects.

   a. *Upgrading the two existing sewage treatment plants*
   Mathura's wastewaters of 43 mld is collected (Kumar, 2004) through 19 major drains and a part pumped for treatment in two sewage treatment plants (oxidation pond type)] of 28.1 mld total capacity. The existing wastewater treatment facilities are incomplete in respect of both, the capacity for treatment of the entire wastewater collected and the degree of treatment because the oxidation pond type of treatment is neither complete nor efficient. Therefore, not only the augmentation of the total treatment capacity of the two plants is necessary, but the treatment should be made complete.
   b. *Proper disposal of (partially) treated sewage*
   The sewage in excess of the existing capacity of the two treatment plants finds direct entry into the river without undergoing any treatment. Therefore, in such situations alternative drainage systems should be made so that the entire wastewater is disposed off on the river's downstream side in such a manner as not to create low dissolved oxygen (DO) conditions in the river. This can be effected through disposal of the wastewater on the downstream river side through outfalls properly designed in respect of their flow rates and spacings with due regard to the river's self-purifying coefficients and abilities (Bhargava, 1985b).
   c. *Work plan for sewage pumping station*
   In view of the frequent power breakdowns, arrangements must be made for alternative power sources. Further, the collection of wastewater for pumping should be carried out from more than one location. Table 3 shows the various zones (from a consideration of topography, pumping distances and uniformity of wastewater volumes) within and outside of Mathura city. The outside city (newly developed through merger of small villages) is growing faster than the inside city zone. The partially treated sewage can also be tried for ground water recharge in areas where the water table is low and sinking.
3. *Industrial waste water management*
The most haphazardly scattered small and big industrial growth of Mathura city has closely followed the rise in population. Therefore, the planning, land use regulations and consents for treated effluent discharges should strictly be enforced within industries and the various in-plant practices aimed at reducing the quantity and severeness of the pollutants should invariably be adopted. Such practices include (i) modifications in the use of raw materials ; (ii) application of latest process technologies; (iii) alterations in the waste generation process ; (iv) reducing wastewater (after generation) through material recovery system, effluent reuse, wastewater treatment, etc.; (v) wastewater load equalization to reduce peak flows ; (vi) neutralization of the wastewater before its release ; (vii) segregation of industrial waste of varying kinds for special treatments like evaporation, incinera-

Table 3 Mathura city zones inside and outside for Sewage Pumping

No.	Zone	Sub Zone	Covered area
1.	Inside	(i) STP Masni Nala	City area inside of Old Agra Road via. Tank chauraha, upto near bus-stand and Delhi Railway Track, National High way.
2.	Outside	(i) Moti Kunj	Moti Kunj, Chadanvan, Chandrapuri, Dholipayu, Up to national high way and right hand side of Main Railway Track.
		(ii) Maholi Road	Area of left hand side of Main Railway track and Maholi Road developments.
		(iii) Krishna Nagar	Krishna Nagar, Radha Nagar, Ambedkar Nagar, Radhika Vihar, to Sukhdev Nagar. (area between Bhuteswar, Mathura-Delhi Railway Track, National Highway and Sukhdev Nagar)
		(iv) New Zones	Other separate zone can be developed on the outside of National High way for newly developed residential area.

Source : Kumar, 2004

tion, pumping into deep soakage wells; (viii) consideration (as a last resort0 to tailor industrial production. Common effluent treatment plants (with assistance of the Pollution Control Board) for the various clusters of small industries should also be attempted. Numerous textile, dying and printing units are working in Mathura. These toxic dye bearing wastewaters may be carcinogenic, apart from creating visibility and aestheticity related problems. Tree leaves may act as low cost adsorbents. Such trees can be grown along the open effluent flow channels. Capacity data of different trees (that can be grown in Mathura region) used for different dyes are given in Table 4.

4. *Improving agriculture practices*
   After the 'green revolution' (evolved to increase the crop yield through the use of chemical fertilizers, insecticides, pestticides, etc.) in India, farmers started the use of various fertilizers, insecticides, pesticides, etc. A greed for greater yield and better quality compelled the illiterate farmers to use much larger amounts of these chemicals than their required prescribed doses, and the green revolution became a curse. As a result, the excess amounts of these chemicals entered the ground and surface water sources to pollute them significantly during the flood periods. The lakes/ponds thus manifested eutrophication. This kind of situation should be controlled through an efficient (and scientific) use of the stated chemicals ; erosion control for preventing the movement of the sand particles (coated with these chemicals) into the various surface water sources ; making use of the agricultural land for disposal of sewage, etc.
5. *Environmental control*
   Looking at what floats on the surface of the city stretch of a river indicates whether the city is a clean or dirty one. This reflects on the general environmental and sanitary management systems prevailing in the city, such as for street cleaning, solid waste collection and disposal, public utilities, etc. As for Mathura, the major control aspects include the following:
   a. *Solid waste management*
      Mis-management of solid waste in Mathura city causes heavy pollution in the Yamuna river. The solid waste of Mathura (Kumar, 2004), mainly of garbage is about 72 tons per day. Although reduction in waste generation is important, industry, business as well as the general public all have a role to play in recycling, reusing and reducing their respective wastes. A major portion of Mathura's biodegradable waste (cow dung and other dairy wastes, vegetables and fruits wastes; venders selling eatables ; bio-packing waste; food waste; etc.) can conveniently be collected from some identified major generation points listed in Ta-

Table 4 Sorption capacity of leave powders obtained from the different plants (Co = 100 mg/l, Temperature = 30°C)

Name of plant	Sorption capacity, mg/g		
	Methylene blue	Malachite green	Safranine
Peidium guyava	90.1	86.0	84.8
Mangifera indica	90.8	85.5	84.2
Dalbergia sissoo	91.10	75.0	84.8
Ficus elastica	89.6	60.5	87.3
Ashok	89.9	67.0	86.0
Citrus limon	72.5	54.5	85.4

Source: Singh and Srivastava, 1999

ble 5. Door to door collection and segregation of solid wastes in three bags/bins (one for biodegradable waste, the second for recyclable waste and the third for mixed waste) can also be practiced. Some non - governmental organizations may select various dirty littered markets/roads in Mathura and engage labour to segregate solid wastes into four bins respectively for iron-glass pieces, waste paper, fruit skins and organic matter to be sold to agents for recycling (iron, glass, paper, etc.), cattle feed (fruit skins, etc.) and pig feed (organic matter). The money thus earned would be utilized for labour wages and other expenses. This self supporting sustainable system (4 'S') strategy would generate some employment, avoid pig and cattle menace in the streets and improve the business, tourism and aestheticity of Mathura or any other Indian town.

Vermiculture biotechnology (earthworms are used to convert organic solid waste into a valuable byproduct, vermicomposting, a rich manure of use is agriculture and horticulture) can be applied. Fuel pellet (small cubes or cylinders made out of garbage whose calorific value is quite close to coal) can replace petroleum products for domestic and industrial use. Pyrolysis (a high-temperature thermal process and a possible alternative to incineration) of solid wastes refers (Kumar, 2004) to the thermal decomposition of the wastes in an inert atmosphere. The main advantage is lesser air pollution problems (when compared to incineration) resulting from a reduced volume of waste gases. Pyrolysis can also be used for the processing of discarded rubber tires; rubber tires can also be shredded and added to asphalt paving material for road construction. The slogging operation provides 97% volume reduction and non-putrescible residue.

b. *Construction of crematoria*
Crematoria construction, a costly alternative for the disposal of dead bodies, hardly proves useful in India because of the severe power shortage and lack of maintenance. However, the appearance and pollution of the river will improve if they were constructed at the burning ghats where Hindus cremate their dead.

c. *Construction of public toilets*
Public toilets along the banks of the Yamuna river at Mathura's heavily populated areas and bathing ghats should be constructed for use of devotees and poor people. Suitable sites for such complexes are available near the old railway bridge and Bengali ghat, the Swami ghat, the Dhobi (washerman) ghat and the Shamshan (cremation) ghat where the pilgrims are usually present in larger numbers.

d. *Development of a holy pond*
Huge amounts of holy material (i.e. *pooja samagree)* are regularly dumped into the river. Religious convictions and beliefs do not allow such material to be thrown elsewhere together with other solid wastes. It is certainly not easy to prevent the dumping of such holy material into the river through laws, fines, etc. Therefore, if holy Yamuna ponds were constructed and filled with only Yamuna water, then the holy materials collected from different locations could be immersed into the ponds where the material would sink to the pond bed. The clarified water of the pond (after primary treatment if required) could then be discharged back into the river. This fill and draw type of pond would then be filled again with the river water after removing the pond sediments which can be used as manure. The plants of lotus could also be grown in this pond to absorb heavy metals (Kumar, 2004).

Table 5 Major collection points for biodegradable wastes in Mathura

Location	Type of waste
Sonkh road (Mandi Choraha)	Vegetable and fruit waste, Jute Bags etc.
National High way (Mandi gate)	Vegetable and fruit waste
Maholi Road (Near Jaygurdev temple)	Packaging wastes from industries, agricultural waste
Bardh Pura	Dairy waste
Near Sadar Chauraha	Dairy waste, vegetable waste
Laxmi nagar Chauraha	Vegetable & fruit waste
Holi gate	Vegetable & fruit waste, packaging waste, vendor selling eatables
Jaysingh Pura	Dairy waste
Shri. Krishna Janm Bhumi	Vendor selling eatables, food waste
Deeg Gate	Vegetable and fruit waste packaging waste
All small and large milk dairies	Dairy waste
All restaurants	Vegetable waste & food waste

Source : Kumar, 2004

For collection of holy material, pots which may be named as holy pots could be placed all along the river bank at all bathing ghats, near temples, at both sides of bridges, etc. to enable the pilgrims a handy disposal of their holy materials.

6. *Temperature control*
A higher temperature of effluents particularly from thermal plants quickly reduces the DO levels in a stream through increased microbial activities at higher temperatures. Therefore the temperature of hot effluents should be reduced through spray, cascading, etc. before their disposal into the streams. This would also oxygenate the waters.
7. *Development of a park area*
The entire right bank of the Yamuna can be developed into a high embankment to be used as a park with fountains, artificial falls, play ground, grassy land, water sports, flow channels, ponds, plantation, etc. This high embankment would also control the pollution of the Yamuna by serving as a barrier between the river and the city (Bhargava 1998). These parks would prevent the unauthorized dumping of solid wastes on the river banks and also give an aesthetic view to the river, which would not only win the public esteem but could also ensure public awareness and public participation to make the river pollution free. At Mathura, some possible sites for the development of embankment parks along the river bank include Suraj Chanda ghat to Bangalee ghat, Swami ghat to Kans Killa and Kans Killa to gaytri tapobhumi (Kumar, 2004). These park areas could be used to create artificial aeration facilities to improve the DO level and self-purification of the river. A number of already existing permanent structures in the river Yamuna at Mathura, such as ancient wells, bridge piers, old ghats, etc. could also be developed to make in stream aeration. Involvement of architects in the design of such beautification works would be desirable.
8. *Afforestation along the Yamuna river bank*
Afforestation along the river banks would control siltation, erosion, agricultural run offs containing pesticides and fertilizers, etc. Afforestation could also serve as habitat to different species which may be helpful in cleaning the river. The most favorable tree for plantation along the river banks is Banyan tree (*Bargad* or *Vut*) having a long life and high soil binding capacity. This would also provide shelter to the pilgrims during the summer months specially.
9. *Planning and zoning of the wastewater outfalls*
The various drains carrying the treated or untreated waste water should outfall into a river in such a manner that the streams DO level does not fall below a certain level at any point. This control would involve a DO sag (simple or compound) analysis for designing the location of the various outfalls. The details of such DO sag models in various situations, their development and applications in the Ganga and Yamuna rivers are available in Bhargava (1983b) and Bhargava et al, 1995).
10. *Canal strategy*
In Mathura (as also in most other Indian cities), more than 50% unsewered housing (narrow lanes would not allow sewer construction), existence of *jhuggi-jhompries,* industrial activities in private homes, etc. result in wastewater (also toxic wastes) which flow directly into the river through open drains. Such wastes also seep to pollute the subsurface water. The drains generally outfall on the upstream of ghats. Regularly organized camps/*melas* (religious gatherings on the ghats), disposal of dead bodies into the river, dumping of solid wastes in and around the rivers, open defecation into the rivers, use of faulty, arbitrary and whimsically framed effluent standards, corruption, dominance by pseudos (persons who are not qualified environmental technologists) etc. are some of the other Indian circumstances which can not allow the Yamuna (or any other Indian river) to ever get cleaned up despite any number of action plans. Therefore, Indian rivers need a strategy which is foolproof to ensure that not a drop of wastewater may enter the river's city stretch at least. This can be made possible only by creating a barrier between the river and the city/town *either* through a covered parallel canal for carrying all the town's wastewater to some 5 km downstream of the city or by constructing a *bandha* (a kind of retaining wall or dam extending from a few metres below the river bed to the river's flood level) on either or both sides of the river. On city sides of such bandhas, a canal/trunk-sewer may carry all the wastewaters to the downstream of the city for treatment (if possible, economically) before disposal into the river.
11. *Legislation and fines*
A good method of control involves the formulation of stream (or river) standards depending on the proposed river uses. River standards represent the concentrations of the various pollutants at specific points in the river. When compared to the rest of the world, such river standards have to be very different in India in view of the direct consumption of the river water by the Hindu pilgrims. Based on the self purifying abilities and waste assimilation capacities of a river, the effluent standards should be worked out separately for each of the various polluters (Bhargava, 1985b). The methodology involves a mass balance exercise at each wastewater outfall point to determine the resulting river BOD (or any other pollutant for that matter) and utilization of river's self-purification coefficients to evaluate the river BOD (or any other non-conservative pollutant) attained at a

ghat downstream of the wastewater outfall (Bhargava, 1985b). Fixing of a desired level at the ghat and then working back would yield the required dilution ratio as well as the permissible effluent BOD level (the effluent standard in other words) of the outfalling wastewater. This way, the effluent standards for each polluter could be worked out in respect of any pollutant. Such effluent standards should strictly be enforced legally in India where arbitrarily (or whimsically) framed standards are all too often used at official levels. Imposition of fines on the defaulters is a must for Indian situations, and as a protection against blackmail, scams, etc. the fine collector be officially given a percentage based good commission/bonus for ensuring duty bound devotion, honesty and sincerity from the fine collectors posted in rotation.

12. *Better management of funds and supervision*
The supervision of construction works should better be managed. Especially, river pollution control related planning and execution should not be left to persons not qualified as environmental engineers/technologists, the so called pseudos, who have dubiously started dominating in India to seek highly remunerative private and government sponsored environmental consultancy. The principle of right people in the right places should strictly be adopted at all levels in India. The corruption at various levels be curbed through stricter punitive legislation to ensure full availability of funds allocated for the river pollution control projects in India.

3.2. Pro-active approaches

1. *Creation of awareness amongst the masses*
The Indian public is mostly unaware of the pollution related matters and implications. As a result, not sufficient pressure is built up against the defiled environment. Mass awareness programmes should therefore be organized through seminars, media and non-governmental organizations (NGOs). The ignorant type of Indian public needs taming and made to realize that they have a duty (as much as a right) for the protection of the environment they live in. Once they realize that the rivers, forests and the urban environment are their very own, they would expectedly contribute their bit. They can organize, as an example, street/market cleanings through rag-pickers who can collect fruit-vegetable wastes, waste papers, metal pieces, organic matter, etc. regularly and sell them respectively to the cow-dairies, paper mills, foundries, pig farms, etc. Such "self supported sustainable system" (the four S strategy) would increase business in the markets and relieve the environment at the same time.
2. *Improving the dilution ratio of the river*
To make a minimum dilution ratio available in a stream, the stream's low flow has to be augmented. This can be done by (i) impounding the river so that the water can be stored during the monsoon period and released during the dry periods (ii) dilution of the river through inter basin links and tributaries. River Chambal, the largest tributary of river Yamuna contributes flow 5 to 10 times the flow of the Yamuna in dry weather. River Chambal joins river Yamuna at Juhikha (Uttar Pradesh) near Kalpi. The Chambal could be diverted to join river Yamuna at the upstream of Mathura. Apart from improving the water quality at Mathura and Agra, this diversion would decrease the irrigation problems of Bharatpur district and other areas of Rajasthan.
3. *Artificial and in–stream aeration*
The stream, its tributaries and the various *nalas* (open drains) carrying the wastewater can be subjected to artificial aeration through (i) diffused aerators placed in the bottom of the stream and pumping air or oxygen which diffuses from a compressed state to a free state, (ii) mechanical surface aerators which circulate and splash the surface water into the air such that the falling droplets would get saturated with the DO, (iii) creating cascades in the stream such that the water will flow in thin sheets and get sufficiently aerated.
4. *Increasing the river's waste assimilative capacity*
Through modification of the pattern of the river flow, its waste assimilative capacities could be enhanced. Biological parks can also be developed for this effect. They would enable the conservation of turtles, fresh water sponges and other aquatic species, which can be helpful in in-stream cleaning of the river. Likewise, the self purifying abilities of the stream can be enhanced by altering the parameters of self-purification which are affected also by the stream's bed slope, velocity, flow rate and surface area to depth ratio.
5. *Better use of assimilation capacity*
By adopting a scientific effluent distributions policy and considering the redistribution of effluents in time and space, the river's assimilative capacity can be put to better use. In other words, the spacings and flow rates of effluent outfalls should be designed in compatability with the stream's self-purification coefficients and abilities such that the desired river quality is maintained at its various ghats. It would also be helpful if the various nalas/drains carrying heavily polluted wastewaters were designed to fall into those stretches of the river. It would further be worthwhile, not to spend money on repetitive stream quality surveys as the water quality status of rivers is already well documented as bad.
6. *Creation of an artificial lake*
On the upstream of Mathura city, the Yamuna water can be diverted to an artificially created lake where the excess flood water would be stored. During lean flow times, waters of this lake could be made to flow back into the

Yamuna river. This regulated flow would provide the desired dilution of the Yamuna river and would maintain a higher flow of the river apart from improving the river's water quality during dry seasons in particular.

4. Conclusion

The Yamuna river at Mathura and the sorrounding region has high religious importance. It is seriously unhealthy, and calling for a right cure. The pollution in the Yamuna river originates from domestic, industrial and agricultural activities apart from a totally mismanaged solid waste collection and disposal. Mass bathing in the river, open defecation and disposal of dead animals also add to the problem. The management for the collection and disposal of the city's waste is neither effective nor scientific. The various efforts of the government have not remedied the situation for numerous reasons and technical faults. The public is equally responsible, for mainly because of ignorance, indiscipline and an unhygienic culture. The various strategies for the control of Yamuna river's pollution are grouped into defensive and proactive approaches. The defensive strategies include scientific collection, treatment and disposal of all the wastewaters originating in Mathura, industrial wastewater's management within the industrial campuses, improvement in the existing agricultural practices through controlled use of chemical fertilizers, insecticides and pesticides, better solid waste management strategies, construction of public conveniences at major ghats including alternatives for disposal of holy materials, and development of recreation parks and embankments, or retaining walls (serving as barrier between the town and the river) along the river banks as part of the foolproof pollution control strategy to prevent the flow of wastewater into the Yamuna river, legislative measures including the adoption of scientifically evolved effluent standards, and corruption free management of funds and a sincerely strict qualified supervision of constructional works. The pro-active strategies include creation of awareness and duty amongst the Indian masses and unconcerned public, maintaining enough flow in Yamuna specially during the lean periods, enforcement of the Yamuna river's self-purifying abilities through artificial and in-stream aeration, scientific exploitation of the river's waste assimilative capacity and creation of an artificial lake for storing the flood waters and later its release into the Yamuna river during the dry flow periods. Apart from adopting the various control strategies outlined in this paper, there is a sincere need to punish the polluters and defaulters through a system of fines with adequate bonus to the fine collectors to keep them duty bound and honest. Creation of public awareness on the suggested lines and keeping away from persons not qualified in environmental technology will also expedite the Yamuna river cleaning.

References

Bhargava, D.S.: 1983a, 'A light- penetration model for the rivers Ganga and Yamuna,' *International Journal for Development Technology (England)*, **1**(3), 199–205.

Bhargava, D.S.: 1983b, 'Most rapid BOD assimilation in Ganga and Yamuna rivers,' *Journal of Environmental Engineering, American Society of Civil Engineers*, 109(1), Proc. No. 17674, 174–188.

Bhargava, D.S.: 1983c, 'Use of water quality index for river classification and zoning of Ganga river,' *Environmental Pollution, Series B (England)* **6**(1), 51–67.

Bhargava, D.S.: 1985a, 'Expression for drinking water supply standards,' *Journal of Environmental Engineering American Society of Civil Engineers,* **111**(3), 304–316.

Bhargava, D.S.: 1985b, 'Technology of rationally setting effluent standards for water pollution administration,' *Journal of Environmental Engineering Division, Institution of Engineers (India)*, **66**(1), 12–15.

Bhargava, D.S.: 1985c, 'Water quality variations and control technology of Yamuna River,' *Environmental Pollution, Series A (England),* **37** (4), 355–376.

Bhargava, D.S.: 1992, 'Why the Ganga (Ganges) could not be cleaned,' *Environmental Conservation*, Switzerland, **19** (2), 170–172.

Bhargava, D.S.: 1994, 'River BOD prediction under non-point discharge conditions,' *Indian Journal of Engineering and Material Sciences,* **1**(1), 35–40.

Bhargava, D.S.: 1998, 'Foolproof pollution control of Indian rivers,' *Indian Journal of Engineering and Material Sciences.* **5**(4), 162–166.

Bhargava, D.S.: 2000. 'Can Indian rivers be made pollution free?,' Environmental Protection Information, *Indian Journal of Environmental Protection.*, **20**(6), 476–480.

Bhargava, D.S., Tyagi, B. (Mrs), and Gakkhar, S. (Mrs) (1995), 'Polynomialization of the models for dissolved oxygen sag parameters,' TN : *Water Maritime and Engergy, Proceedings of the Institution of Civil Engineers,* UK, **112**, 72–74.

Chatterjee, AK: 1987, 'Water supply and sanitary engineering,' *Khanna Publishers*, Delhi, 3rd ed., 487.

CPCB: 2000, 'Water quality status of Yamuna river,' *Central Pollution Control Board, N*ew Delhi, series ADSORBS/32/1999–2000. April 2000.

CPCB: 2002, 'Water quality criteria and goals,' *Central Pollution Control Board*, New Delhi, series MINARS/7/2001–2002.

Kumar Y: 2004, 'Strategy for Pollution Control of Yamuna river at Mathura,' Master's *Thesis*, IET, Lucknow, 2004.

HT: 2004a, 'Yamuna water too polluted for religious rites,' *Hindustan Times*, New Delhi., 27–3–2004, p 3.

HT: 2004b, 'Fast, dharna against Yamuna river pollution,' *Hindustan Times*, New Delhi., 29–3–2004, p 3.

HT: 2004c, 'Mathura's ghats losing sheen,' *Hindustan Times*,New Delhi., 27–6–2004, p 3.

HT: 2004d, 'Pollution in Yamuna river cause of alarm,' *Hindustan Times*, New Delhi., 14–11–2004, p 3.

HT: 2004e, 'Fishes found dead in Yamuna,' *Hindustan Times*,New Delhi., 20–11–2004, p 3.

HT: 2004f, 'Experts ring Taj alarm bells : clean Yamuna, remove corridor remnants, says UNESCO report,' *Hindustan Times*, New Delhi., 26–11–2004, p 13.

HT: 2004g, 'Mathura water unfit for drinking,' *Hindustan Times*, New Delhi., 22–11–2004, p 3.

Singh, D.K. and Srivastava, B.: 1999. 'Removal of basic dyes from aqueous solution by chemically treated Psidium Guyava leaves,' *Indian Journal of Environmental Health,* **41**(4), 333–345.