Assessment of minimum water flow requirements of Chambal River in the context of Gharial (*Gavialis gangeticus*) and Gangetic Dolphin (*Platanista gangetica*) conservation

Study Report

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

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CONTENTS

EXECUTIVE SUMMARY

The Chambal River originates from the summit of Janapav hill of the Vindhyan range at an altitude of 854 m above the msl at $22^0$27’ N and $75^0$37’ E in Mhow, district Indore, Madhya Pradesh. The river has a course of 965 km up to its confluence with the Yamuna River in the Etawah district of Uttar Pradesh. It is one of the last remnant rivers in the greater Ganges River system, which has retained significant conservation values. It harbours the largest gharial population of the world and high density of the Gangetic dolphin per river km. Apart from these, the major fauna of the River includes the mugger crocodile, smooth-coated otter, seven species of freshwater turtles, and 78 species of wetland birds. The major terrestrial fauna of the adjacent areas are Indian wolf, golden jackal, caracal, jungle cat, desert cat, ratel, small Indian civet and neelgai. Unlike other rivers of greater Ganges drainage system the Chambal River is relatively unpolluted.

A 600 km stretch of the Chambal River, between Jawahar Sagar Dam (Rajasthan) and Panchhnada (Uttar Pradesh), has been declared as the National Chambal Sanctuary primarily for the conservation of gharial and associated aquatic fauna. The Sanctuary is managed by the Rajasthan, Madhya Pradesh and Uttar Pradesh Forest Departments.

During early 1970, four major hydro electric projects over Chambal River were undertaken namely Gandhi Sagar, Rana Pratap Sagar, Jawahar Sagar and Kota Barrage. This has reduced the flow of the Chambal River below the Kota barrage to zero during the lean seasons, leading to reduction in gharial habitat between Kesoria Patan to Chambal - Parvati confluence and dolphin habitat between Chambal - Parvati confluence to Rahu Ka Gaon. Thereafter, with inflow of water from Kali Sindh and Parbati Rivers and through ground water inflow, the Chambal River rejuvenates itself and forms the main aquatic wildlife habitat.

Environmental water requirements also referred to as ‘Environmental Flows’ are a compromise between water resource development and the maintenance of a river at ecologically acceptable or agreed condition. Based on this principle, we assessed the minimum environmental flow of Chambal River taking Gharial and Gangetic dolphin as umbrella species using a combination of flow analysis and habitat modeling. We attempted to answer the following key questions pertaining to the environmental flow of the Chambal River (i) What is the mean monthly flow of Chambal River and its trend? (ii) Is there any relationship between flow and depth? (iii) In the present flow regime, what percentage of Chambal River is suitable for adult gharial and Gangetic dolphin?, and (iv) What will be the cumulative impact of proposed water harvesting projects on the habitat quality?

To address the above mentioned questions, we have used monthly flow data from 1996-2004 from Central Water Commission for three stations namely Pali, Dholpur and Udi, located downstream to the Kota Barrage. We measured water depth at 440 locations between Dholpur (Rajasthan) to Panchhnada (U.P.) during February, April and June 2010. We also measured the actual flow during the same period at 29 locations to derive the relationship between flow and depth. Based on these data we have assessed the depth of the river stretch from Dholpur to Panchhnada with a view to appraise the suitability of the river stretch for gharial and dolphin.

Our analysis revealed that the mean monthly flow of Chambal River for the period 1996-2004 varies between 2074. 28 m^3/sec in August to as low as 58.53 m^3/sec in April. During the last 20 years the flow regime of Chambal River has shown a declining trend of *ca* 3.5% per annum.

The required water depth for gharial has been found to be 4 m and above, where as for dolphin it is 10 m and above. Based on the relationship developed by us from the actual data collected on depth and flow, we found that the minimum flow requirement for long term survival of gharial is 164.34 m^3/sec and for dolphin it is 289.67 m^3/sec. At present, this flow is available only during the months of July to October for gharial and July to September for dolphin in the river stretch between Dholpur and Panchhnada.

Analysis of monthly data on mean flow suggests that there is reduction in flow of almost 50% or less in the month of February to June so far as gharial is concerned. For dolphin the reduction of 50% or less is noticed from November to June, *i.e.* for 8 months in a year. The cumulative requirement in post project scenario has been worked out and it is found that the pre-project reduction in flow by 50% or less is further reduced significantly in the months of November to March for both the species. The period of reduced availability of flow also corresponds to the breeding season of gharial. As the suitable habitat at present is already compromised by 50% or less in lean months, further drawl of water will negatively impact the habitat suitability for gharial and dolphin significantly. The declining trend of flow of 3.5% per annum recorded over the last 20 years needs to be factored in for future water management programme for Chambal River.

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1. Background

In the 18th meeting of the Standing Committee of NBWL held on 12th April, 2010 it was decided to carry out a study to assess the cumulative impacts of various water harvesting projects proposed on Chambal River and its aquatic life *vis a vis* water availability. This report presents the assessment of environmental flow of Chambal River taking Gharial (*Gavialis gangeticus*) and Gangetic dolphin (*Platanista gangetica*) as umbrella species.

2. Introduction

Environmental water requirements, also referred to as 'Environmental Flows' (Dyson et al. 2003; Acreman and Dunbar 2004), are a compromise between water resource development and the maintenance of a river in some ecologically acceptable or agreed condition. An environmental flow is the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated. Environmental flows provide critical contributions to river health, economic development and poverty alleviation. It ensures continued availability of the many benefits that healthy river and groundwater systems bring to society (Dyson et al. 2003).

For day-to-day management of a river, environmental requirements are often defined as a suite of flow discharges of certain magnitude, timing, frequency and duration. These flows ensure a flow regime capable of sustaining a complex set of aquatic habitats and ecosystem processes and are referred to as *"environmental flows", "environmental water requirements or "environmental flow requirements", "environmental water demand"* (Knights 2002; Lankford 2002; Dyson et al. 2003; Smakhtin et al. 2007).

This report presents an assessment of minimum flow requirement of Chambal River taking gharial (*Gavialis gangeticus*) and Gangetic dolphin (*Platanista gangetica*) as umbrella species.

3. The Chambal River

The Chambal River originates from the summit of Janapav hill of the Vindhyan range at an altitude of 854 m above the msl at $22^0$27' N and $75^0$37' E in Mhow, district Indore, Madhya Pradesh. The river has a course of 965 km up to its confluence with the Yamuna River in the Etawah district of Uttar Pradesh. From the place of its origin the Chambal River flows for some 320 km in a generally northerly direction before entering a deep gorge in Rajasthan at Chaurasigarh, about 96 km upstream of Kota. The deep gorge extends up to Kota and the river then flows for about 226 km in Rajasthan in a northeasterly direction, and then forms the boundary between Madhya Pradesh (M.P.) and Rajasthan for about 252 km. Thereafter, the river forms the boundary between M.P. and Uttar Pradesh (U.P.) for about 117 km; enters U.P. near Chakar Nagar village and flows for about 40 km before joining river Yamuna (Figure 1).

The Chambal River averages 400 m in width while depth ranges from 1 to 26 m (Hussain and Choudhury, 1992). During monsoon the water level rises 10 to 15 m and often spreads to more than 500 m from either bank. The mean maximum discharge of the river is 2074.28 m^3/s and the minimum 58.53 m^3/s as recorded during 1996-2004. Between 1960 and 1972 four multipurpose dams namely Gandhi Sagar, Jawahar Sagar, Ranapratap Sagar and Kota Barrage were built on Chambal River which have affected its flow considerably (Hussain and Choudhury, 1992).

The Chambal River is one of the last remnant rivers in the greater Ganges River system, which has retained significant conservation values. It harbours the largest gharial (*Gavialis gangeticus*) population (Singh, 1985; Hussain, 1993), high density of the Gangetic dolphin (*Platanista gangetica*) (Singh and Sharma 1985; Rao, 1989) and besides being a staging ground for migratory waterfowls, it is one of the last remnant nesting ground for Indian skimmer (*Rynchops albicollis*) and small Indian pratincole (*Glareola lactea*). Apart from the gharial and Gangetic dolphin, the major fauna of the Chambal River includes, the mugger crocodile (*Crocodylus palustris*), smooth-coated otter (*Lutra perspicillata*), seven species of freshwater turtles, and 78 species of wetland birds (Sharma and Singh, 1986; Hussain, 1993; Hussain, 1996; Hussain and Choudhury, 1997; Sharma, 2006). The major terrestrial fauna of the adjacent areas are Indian wolf (*Canis indica*), golden jackal (*Canis aureus*), caracal (*Caracal caracal*), jungle cat (*Felis chaus*), desert cat (*Felis silvestris ornata*), ratel (*Mellivora capensis*), small Indian civet (*Viverricula indica*) and neelgai (*Boselaphus tragocamelus*).

Unlike other rivers of greater Ganges drainage system, the Chambal River is relatively unpolluted (Hussain, 1999). The water quality exhibits very low suspended solids and low Biological Oxygen Demand (BOD) and high Dissolved Oxygen (DO). There is no indication of organic matter discharge or eutrophication in the river as the value of Chemical Oxygen Demand (COD), ammonia (NH_4) and phosphate (PO_4) are below the threshold limits. The essential cations (Ca, Mg, Na and K) are also within the range to support the aquatic organism. On the basis of standards set by Central Pollution Control Board (CPCB), Government of India, the Chambal River water can be considered as `A' category. Also by comparing the water quality parameter with ranges given by Allen (1989) the Chambal River can be considered as clean.

4. Existing and proposed water related projects in Chambal River

There are 7 major, 12 medium and 134 minor irrigation projects in Chambal River Basin, as well as some small irrigation systems (covering <20 ha) constructed and operated by various '*Panchayat samities'*. Around 52 irrigation projects, including 7 medium projects with a total live storage capacity of 271 million m^3, were under construction during early 1990s in the Chambal Basin (Rajasthan Irrigation Department). During early 1970, four major hydro electric projects over Chambal River were undertaken namely Gandhi Sagar, Rana Pratap Sagar, Jawahar Sagar and Kota Barrage (Figure 1). The former three dams are storage reservoirs, whereas the later diverts water for irrigation purpose. This has reduced the flow of the Chambal River below the Kota barrage to zero during the lean seasons, leading to loss of gharial downstream to Kota Barrage up to Chambal - Parbati confluence and River dolphins between Parbati confluence to Rahu Ka Gaon.

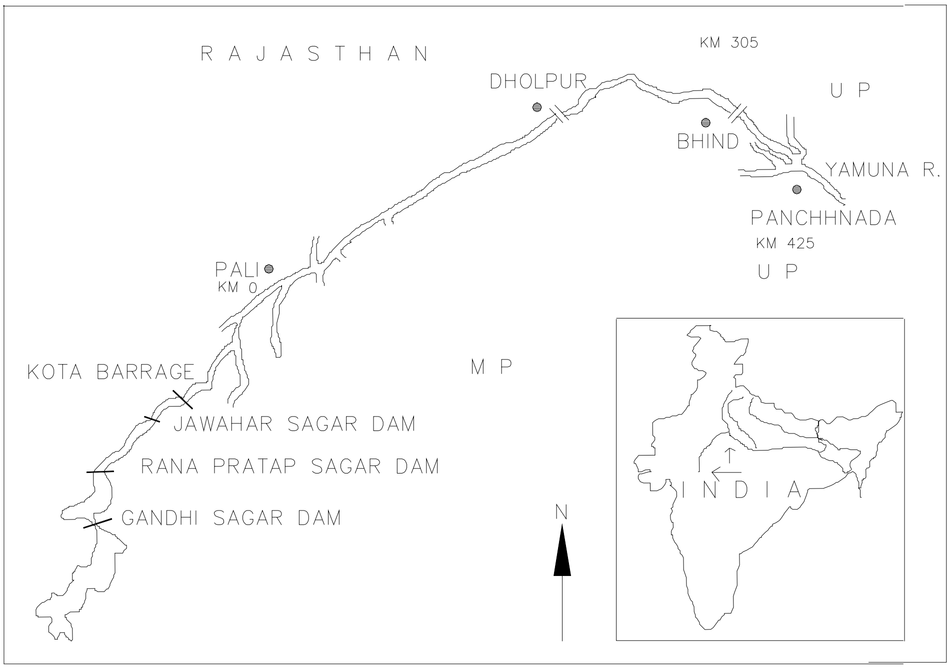

Figure 1. Map of Chambal River showing location of major dams

Thereafter by receiving water from Kali Sindh and Parbati Rivers and through ground water inflow the Chambal River sustains itself and forms the main aquatic wildlife habitat. Small scale water abstraction projects such as Pinhat lift which was constructed without the grant of environmental clearance, draws water at a rate of 8.5 m^3/sec. A schematic representation of various water harvesting project has been given in Figure 2. The proposed Parbati-Kalisindh-Chambal link project envisages the diversion of water from Parbati and Kalisindh sub-basins to Gandhi Sagar dam/Rana Pratap Sagar dam (National Water Development Agency, Government of India) which is likely to further reduce the flow affecting the ecological process of Chambal River. Thus construction of Patanpur dam on Parbati River is likely to have severe impact on Chambal ecology.

Currently, three lift irrigation projects viz Chambal lift, Aisha Lift and Kanera Lift are being planned by the Rajasthan and Madhya Pradesh Governments which are in various stages of development (Plate 1, 2 & 3). The details of the proposed and ongoing projects have been summarized in Table 1.

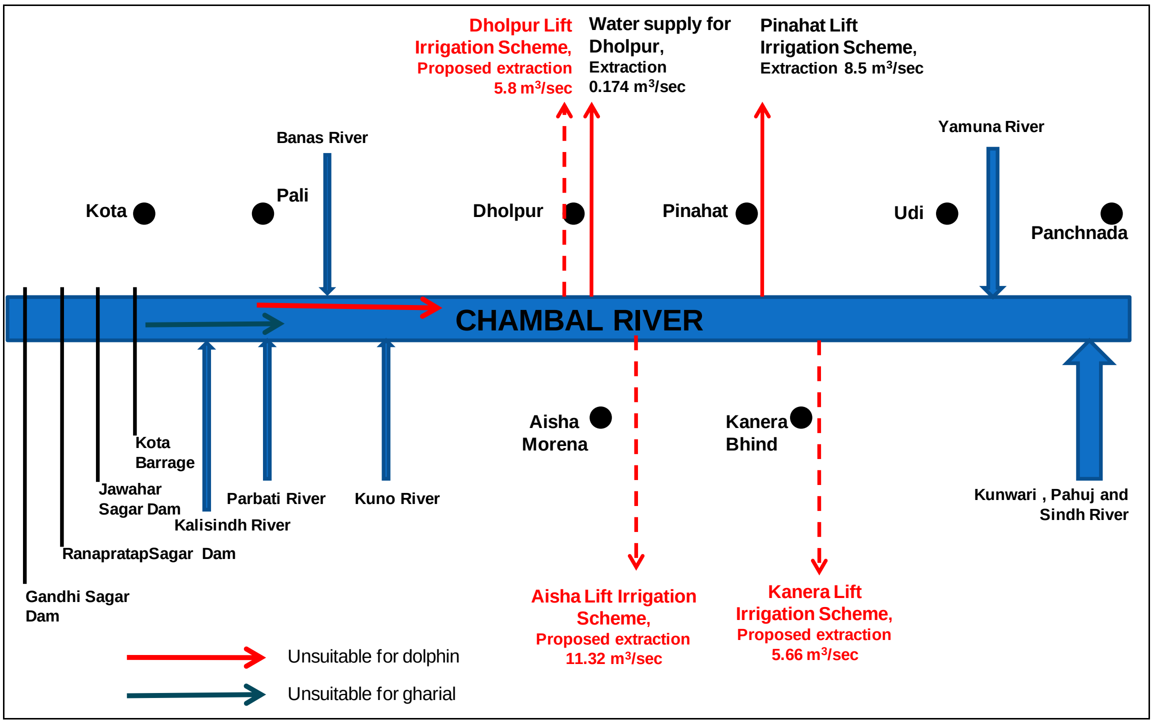

Figure 2. Schematic representation of dams, water extraction projects and river flow at different locations

Table 1. Proposed and ongoing water related projects on Chambal River between Pali (Rajasthan) and Panchhnada (U.P.).

Projects	**Location**	**Water requirements**	**Present status**
Kanera Lift Irrigation	Kanera, Bhind, M.P.	5.66 m^3/sec	Proposed
Dholpur Lift Irrigation	Dholpur, Rajasthan	5.8 m^3/sec	Under evaluation
Aisha Lift Irrigation	Morena, M.P.	11.32 m^3/sec	Proposed
Pinahat Lift Irrigation	Pinahat, U.P.	8.5 m^3/sec	Operating
Dholpur City Drinking Water	Dholpur, Rajasthan	0.174 m^3/sec	Operating

Source: Office of The Executive Engineer, W.R. Division, Bhind. Projects only for which data was available.

Plate 1. Proposed Dholpur Lift Irrigation project

Plate 2. Pinahat Lift Irrigation project

Plate 3. Way to Proposed Kanera Lift Irrigation project

5. National Chambal Sanctuary

The National Chambal Sanctuary was notified primarily for the conservation of gharial by the states of Madhya Pradesh, Uttar Pradesh and Rajasthan vide gazette notifications No. 7835 XIV-3103-78, Jan. 29, 1979 (Uttar Pradesh), No. 15-12-X(2)-82, Bhopal, dt. 24.12.1982 (Madhya Pradesh) and in Rajasthan State Gazette Vol. 35, No. 24 Sept. 15, 1983, (Rajasthan). The sanctuary includes a stretch from Jawahar Sagar Dam to Kota barrage, then after Panchhnada a free zone of about 18 km, the Sanctuary again begins from Keshoraipatan and extends to where Kuwari Pahuj and Sindh rivers form a confluence with river Yamuna. The length of the Sanctuary from Keshoraipatan to Panchhnada is 572 km that includes about 15 km of Yamuna after Chambal-Yamuna confluence.

The width of the river that is included inside the Sanctuary is 500-1000 m from either bank in Rajasthan and Madhya Pradesh. The width in Uttar Pradesh is greater than the above and extends to cover adjacent important areas.

6. Gharial

The gharial (*Gavialis gangeticus* Gmelin, 1789) is endemic to the Indian subcontinent occurring in the Indus, Ganges, Brahmaputra and the Mahanadi River systems (Smith, 1939; Groombridge, 1987; Whitaker, 1987; Hussain, 1991; 1999). By the mid-1970's it was on the verge of extinction due to loss of habitat, mortality in fishing nets (Whitaker, 1987; Hussain 1999) and poaching (Daniel, 1970; Honegger, 1971; Bustard, 1979; Whitaker and Basu, 1983). It is believed that the gharial is now extinct from Myanmar, Bhutan and Pakistan. In Bangladesh, fewer than 20 individuals may be present (Groombridge, 1987).

The gharial, once widespread is now listed as ‘Critically Endangered’ in IUCN Red List. As much as 96 to 98% of its population has declined in last 60 years. Its population in recent years has been reduced to a very small number of widely spaced sub-populations with less than 200 adults. The drastic decline in the gharial population over the last 60 years is attributed to a variety of causes including over-hunting for skins and trophies, egg collection for consumption, killing for indigenous medicine, and accidental mortality in fishing nets (Hussain 1999; Choudhury et al 2007; Hussain 2009). While hunting is no longer considered to be a significant threat, construction of dams, barrages, irrigation canals, siltation, changes in river course, artificial embankments, sand-mining, riparian agriculture have combined to cause an extreme limitation to gharial range due to this excessive and irreversible loss of riverine habitat. The decline of gharial has occurred hand in hand with the decline of other riverine species once reportedly abundant and now endangered, including the Ganges River Dolphin (*Platanista gangetica*) and the Mugger crocodile (*Crocodylus palustris*) as well as numerous waterfowl species and turtles (Choudhury et al. 2007). The gharial requires water depth 4-5 m. Any activity that reduces the water depth of its habitat <4-5 m can severely affect its survival (Hussain 2009).

The Chambal River holds the largest breeding subpopulation of gharial with an estimated 48% of its total adult population (Table 2). By the year 1997 as many as 226 mature animals and 81 nests were recorded in the Chambal (Sharma 1999; Basu and Sharma 2004). However, between 1997 and 2006, the gharial population of Chambal River has declined by as much as 40%. This was largely attributed to reduction in water flow as well as available nesting beaches, modification of river morphology and increased mortality in fishing nets (Hussain 2009). The diversion of water from Chambal River downstream to Kota Barrage has altered the gharial distribution range. There is no report of gharial from Kesoriapatan and Pali in recent years.

Table 2. Population trend of gharial in the National Chambal Sanctuary.

Year	**Survey stretch**		**Length (km)**	**Total estimated population**	**Density (gharial/River km)**
	From	To			
1983	Rahu ka Gaon	Panchhnada	315	451	1.432
1984	Pali	Panchhnada	425	605	1.424
1985	Pali	Gyanpura	385	627	1.629
1988	Pali	Panchhnada	425	820	1.929
1990	Pali	Panchhnada	425	982	2.311
1993	Pali	Panchhnada	425	898	2.113
1994	Pali	Bhare	415	1026	2.670
1995	Pali	Bhare	415	1042	2.925
1996	Pali	Bhare	415	1078	2.993
1997	Pali	Bhare	415	1121	3.106
2003	Pali	Chakarnagar	395	514	1.301
2004	Pali	Chakarnagar	395	552	1.397
2007	Pali	Bhare	415	865	2.084

Source: Hussain 1999; Basu and Sharma, 2004

With new schemes proposed for water extraction, it is likely that the long term survival of gharial and other large aquatic vertebrates such as Gangetic dolphin (*Platanista gangetica*) will be severely affected.

7. Gangetic dolphin

The Gangetic dolphin (*Platanista gangetica*) is distributed in the northern parts of the Indian sub-continent and inhabits the Ganges, Brahmaputra and the Meghna river system and their major tributaries. Once abundant, its population is now declining all over its range due to habitat loss, commercial exploitation and mortality in passive fishery (Perrin and Brownell, 1989; Rao et al., 1989). Apart from these, construction of dams and barrages along the major tributaries has isolated its population into several pockets thereby making these isolated populations vulnerable (Mohan, 1989). In recent years the Gangetic dolphin is receiving considerable attention as it has been declared as The National aquatic species of India. It is listed as Schedule I species under Indian Wildlife (Protection) Act, 1972. The Chambal River has fluctuating population of dolphin with the density varying between 0.147 to 0.386 dolphins/river km (Table 3).

Table 3. Status of Gangetic dolphin in National Chambal Sanctuary.

Year	Length of river surveyed (km)	Total Adults	Sub Adults	Juveniles	Calves	Unidentified	Total
1993	425	39	13	6	10	4	72
1994	415	41	14	8	9	3	75
1995	415	42	23	7	9	3	84
1996	415	44	18	10	11	6	89
1998	230	46	18	10	9	-	83
2001	425	48	17	11	12	-	88
2002	315	50	17	12	14	-	93
2003	395	37	12	9	8	-	66
2004	395	36	12	8	7	-	63
2005	395	37	11	8	8	1	65
2006	255	40	13	8	7	1	69
2007	425	52	19	7	13	-	91
2008	425	45	19	7	14	1	86

8. Objectives of assessment

The flow and depth of a river are determining factors for ecological distribution and viability of the habitat for aquatic species. To assess the minimum flow requirement of Chambal River for long term survival of gharial and Gangetic dolphin we put forth the following key questions:

(a) What is the mean monthly flow of Chambal River between Pali (Parbati – Chambal confluence at Rajasthan) and Chakarnagar (prior to the Chambal-Yamuna confluence at Uttar Pradesh)?

(b) Is there any relationship between flow and depth *i.e* whether increase in flow will improve the habitat availability in terms of water depth?

(c) In the present flow regime, what percentage of habitat (Chambal River) is optimal for adult gharial and Gangetic dolphin in terms of water depth?

(d) What will be the cumulative impact of proposed water harvesting projects on the habitat quality?

Plate 4: Habitat of gharial

Plate 5: Nesting site of gharial

Plate 6: Gangetic dolphin habitat

9. Methods of assessment

This analysis is applicable to river stretch between Pali and Panchhnada (425 km) and it is based on surface runoff/flow only. Because of lack of information on ground water inflow and outflow and evapo-transpiration we have not taken these parameters into account. We have not taken into account how increase or decrease in flow will affect the prey (fish) availability for gharial and dolphin.

Mean monthly flow of Chambal River between Pali and Chakarnagar

To derive the mean monthly flow of Chambal River between Pali (Parbati – Chambal confluence at Rajasthan) and Chakarnagar (prior to the Chambal-Yamuna confluence at Uttar Pradesh) we used flow data from Central Water Commission of the stations situated at Pali (Sawai Madhopur District), Rajghat (Dholpur district) and Udi (Etawah District), for the period of eight years from 1996 to 2004 and the mean flow was calculated for each month.

Relationship between flow and river depth

To answer the question in terms of water depth and percentage of river stretch available for gharial and dolphin, we measured water depth of Chambal River between Rajghat (Dholpur district) and Panchhnada (Downstream to Chambal – Yamuna confluence) at every 500 m interval using Garmin depth finder during February, April and June 2010. Based on the published work on water depth preference of gharial, we calculated the percentage of river stretch having depth >4 m, because gharial >180 cm in length including sub-adults and adults prefer water depths >4 m (Hussain 2009) (APPENDIX I). We calculated habitat preference of dolphin using Bonferroni confidence interval and analysis was made taking water depth preference of dolphin at >10.0 m (APPENDIX II).

During the same period i.e. February, April and June 2010 depending on the accessibility and ease of measurement, we measured river flow at 8 to 11 locations and mean flow for these months were calculated. Flow was calculated as m/sec and was multiplied by mean depth of that site to get the volumetric flow in m^3/sec (Chitale, 1974). At each site, the entire width of the river was divided into 6-7 locations, and at each location, depth was measured once and flows were measured five times and mean flow was derived. Liner regression was performed to derive the relationship between flow and river depth at each measuring location (n=29 locations).

Percentage of river stretch optimal for adult gharial and dolphin

To relate the percentage of river stretch optimal for gharial, liner regression was performed to derive the relationship between mean river flow and percentages of optimal river stretch during the sampling period. Percentage of optimal river stretch was derived from the extent of river stretch >4 m depth for gharial and >10 m for Gangetic dolphin during the three consecutive sampling periods.

10. Results

Trends in river flow

During 1996 - 2004 the mean monthly flow of Chambal River varied between 58.53 m^3/sec in the month of April to 2074.28 m^3/sec in August. As little as 16.38 ±1.99 m^3/sec flow was recorded during the months of June-July 2009 (WII, 2010). Often the flow in lean season goes down to 6.13 m^3/sec per annum at Udi (Central Water Commission). In the last decade the river flow showed a decreasing trend of 6.3% in Pali, 2.3% at Dholpur and 1.5% at Udi (Fig. 3; mean 3.4%). Figure 4 shows the river depth profile of Chambal River between Rajghat and Panchhnada as derived during February, April and June 2010. We observed statistically robust relationship between the river flow and river depth (R^2 = 0.99, p <0.001) *i.e.* as the flow increases the depth also increases correspondingly (Fig. 5).

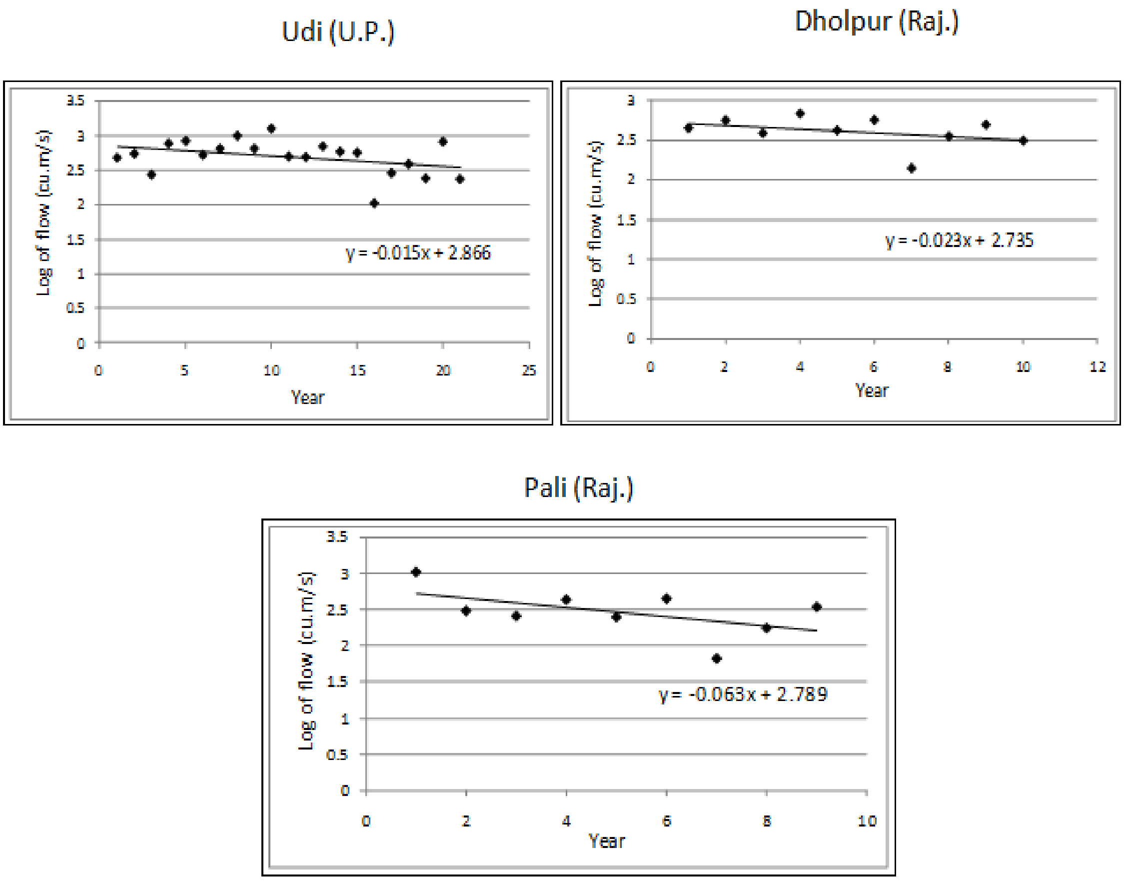

Figure 3. The state of flow of Chambal River recorded at three stations.

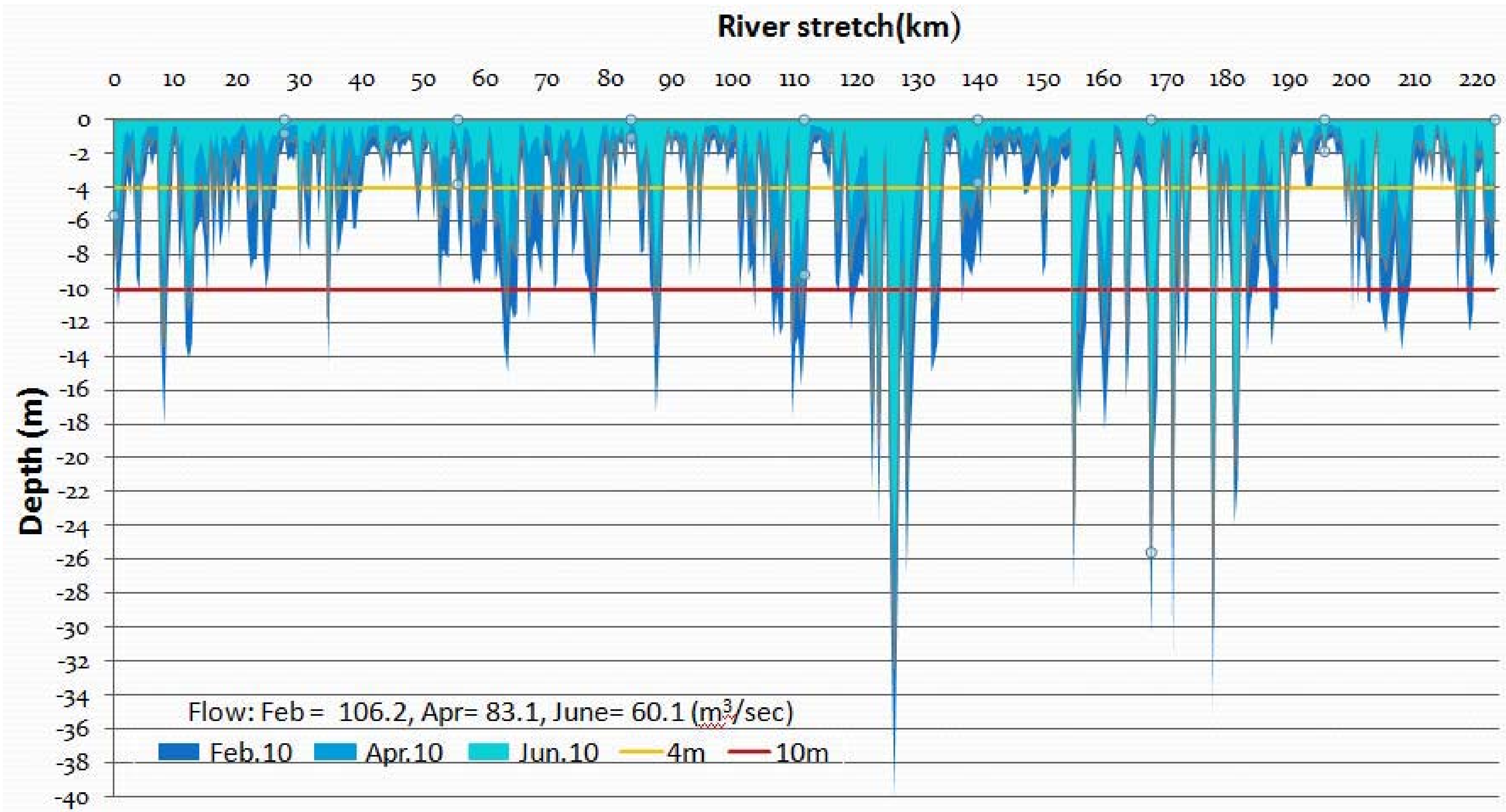

Figure 4. The River depth profile of Chambal River between Rajghat and Panchhnada as derived during February, April and June 2010 showing extent of area suitable for gharial and dolphins.

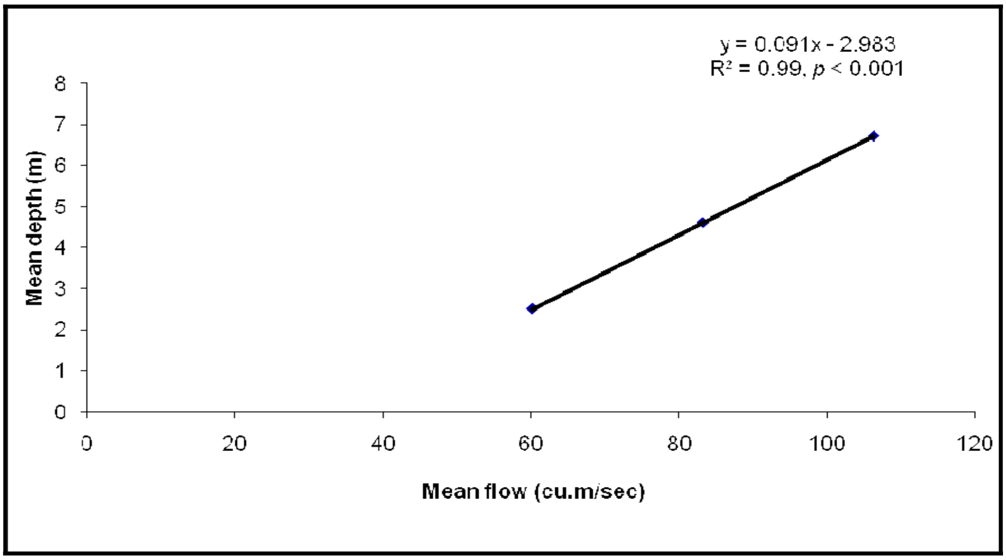

Figure 5. Relationship between river flow and river depth.

Relationship between flow and habitat suitability for gharial

In the present flow regime, the percentage of river stretch optimal for adult gharial was 53.9%, 45.0% and 19.2% respectively during the month of February, April and June 2010 (Table 4). Subsequently, linear regression was performed to derive the relationship between mean flow and percentage of river stretches optimal for gharial. The relationship between flow and suitability of the habitat showed positive trend (Fig. 6; $R^2 = 0.926$, $p > 0.05$). The insignificant p value could be due to smaller sample size. Using the linear regression equation $y = 0.7534x - 23.258$ we derived the percentage stretch optimal for adult gharial (Table 5).

In the present flow regime the percentage of habitat optimal for gharial during the lean seasons varied between 20.6% in the month of April to 96% in the month of December. There was no constraint of flow during the monsoon months (Table 5).

Table 4. Mean flow and percentage stretch optimal for gharial and Gangetic dolphin in Chambal River.

Month	**Mean flow (m^3/sec)**	**Observed % stretch optimal for gharial**	**Observed % stretch optimal for dolphin**
February	106.2	53.9	22.82
April	83.1	45.0	8.50
June	60.1	19.2	2.91

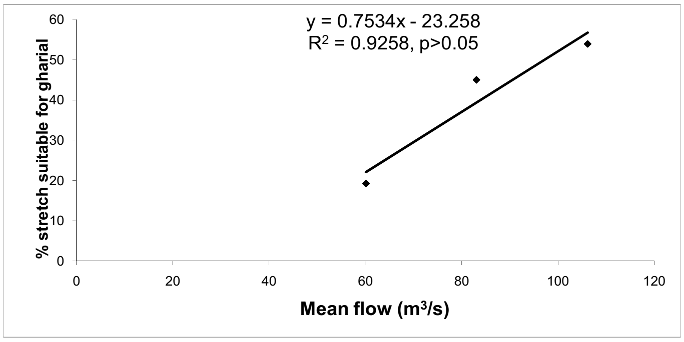

Figure 6. Relationship between mean flow and percentage stretch optimal for gharial in Chambal River.

The change in suitability of habitat for gharial after proposed extraction is significant ($p < 0.01$) which may vary between 0.2% in the month April to as much as 16.8% during the month of January (Table 6). As observed in past, the reduced flow may further minimize the distribution range of gharial in the Chambal River, restrict home range of adult gharial in terms of pool depth and length thereby destabilizing the existing 16-18 nesting sites/breeding populations (Appendix III) on which long term survival of gharial in the Sanctuary depends. Reduction in breeding pool length and depth is likely to increase male to male and female to female conflicts for space leading to higher degree of mortality among adults and competition for nesting beaches leading to reduced breeding success. Besides, reduced flow may affect the prey availability in the long run.

Relationship between flow and habitat suitability for dolphin

In the present flow regime, the percentage of river stretch optimal for Gangetic dolphin as observed was 22.8%, 8.5% and 2.9% respectively during the month of February, April and June 2010 (Table 4). The relationship between flow and percentage habitat optimal for dolphin showed a positive trend (Fig. 6; $R^2 = 0.940$, $p > 0.05$). The insignificant *p* value could be due to smaller sample size. Using the linear regression equation $y = 0.43x - 24.56$ we derived the percentage of river stretch optimal for dolphin. During the lean seasons the percentage of river stretch optimal for dolphin varied between 0.6% in the month of April to 43.8% in the month of December. There was no constraint of flow during the monsoon months (Table 5). The change in suitability of habitat for dolphin after proposed extraction is significant ($p < 0.01$) which may vary between 0.08% in the month of April to as much as 9.6% during the month of January (Table 6).

Table 5. Mean flow and predicted percentage stretch optimal for gharial and Gangetic dolphin in Chambal River.

Month	Mean flow (m^3/sec)	% stretch optimal	
		Gharial	Dolphin
July	1333.61	100.0	100
August	2074.28	100.0	100
September	1062.83	100.0	100
October	283.53	100.0	97.36
November	100.89	52.4	18.82
December	159.04	96.0	43.83
January	101.02	52.5	18.88
February	80.64	37.2	10.11
March	64.56	25.2	3.20
April	58.53	20.6	0.61
May	62.54	23.6	2.33
June	97.68	50.0	17.44

Reduced flow regime will further minimize the distribution range of dolphin in the Chambal River, reduce home range size due to decreased water depth and pool length. Reduced movement between pools may lead to lesser genetic interaction, reduced breeding success and increased mortality in passive fishery and decreased reproductive fitness. Reduced flow may also affect the prey availability in the long run.

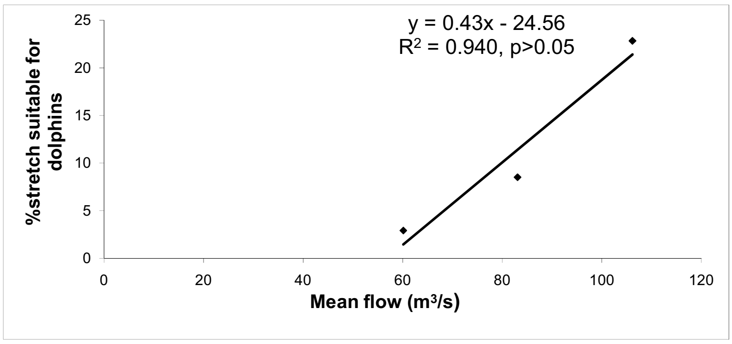

Figure 6. Relationship between mean flow and percentage stretch optimal for Gangetic dolphin in Chambal River.

At present, three water harvesting projects have been proposed (Table 1) which are at various stages of construction (page 9). Extraction of water through proposed Dholpur lift will reduce the optimal habitat of gharial to almost 20.5% and dolphin to almost 0% in the months of March and April (Table 7). At the present flow regime during the lean seasons the major portion of the dolphin habitat is fragmented. Table 8 provides the minimum flow requirement at different management regimes. To maintain the habitat suitability of gharial at >90%, around 151 – 164.3 m^3/sec of flow is required in the lean seasons (Table 8). To maintain the habitat suitability of dolphin at >90%, around 266.4 – 289.7 m^3/sec of flow is required in the lean seasons (Table 8). This could be achieved if flow from Kota barrage and other subsidiary dams in the Chambal basin is restored.

To maintain 'good' habitat conditions at 90-100% levels the flow requirement will be 151.0to 289.7 m^3/sec (Table 8). This entails and additional flow of 5.3 to 105.8 m^3/sec during lean seasons to maintain the optimal habitat of gharial at 90-100% level, where as for dolphin the additional flow requirement is 6.14 to 231.14 m^3/sec (Table 9). Extraction beyond this limit will make the habitat poorer affecting the conservation of both the key species.

Table 6. Change in habitat suitability of gharial and Gangetic dolphin after proposed extraction of water from the Chambal River.

	Gharial			**Dolphin**		
Month	**% stretch existing**	**% after extraction**	**% change**	**% stretch existing**	**% after extraction**	**% change**
July	100	100	0	100	100	0
August	100	100	0	100	100	0
September	100	100	0	100	100	0
October	100	100	0	97.36	88.62	8.74
November	52.41	37.46	14.95	18.82	10.28	8.55
December	96.02	80.94	15.08	43.83	35.21	8.62
January	52.51	35.70	16.81	18.88	9.27	9.61
February	37.22	21.80	15.42	10.11	1.30	8.81
March	25.16	12.03	13.13	3.20	0.00	3.20
April	20.64	20.46	0.18	0.61	0.53	0.08
May	23.65	23.37	0.28	2.33	2.20	0.14
June	50.00	49.52	0.48	17.44	17.19	0.25

Table 7. Water requirement of proposed water harvesting projects and predicted percentage suitability of river stretch for gharial and Gangetic dolphin in Chambal River.

Month	Mean flow (m^3/sec)	Dholpur Project (m^3/sec)	Remaining (m^3/sec)	% suitable	Aisha Project (m^3/sec)	Remaining (m^3/sec)	% suitable	Kanera Project (m^3/sec)	Remaining (m^3/sec)	% suitable	Total remaining flow (m^3/sec)	% suitable
GHARIAL												
Jan	101.02	5.37	95.65	48.44	11.33	89.69	43.97	5.66	95.36	48.22	78.66	35.70
Feb	80.64	3.51	77.13	34.55	11.33	69.31	28.68	5.66	74.98	32.93	60.14	21.80
Mar	64.56	0.46	64.09	24.77	11.33	53.23	16.62	5.66	58.90	20.87	47.10	12.03
Apr	58.53	0.19	58.34	20.46	0.0	58.53	20.60	0.0	58.53	20.60	58.34	20.46
May	62.54	0.32	62.22	23.37	0.0	62.54	23.61	0.0	62.54	23.61	62.22	23.37
Jun	97.68	0.59	97.09	49.52	0.0	97.68	49.96	0.0	97.68	49.96	97.09	49.52
Jul	1333.61	0.0	1333.61	100	0.0	1333.61	100	0.0	1333.61	100	1333.61	100
Aug	2074.28	0.17	2074.11	100	0.0	2074.28	100	0.0	2074.28	100	2074.11	100
Sep	1062.83	0.54	1062.29	100	11.33	1051.50	100	5.66	1057.17	100	1045.30	100
Oct	283.53	3.34	280.20	100	11.33	272.20	100	5.66	277.87	100	263.21	100
Nov	100.89	2.89	98.00	50.20	11.33	89.56	43.87	5.66	95.23	48.12	81.01	37.46
Dec	159.04	3.06	155.98	93.69	11.33	147.71	87.49	5.66	153.38	91.74	138.99	80.94
DOLPHIN												
Jan	101.02	5.37	95.65	16.57	11.33	89.69	14.01	5.66	95.36	16.45	78.66	9.27
Feb	80.64	3.51	77.13	8.61	11.33	69.31	5.24	5.66	74.98	7.68	60.14	1.30
Mar	64.56	0.46	64.09	3.00	11.33	53.23	0.00	5.66	58.90	0.77	47.10	0.0
Apr	58.53	0.19	58.34	0.53	0.0	58.53	0.61	0.0	58.53	0.61	58.34	0.53
May	62.54	0.32	62.22	2.20	0.0	62.54	2.33	0.0	62.54	2.33	62.22	2.20
Jun	97.68	0.59	97.09	17.19	0.0	97.68	17.44	0.0	97.68	17.44	97.09	17.19
Jul	1333.61	0.0	1333.61	100	0.0	1333.61	100	0.0	1333.61	100	1333.61	100
Aug	2074.28	0.17	2074.11	100	0.0	2074.28	100	0.0	2074.28	100	2074.11	100
Sep	1062.83	0.54	1062.29	100	11.33	1051.50	100	5.66	1057.17	100	1045.30	100
Oct	283.53	3.34	280.20	95.92	11.33	272.20	92.49	5.66	277.87	94.93	263.21	88.62
Nov	100.89	2.89	98.00	17.58	11.33	89.56	13.95	5.66	95.23	16.39	81.01	10.28
Dec	159.04	3.06	155.98	42.51	11.33	147.71	38.96	5.66	153.38	41.39	138.99	35.21

Table 8. Management class for maintaining optimal habitat for gharial and dolphin in the Chambal River.

Management class	% stretch optimal	Flow requirement (m^3/sec) for gharial	Flow requirement (m^3/sec) for dolphin
A: habitat suitability 90-100%	100	164.34	289.67
	90	151.01	266.42
B: habitat suitability 70-80%	80	137.68	243.16
	70	124.34	219.91
C: habitat suitability 50-60%	60	111.01	196.65
	50	97.68	173.40

Table 9. Surplus/deficit flow of the Chambal river at the existing scenarios.

Month	Present Mean flow (m^3/sec)	Surplus/Deficit for Gharial (m^3/sec)			Surplus/Deficit for Dolphin (m^3/sec)		
		100%	90%	80%	100%	90%	80%
July	1333.61	1169.27	1182.57	1195.93	1043.94	1067.19	1090.45
August	2074.28	1909.94	1923.27	1936.6	1784.61	1807.86	1831.12
September	1062.83	898.49	911.82	925.15	773.16	796.41	819.67
October	283.53	119.16	132.52	145.85	-6.14	17.11	40.37
November	100.89	-63.45	-50.12	-36.79	-188.78	-165.53	-142.27
December	159.04	-5.3	8.03	21.36	-130.63	-107.38	-84.12
January	101.02	-63.32	-49.99	-36.66	-188.65	-165.4	-142.14
February	80.64	-83.7	-70.37	80.64	-209.03	-185.78	-162.52
March	64.56	-99.78	-86.45	-57.04	-225.11	-201.86	-178.6
April	58.53	-105.81	-92.48	-79.15	-231.14	-207.89	-184.63
May	62.54	-101.8	-88.47	-75.14	-227.13	-203.88	-180.62
June	97.68	-66.66	-53.33	-40.0	-191.99	-168.74	-145.48

- *Baseline flow is 164. 34 m^3/sec for gharial and 289.67 m^3/sec for dolphin*

11. Discussion

Maintaining environmental flows is a key step in achieving ‘Good Status’ of a river or stream. ‘Good Status’ is a combination of Good Chemical Status (GCS) and Good Ecological Status (GES). GES is defined qualitatively and includes populations and communities of large vertebrates, fish, macro-invertebrates, macrophytes, phytobenthos and phytoplankton. It also includes supporting elements that will affect the biological elements, such as channel form, water depth and river flow (Dyson et al., 2003). Our previous studies (Hussain and Singh 1999, Hussain 2009) suggest that because of natural setting, the Chambal River below Pali (Rajasthan) has Good Chemical Status; however its ecological status is extremely poor. As the discharge below the Kota Barrage is zero during the lean season, the river stretch below Kota barrage and

Chambal - Pali confluence is ecologically dead. This has limited the occurrence of River dolphin above Rahu Ka Gaon and gharial above Pali.

According to different ecological management options, there are four target classes or 'Environmental Management Class' that need to be identified based on existing empirical relationships between flow changes and ecological status/conditions, which are associated with clearly identifiable thresholds (Hughes and Münster, 2000; Hughes and Hannart, 2003). These are:

A - Negligible modification from natural conditions. Negligible risk to sensitive species.

B - Slight modification from natural conditions. Slight risk to intolerant biota.

C - Moderate modification from natural conditions. Especially intolerant biota may be reduced in number and extent.

D - High degree of modification from natural conditions. Intolerant biota unlikely to be present.

Application of such objective-based approach necessitates that first the desired status of the river has been set. It is then possible to define threshold flow above or below which a change in status of the river in terms of its structure and functions will be evident. In Australia for example the probability of having a healthy river falls from high to moderate, when the hydrological regime is less than two-thirds of the natural flow regime (Scanlon 2002). Whilst this seems a reasonable figure, there is little scientific evidence to support it. Indeed from a theoretical point of view it may not be possible to define the flow regime that will maintain a desired river condition. From a practical standpoint, the assessment of an environmental flow remains a practical river management tool. However, it should be noted that, as long as knowledge of the aquatic environment remains limited, setting threshold for environmental flows will inevitably retain an element of subjective judgment. In the present study we have taken water depth preference of gharial, but we lack data on how this depth optimizes the prey availability of gharial thereby affecting its long term survival.

In many streams in the USA, a threshold of 10% of the Mean Annual Runoff (MAR) is reserved for aquatic ecosystem/streams, which is considered to be the lowest limit for Environmental Flow (corresponding to severe degradation of a system). Fair/good habitat conditions could be ensured if 35% of the MAR is allocated for environmental purposes (Smakhtin and Anputhas, 2006). Allocations in the range of 60 - 100% of the MAR represent an environmental optimum (Tharme 2003). Taking this as an example, our analysis suggest that the minimum ecological flow requirement for gharial as key species of Chambal River is 151 - 164.34 m^3/sec and for Gangetic dolphin it is 266.42 - 289.67 m^3/sec during lean seasons. Water abstraction below this level will impact the sustained reproduction and thereby conservation of gharial and Gangetic dolphin in the long run. To maintain the habitat suitability of gharial and dolphin at ecologically acceptable >90% level, around 151 - 266 m^3/sec of flow will be required. This could be achieved if water from the Kota Barrage and other subsidiary dams in the Chambal basin is released.

The average quantity of water used for irrigation by Rajasthan and Madhya Pradesh through the creation of Gandhi Sagar dam and water abstraction via Kota Barrage has decreased by 22.6% and 41.4% respectively in last 17-18 years, whereas the use of water for non-irrigation (industrial and drinking water purpose) has increased three folds (Gupta and Attari, 2007) resulting in shortage of water in the downstream. By the year 2002-03 the net water use for non-irrigation purpose was almost 41% (Gupta and Attari 2007).

In view of the foregoing discussion, it is not feasible to have new irrigation projects in Chambal River, as any further abstraction of water would adversely impact the conservation of the two major vertebrate species - the “Critically Endangered” gharial and the Gangetic dolphin which has also been designated as “National aquatic animal”.

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APPENDIX: I

Conclusion on preference and/or avoidance of various water depths by gharial along the 425 km stretch of the Chambal River within the National Chambal Sanctuary, India. P = used more than available, A = used less than available, U = used in proportion to available.

Water depth category and gharial size classes	Number of sampling points	Proportion of total sampling points (p_{io})	Number of gharial observed	Expected[a] number of gharial	Proportion[b] observed at sampling point (p_i)	χ^2 distribution[c]	Bonferonni confidence interval for observed proportions			Conclusions
gharial size class III (>180 cm and <270 cm)										
>1.0 and <2.0 m	46	0.11	0.0	15	-	-	0.00	$\leq p1 \leq$	0.00	A
>2.0 and <3.0 m	109	0.27	37	36	0.28	0.05	0.18	$\leq p2 \leq$	0.38	U
>3.0 and <4.0 m	110	0.27	33	36	0.25	0.24	0.15	$\leq p3 \leq$	0.34	U
>4.0 and <5.0 m	52	0.13	23	17	0.17	2.12	0.09	$\leq p4 \leq$	0.26	U
>5.0 m	90	0.22	40	29	0.30	3.81	0.20	$\leq p5 \leq$	0.40	P
Total	407		133	133						
gharial size class IV (>270 cm)										
>1.0 and <2.0 m	46	0.11	0.0	10	-	-	0.00	$\leq p1 \leq$	0.00	A
>2.0 and <3.0 m	109	0.27	1	23	0.01	21.08	0.00	$\leq p2 \leq$	0.04	A
>3.0 and <4.0 m	110	0.27	13	23	0.15	4.51	0.05	$\leq p3 \leq$	0.25	A
>4.0 and <5.0 m	52	0.13	31	11	0.36	36.45	0.23	$\leq p4 \leq$	0.49	P
>5.0 m	90	0.22	41	19	0.48	25.41	0.34	$\leq p5 \leq$	0.62	P
Total	407		86	86						

a: Calculated by multiplying p_{io} x total number of gharial observed (Neu *et al*. 1974).

b: p_i represents theoretical proportion of observation of gharial and is compared to corresponding p_{io} to determine if hypothesis of proportional use is accepted or rejected *i.e.* $p_i = p_{io}$ (Neu *et al*. 1974) at $p<0.05$ based on Byers simultaneous confidence interval.

c: χ^2 contribution was derived from the formula $\chi^2 = \Sigma(Oi - Ei)^2/Ei$ (Byers *et al.* 1984).

Source: Hussain 2009

APPENDIX II

Conclusion on preference and/or avoidance of various water depths by gharial along the 425 km stretch of the Chambal River within the National Chambal Sanctuary, India. P = used more than available, A = used less than available, U = used in proportion to available.

Depth Class	Number of points	Proportion of points	Dolphins Observed	Expected dolphins (E)	Proportion observed	Lower	Upper	Expected proportion	Conclusion
>1-4	203	0.46	0	32	0	0	0	0.457	A
>4-7	49	0.11	4	8	0.058	-0.012	0.128	0.110	U
>7-10	90	0.20	11	14	0.159	0.049	0.270	0.203	U
>10	102	0.23	54	16	0.783	0.658	0.907	0.230	P

Source: Hussain, S.A., Sharma, R.K. et al. (in prep)

APPENDIX III

Status of gharial nesting sites as on 2010 and 2011.

#	Name of the nearest village	Number of nests recorded as on 2010	Present nesting status as on 2011
1	Bagadia Saand	0	Abandoned
2	Gobarda	0	Abandoned
3	Arodari	0	Abandoned
4	Deogir	8	Active
5	Baroli	24	Active
6	Nadigaon	9	Active
7	Barotha	0	Abandoned
8	Banwara	2	Active
9	Kharagpura	0	Abandoned
10	Bharra	0	Abandoned
11	Sevar Pali	0	Abandoned
12	Ajwa Pura	0	Abandoned
13	Daang Basai	6	Active
14	Tighri Rithoura	7	Active
15	Bhabeswari	2	Active
16	Babu Singh Ka Gher	0	Abandoned
17	Pureini	6	Active
18	Daljit Pura	5	Active
19	Barenda	7	Active
20	Basudev Pura	0	Abandoned
21	Khuro (Useith Ghat)	2	Active
22	Shas Ka Pura (Dhora)	0	Abandoned
23	Kanera	6	Active
24	Kherat	0	Abandoned
25	Mahera	0	Abandoned
26	Dinpura	0	Abandoned
27	Lakhnouli	3	Active
28	Chilonga	5	Active
29	Khera	4	Active
30	Gyanpura	2	Active
31	Shankri	2	Active
32	Jagtouli (Barecha)	1	Active

APPENDIX IV
Additional Reading

AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS
Aquatic Conserv: Mar. Freshw. Ecosyst. (2009)
Published online in Wiley InterScience
(www.interscience.wiley.com). DOI: 10.1002/aqc.960

Basking site and water depth selection by gharial Gavialis gangeticus *Gmelin 1789 (Crocodylia, Reptilia) in National Chambal Sanctuary, India and its implication for river conservation*

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ABSTRACT

1. The species diversity of inland waters is among the most threatened of all ecosystems and in many parts of the world it is in continuing and accelerating decline. Such decline could be restrained by acknowledging the scope of target species, so that all relevant stages in their life cycle are considered.
2. The gharial *Gavialis gangeticus* is a prominent riverine species of the Indus, Ganges, Brahmaputra and Mahanadi river systems that is becoming increasingly rare due to reduction in water flow and available nesting beaches, modification of river morphology and increased mortality in fishing nets. Despite these threats, scientific information on habitat selection by gharial is still inadequate, which hinders conservation measures.
3. This paper presents the population status, basking site selection and water depth preferences of different size-classes of gharial based on a study conducted in the National Chambal Sanctuary, India.
4. Between 1992 and 2007 a 40% decline in the gharial population was observed in the National Chambal Sanctuary. The decline was prominent in the recruitment class (< 120 cm), which primarily comes from the nests laid in the wild, and also in sub-adults (> 180 to 270 cm) comprising both wild and reintroduced gharial.
5. Along the Chambal River, gharial preferred sandy parts of the river banks and sand bars for basking and showed less preference for rocky river banks and rocky outcrops. Clay river banks were least preferred.
6. Juvenile gharials < 120 cm and 120–180 cm preferred water depths 1–3 m and 2–3 m, respectively. Gharial > 180 cm (including sub-adults and adults) preferred water depths > 4 m.
7. Increasing demands for sand for development activities, and water abstraction for irrigation and energy generation coupled with mortality in fishing nets, are likely to affect gharial and other aquatic species, and steps need to be taken to maintain the minimum river flow necessary to sustain ecosystem processes.

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KEY WORDS: river conservation; crocodiles; gharial; *Gavialis gangeticus*; habitat selection

INTRODUCTION

Of all ecosystems rivers are the ones most degraded by humans (Naiman and Turner, 2000; Sala *et al*., 2000; Gleick, 2003) largely due to changes in hydrology, pollution (Naiman *et al*., 2002) and other development activities (Jackson *et al*., 2001; Arthington and Pusey, 2003; Nilsson *et al*., 2005; Dudgeon *et al*., 2006) which profoundly change the processes that drive ecosystem structure and functioning (Poff *et al*., 1997; Jansson *et al*., 2000). The species diversity of inland waters is among the most threatened of all ecosystems and in many parts of the world it is in continuing and accelerating decline (MEA, 2006). Such decline could be restrained by acknowledging the scope of target species, so that all relevant stages in their life cycle are considered (Lake *et al*., 2007; Muotka and Syrjanen, 2007).

Of the 23 species of crocodilians, which inhabit a range of aquatic ecosystems, four species are critically endangered, three are endangered, and three are vulnerable (IUCN, 2006). The other species are at lower risk of extinction, but depleted or extirpated locally in some areas (Revenga and Kura, 2003). The gharial *Gavialis gangeticus* Gmelin 1789 is endemic to the Indian subcontinent occurring in the Indus, Ganges, Brahmaputra and the Mahanadi river systems (Smith, 1939; Singh, 1978; Groombridge, 1987; Whitaker, 1987; Hussain,

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1991, 1999). By the mid-1970s it was on the verge of extinction due to loss of habitat, mortality in fishing nets (Whitaker, 1987; Hussain, 1999) and poaching (Daniel, 1970; Honegger, 1971; Choudhury and Bustard, 1979; Whitaker and Basu, 1983). It is believed that the gharial is now extinct in Myanmar, Bhutan and Pakistan. In Bangladesh, fewer than 20 individuals may be present (Groombridge, 1987). Increasing demand for fresh water, particularly from rivers, may affect its existence in other countries too. To conserve this species a captive breeding programme was initiated in India (Bustard, 1980, 1984) during 1975, and several other conservation measures were undertaken. As a part of this programme, captive-reared crocodiles were reintroduced into newly created protected wetland areas to augment the wild populations. By 1995, the population of gharial was made secure in the wild with around 1200 gharials in the Chambal River within the National Chambal Sanctuary (Hussain, 1999; Rao, 1999; Sharma, 1999), 25 gharials in the Girwa River within the Katerniaghat Wildlife Sanctuary, and 30 in the rivers of Nepal (Maskey, 1999). Apart from these, a non-breeding population of 15 gharials was reported from Ken Gharial Sanctuary, 32 in Sone Gharial Sanctuary (Sharma *et al*., 1999) and 42 in Ramganga River within the Corbett Tiger Reserve (Nawab and Hussain, 2006).

However, since 1999 the gharial population has shown a dramatic decline throughout its entire range. There were 436 breeding adults in 1997 but by 2006 this number had declined to just 182, a reduction of 58% over the last 10 years (IUCN, 2007). The total breeding population of gharial is now estimated to be less than 200 individuals making gharial a critically endangered species (IUCN, 2007). Such a drastic decline within the last decade is largely the result of anthropogenic pressures such as reduction in the availability of nesting beaches, encroachment on river banks for agriculture, construction of dams and barrages, reduction in water flow, siltation, channelization, modification of river morphology by development activities and increased mortality in fishing nets (Hussain, 1999; IUCN, 2007).

Although there is increasing concern from conservationists about the trend in gharial populations, information on habitat selection by gharial is still inadequate which hinders conservation measures. This paper describes the population status, basking site selection and water depth preferences of different size-classes of gharial based on a study conducted along the 425 km stretch of the Chambal River within the National Chambal Sanctuary, India.

STUDY AREA

The Chambal is a clear and fast-flowing river that rises in the Vindhya hill range in Central India. Lying between 24°55′ and 26°50′N, 75°34′ and 79°18′E, it flows north east and joins the Yamuna River to form a part of the greater Gangetic drainage system. The Chambal on average is 400 m wide and 26 m deep (Hussain, 1993). During the monsoon seasons the water level rises 10–15 m and often spreads 500 m from either bank. The maximum discharge of the river is 54 500 $m^3 s^{-1}$ and the minimum 27 000 $m^3 s^{-1}$ (Hussain, 1993). A 600 km stretch of the Chambal River, between Jawahar Sagar Dam and Panchhnada, has been protected as the National Chambal Sanctuary. The main study area lies between Pali (km 0) and Panchhnada (km 425) within the Sanctuary (Figure 1). The area lies within the semi-arid zone of north-western India at the border of Madhya Pradesh, Rajasthan and Uttar Pradesh States. Ambient temperature ranges from 2–46°C. Annual precipitation (mean = 591.2 mm) largely depends on the south-western monsoon which lasts from the third week of June until early October. Much of the Sanctuary area is ravine thorn forest (Champion and Seth, 1968), evergreen riparian vegetation is completely absent, and the severely eroded river banks and adjacent ravine lands have sparse ground-cover (Hussain, 1993, 1999).

Unlike other rivers of the greater Ganges drainage system the Chambal River is relatively unpolluted (Hussain and

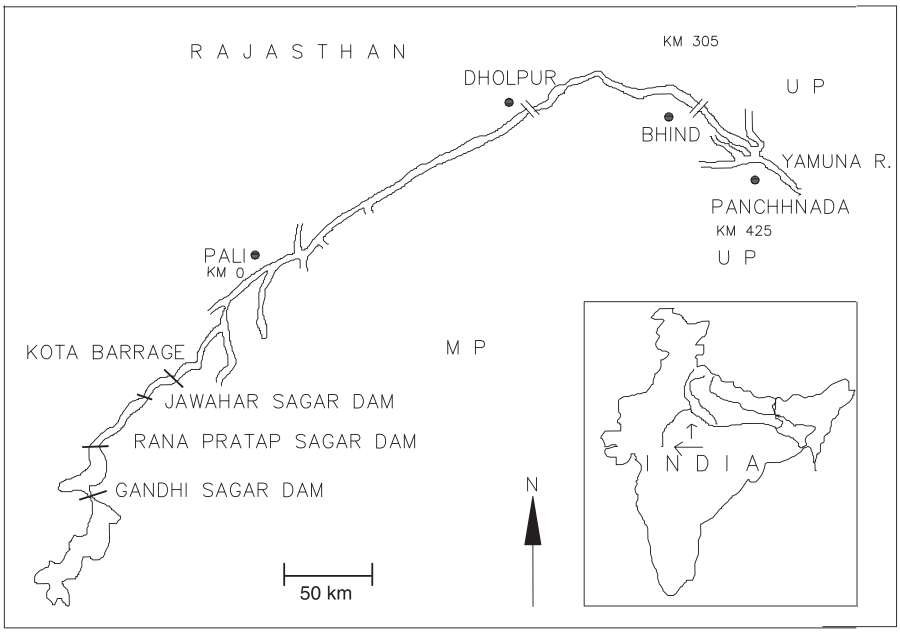

Figure 1. Map of the Chambal River with some of the important tributaries and landmarks. Pali is at river km 0 and Panchhnada is at river km 425.

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Singh, 1999). The water contains very low levels of suspended solids, low Biochemical Oxygen Demand (BOD) and high levels of dissolved oxygen (DO). There is no indication of organic matter discharge or eutrophication in the river as the values of chemical oxygen demand (COD), ammonia (NH_4), and phosphate (PO_4) lie below detection limits. On the basis of standards set by the Central Pollution Control Board (CPCB), the Chambal River is classified in category 'A'.

METHODS

Population status

Basking gharials were counted from a motor boat driven by a 40 HP Yamaha engine. All counts were made between 1000 and 1600 h in February (winter), a period coinciding with intensive basking frequency and aggregation of large gharials for breeding. Usually, two observers were stationed at the front seat of the motor boat, each searching for gharials on either bank with 8×40 mm prismatic binoculars. The motor boat moved at 8–10 km h^{-1}, down mid-river. Whenever basking gharials were seen, their approximate size, basking site topography, substrate characteristics and the mid-river water depth were recorded. The gharials were sized in 30 cm increments. Individuals <60 cm long were considered to be hatchlings, those 60–120 cm as yearlings, >120–180 cm as juveniles, >180–270 cm as sub-adults and those >270 cm as adults.

Habitat use

To check the seasonal variations in basking site and water depth preference, a 25 km reach covering all habitat types and nesting adults was monitored. Because of varying depth and the nature of basking sites, their availability and utilization is difficult to quantify. Hence, in the present study a non-mapping technique (Marcum and Loftsgaarden, 1980) was adopted to quantify the availability of river depth, basking and nesting sites along the reach. In this case each sampling point has been considered as one habitat unit. The basking sites were grouped into three categories — sandy banks or sand bars, clay banks, and rocky banks and rocky outcrops. The nature of the basking sites at 1 km intervals was recorded. As there were 426 sampling points on each of the two banks and 59 mid-river rocky islands and outcrops, a total of 911 points were sampled. Similarly, the mid-river depth was measured at 407 points, 1 km apart along the 425 km stretch of the Chambal River. The water depths were divided into five categories at 1 m intervals between 1 and 5 m and above 5 m.

The habitat use analysis is based on 759 gharials seen basking on different habitat types. The data were analysed in the resource availability and utilization framework proposed by Neu *et al.* (1974) in conjunction with a chi-square goodness-of-fit test. This test was used to determine whether or not there was a significant difference between the expected utilization of different depth categories, type of basking sites and the observed frequency of their usage. If a statistically significant difference was found between utilization and availability, the data were further investigated by Bonferroni confidence intervals following Byers *et al.* (1984) to determine which category of habitat was preferred, avoided or used in proportion to availability.

RESULTS

During a countrywide survey of crocodiles in 1974 the Chambal River was identified as an important gharial habitat. In the 600 km stretch of the Chambal River between Jawahar Sagar Dam in Rajasthan and Panchhnada in Uttar Pradesh (Figure 1) the initial gharial population was reported as 107 individuals of different age and sex, of which 29 were adults (Singh, 1985). In 1978 this stretch of the Chambal River was declared the National Chambal Sanctuary under the Wildlife (Protection) Act 1972. In 1979 a captive-reared restocking programme was initiated and by 2007 about 2010 captive-bred gharials had been restocked into the Sanctuary. By 1992 the gharial population in the Chambal River was 1065 of which 62 were breeding females (Hussain, 1999). Sharma (1999) reported as many as 1242 gharial in the 400 km stretch of the Chambal River between Pali and Bhare.

Table 1 summarizes the size class of gharials seen during the study conducted in 1992 (Hussain, 1999) and in 2007. Of the 865 gharials seen in 2007, 225 were recently released individuals (personal communication, R.K. Sharma, Madhya Pradesh Forests Department). Thus, between 1992 and 2007 a 40% decline in the population was observed. The decline was prominent in the recruitment class (<120 cm), primarily from the nests laid in the wild, and also in sub-adults (>180–270 cm), comprising mostly released gharials. However, a 57% increase was recorded in the adult population.

During the study 62% of gharials were seen basking on sand, 37% on rocky substrata and only 0.8% on clay. Table 2 summarizes the proportional availability of different basking-site types and the number and percentage of basking gharial observed at each type of site, together with the simultaneous confidence intervals using the Bonferroni approach. The result of the test indicates that sandy parts of the river banks and sand bars were the preferred basking sites for gharial. Comparatively less preference was shown for rocky banks and rocky outcrops (Table 2). Clay areas were largely avoided.

Table 3 contains the summarized data on the number of sampling points in different depth categories, number of gharial observed in each depth category, and the simultaneous confidence interval using the Bonferroni approach. The Bonferroni confidence intervals show that juvenile gharial <120 cm preferred water depths 1–3 m and avoided water depths >3.0. Gharial >120–180 cm avoided water depths 1–2 m and preferred water depths 2–3 m. They mostly used water depths >4.0 m when available. This class consisted primarily of captive-bred restocked gharials which do not appear to be fully adapted to wild conditions and displayed inconsistencies in selecting favourable water depths. The sub-

Table 1. Size classes of gharial seen in the National Chambal Sanctuary, India during 1992 and 2007

Size class of gharial	1992	2007	Percentage change
<120 cm	312	212	(–) 32
120–180 cm	348	341*	(–) 02
>180–270 cm	273	104	(–) 62
>270 cm	132	208	(+) 57
Total	1065	865 (640)	(–) 40

*225 captive bred gharials were released during 2006. Source: R.K. Sharma, Madhya Pradesh Forest Department.

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Table 2. Preference and/or avoidance of basking site types by gharial along the 425 km stretch of the Chambal River within the National Chambal Sanctuary, India

Basking site type	Number of sampling points	Proportion of total sampling points (p_{io})	Number of gharial observed	Expected[a] number of gharial	Proportion[b] observed at each sampling point (p_i)	χ^2 distribution[c]	Bonferroni confidence interval for observed proportions Min.		Max.	Conclusions
Clay	387	0.42	6	319	0.01	310.54	0.00	<p1<	0.02	A
Sandy	342	0.38	470	288	0.62	120.20	0.58	<p2<	0.66	P
Rocky	182	0.20	283	152	0.37	113.81	0.33	<p3<	0.41	P
Total	911		759	759						

[a]Calculated by multiplying $p_{io} \times$ total number of gharial observed (Neu *et al*., 1974).
[b]p_i represents theoretical proportion of observation of gharial and is compared to corresponding p_{io} to determine if hypothesis of proportional use is accepted or rejected i.e. $p_i = p_{io}$ (Neu *et al*., 1974) at $p < 0.05$ based on Byers simultaneous confidence interval.
[c]χ^2 contribution was derived from the formula $\chi^2 = \Sigma(Oi–Ei)^2/Ei$ (Byers *et al*., 1984).
P = used more than available, A = used less than available.

adult and adult gharial of size class >180 cm showed preference for water depths >4.0 m. Sub-adult gharial avoided water depths <2 m while adults avoided depths <4 m.

DISCUSSION

The Chambal River holds 85% of the entire gharial population. Hussain (1999) reported the overall exponential rate of increase in this population as 19.6% per annum between 1979 and 1992 and 16.1% in nesting females between 1979 and 1989. The present decline in the population, particularly between 1992 and 2007, is a matter of serious concern. This decline is attributed to mortality in fishing nets and degradation of basking and nesting sites which were encroached upon for agriculture and sand mining. Therefore, it is important to understand the basking site and water depth preference by gharial so as to develop an effective conservation strategy.

It is unlikely that the selection of basking sites and river depth by gharial is merely based on availability. There may be many other ecological factors operating simultaneously at the favoured sites, which influence selection. The mechanisms adopted by ectothermic animals for maintaining the desired level of body temperature differ from those of warm-blooded animals. Gharials, like other crocodilians, usually avoid high ambient temperature ('thermoconformers') (Lang, 1987a,b). Temperature selection (either heat seeking or heat avoidance) within the available habitats is an important daily activity of all species of crocodiles. Thus, basking in the sun during winter and remaining in water most of the time during summer, as has been observed during the study, regulates body temperature without much expenditure of energy and facilitates optimum metabolism. Observations during this study show that individual gharials have strong attachment to particular basking sites to which they return time and again when the disturbance is over. It can therefore be concluded that the selection of basking sites is influenced by physical characteristics of the sites. Sandy parts of the bank are preferred because it seems that gharials find it easier to crawl on sandy surfaces than on rocky or clay surfaces. Another advantage of basking on sandy surfaces is that it contains far more moisture than other surfaces and hence they provide a hot (sun) and cool (moisture in sand) environment, thus reducing the chance of desiccation while basking in the sun. Sites free of disturbance appear to be preferred for obvious reasons. In situations where undisturbed sandy sites are not available, gharials seem to prefer rocky outcrops as second alternative sites for basking. Presence or absence of escape cover (deep water) near the basking site appears to influence selection of particular sites for basking. Often basking gharials feel disturbed or threatened by human presence and whenever this happens they retreat into the water for safety. For this they need deep water close to the basking site. Gharials therefore seem to prefer those sites that are close to easily accessible escape cover. Another factor which seems to influence the selection of basking sites is the capacity of the site and surroundings to camouflage gharials. At times gharials easily merge with the sandy backdrops and appear like pieces of drift-wood. Even when a gharial basks on flat rocks its colour matches with the dark background (Rao and Singh, 1994).

Since the range of depth variations at different sampling points was 1 to 27 m (Hussain and Choudhury, 1990) it is difficult to attribute the ecological basis of selection of certain depths by gharials. However, some biotic and abiotic factors affecting the behaviour of gharials are discernible. Apparently food availability (both quantitative as well as qualitative) and hiding cover value does differ with depth of water. Young gharials feeding only on small fish prefer shallow water for foraging as well as for cover. Similarly, large size gharials feeding on larger fish need deep water both for foraging and cover. Hence, gharials below 120 cm prefer 1–3 m water depths, those above 120 cm and below 180 cm prefer 2–3 m depth, and the sub-adult and adult gharials prefer water deeper than 4 m. The range of depth selection by gharials smaller than 180 cm is quite wide probably because this group consists mostly of captive-bred released gharials that have a tendency to move over long distances (Singh, 1985). Such gharials are more opportunist; they settle wherever they find less competition. Adult gharials, however, prefer deeper water only as it provides sufficient cover for them. The differential water depth preferences of individuals of different size may also reflect the relative abundance of the different prey these individuals eat, as in the case of *Melanosuchus niger* and *Caiman crocodiles* (Herron, 1994). In a study in Nepal, Maskey *et al*. (1995) concluded that habitat selection in gharial may be mediated by tactile qualities of substrate, thermoregulatory considerations and/or by prey availability.

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Table 3. Preference and/or avoidance of various water depths by gharial along the 425 km stretch of the Chambal River within the National Chambal Sanctuary, India

Water depth category and gharial size classes	Number of sampling points	Proportion of total sampling points (p_{io})	Number of gharial observed	Expected[a] number of gharial	Proportion[b] observed at sampling point (p_i)	χ2 distribution[c]	Bonferroni confidence interval for observed proportions			Conclusions
Gharial size class I (<120 cm)										
>1.0 and <2.0 m	46	0.11	45	21	0.23	25.02	0.16	< p1<	0.31	P
>2.0 and <3.0 m	109	0.27	86	52	0.45	23.26	0.36	< p2<	0.54	P
>3.0 and <4.0 m	110	0.27	32	52	0.17	7.63	0.10	< p3<	0.24	A
>4.0 and <5.0 m	52	0.13	15	25	0.08	3.73	0.03	< p4<	0.13	A
>5.0 m	90	0.22	14	42	0.07	19.04	0.02	< p5<	0.12	A
Total	407		192	192						
Gharial size class II (120–180 cm)										
>1.0 and <2.0 m	46	0.11	20	38	0.06	9.50	0.03	< p1<	0.09	A
>2.0 and <3.0 m	109	0.27	157	94	0.45	43.68	0.38	< p2<	0.52	P
>3.0 and <4.0 m	110	0.27	65	94	0.19	8.98	0.13	< p3<	0.24	A
>4.0 and <5.0 m	52	0.13	40	45	0.11	0.45	0.07	< p4<	0.16	U
>5.0 m	90	0.22	66	77	0.19	1.56	0.14	< p5<	0.24	U
Total	407		348	348						
Gharial size class III (>180–270 cm)										
>1.0 and <2.0 m	46	0.11	0.0	15	—	—	0.00	< p1<	0.00	A
>2.0 and <3.0 m	109	0.27	37	36	0.28	0.05	0.18	< p2<	0.38	U
>3.0 and <4.0 m	110	0.27	33	36	0.25	0.24	0.15	< p3<	0.34	U
>4.0 and <5.0 m	52	0.13	23	17	0.17	2.12	0.09	< p4<	0.26	U
>5.0 m	90	0.22	40	29	0.30	3.81	0.20	< p5<	0.40	P
Total	407		133	133						
Gharial size class IV (>270 cm)										
>1.0 and <2.0 m	46	0.11	0.0	10	—	—	0.00	< p1<	0.00	A
>2.0 and <3.0 m	109	0.27	1	23	0.01	21.08	0.00	< p2<	0.04	A
>3.0 and <4.0 m	110	0.27	13	23	0.15	4.51	0.05	< p3<	0.25	A
>4.0 and <5.0 m	52	0.13	31	11	0.36	36.45	0.23	< p4<	0.49	P
>5.0 m	90	0.22	41	19	0.48	25.41	0.34	< p5<	0.62	P
Total	407		86	86						

[a]Calculated by multiplying $p_{io} \times$ total number of gharial observed (Neu *et al*., 1974).
[b]p_i represents theoretical proportion of observation of gharial and is compared to corresponding p_{io} to determine if hypothesis of proportional use is accepted or rejected i.e. $p_i = p_{io}$ (Neu *et al*., 1974) at $p < 0.05$ based on Byers simultaneous confidence interval.
[c]χ^2 contribution was derived from the formula $\chi^2 = \Sigma(Oi–Ei)^2/Ei$ (Byers *et al*., 1984). P = used more than available, A = used less than available, U = used in proportion to available.

There are seven major, 12 medium and 134 minor irrigation projects operating in the Chambal River basin. There are also some small irrigation systems covering less than 20 ha, constructed and operated by village institutions. Around 52 irrigation projects are under construction and 376 projects have been planned in the basin. These water harvesting projects may have improved human well-being, but at the cost of natural resources that will have a tremendous impact on the aquatic wildlife of the Chambal River. Any activity that reduces the discharge of the river below the present level and the water depth to less than 4 m will severely affect the biodiversity of the entire Chambal River. The migratory and dispersal route of the river dolphin *Platanista gangetica*, gharial and mugger *Crocodylus palustris* will be cut off, fragmenting the populations. Over the years, sand mining along the river for construction purposes and agricultural activities on the sandy banks have increased considerably, which is affecting the gharial, mugger, turtles and island-nesting birds. If appropriate steps are not taken, conservation efforts made over the last 30 years in the Chambal basin will go to waste. Under river basin management policy, as proposed by the Ramsar Convention, water abstraction should be such that it maintains the normal flow of the river in low-flow seasons without affecting the hydrological functioning of the river system and aquatic life. Under the Indian Wildlife (Protection) Act 1972 any form of natural resource extraction from the protected areas is banned and the Environmental Impact Assessment of all development projects close to these areas mandatory. Strict implementation of this Act coupled with integrated conservation planning may save this important river system from imminent disaster. The growing human population and resultant demand on provisioning of ecological services calls for ecologically sustainable water management (Bernhardt *et al*., 2006) and restoration of structure and functioning of degraded aquatic ecosystems.

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