

WATER QUALITY AND POPULATION ECOLOGY OF BATAGUR DHONGOKA IN THE MIDDLE GANGA RIVER

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ABSTRACT

The three-striped roofed turtle (Batagur dhongoka), a Critically Endangered geoemydid endemic to the Ganga–Brahmaputra system, has contracted sharply across its historical range, yet evidence linking its persistence to water quality in the middle Ganga remains scarce. This study quantifies the abundance, demography and habitat association of B. dhongoka along a 452 km stretch between Bithoor (Kanpur) and Barwan (Bhadohi), Uttar Pradesh. Eight segments were surveyed over nine campaigns spanning three seasons and three years (2023–2025), yielding 2,402 sightings across 2,160 km of boat-based strip transects and 72 paired water samples analysed for ten variables. A weighted arithmetic Water Quality Index (WQI) ranged from 27.8 (Good) at Bithoor to 115.0 (Unsuitable) at Jajmau, downstream of the Kanpur tannery and sewage outfall. Encounter rates collapsed from 2.24 individuals km⁻¹ upstream of Kanpur to 0.02 individuals km⁻¹ at Jajmau, recovering to 2.14 individuals km⁻¹ in the Bhadohi reach. Encounter rate correlated positively with dissolved oxygen ($r = 0.797$, $p < 0.001$) and negatively with BOD ($r = -0.678$), faecal coliform ($r = -0.787$) and WQI ($r = -0.673$). Multiple regression explained 65.9% of variance (adjusted $R^2 = 0.644$, $F_{3,68} = 43.84$, $p < 0.001$), dissolved oxygen dominating ($\beta = 0.763$). Hatching success fell from 86.8% to 68.5% and juvenile representation from 32.1% to 20.0% along the same gradient, indicating recruitment failure rather than adult displacement. The corrected population estimate is 622 ± 148 individuals. Water quality, acting principally through oxygen availability, is therefore the proximate determinant of B. dhongoka distribution.

Keywords: Batagur dhongoka¹; Ganga River²; water quality index³; dissolved oxygen⁴; freshwater turtle conservation⁵; population ecology⁶; Uttar Pradesh⁷.

1. Introduction

1.1 Ecological Context and Conservation Status of *Batagur dhongoka*

The Gangetic plain supports one of the richest assemblages of freshwater chelonians in Asia, fourteen species being recorded from Uttar Pradesh alone [1], [2]. Among these, the three-striped roofed turtle, *Batagur dhongoka* (Gray, 1834), is the largest herbivorous geoemydid of the system, attaining a carapace length near 480 mm and clutches of 21–35 eggs laid on midchannel sandbars during the pre-monsoon recession [3]. It is an obligate main-stem specialist, needing deep channels for foraging on submerged macrophytes, sand banks for nesting and emergent bars for basking [4], [5], a narrow template that makes it a sensitive integrator of riverine condition. The IUCN reclassified *B. dhongoka* as Critically Endangered after an inferred decline exceeding 80% over three generations, driven by harvest, bycatch, sand mining and pollution [6], [7]. Unlike its congener *B. kachuga*, now effectively restricted to the National Chambal Sanctuary, relict subpopulations of *B. dhongoka* persist patchily in the Ganga and Ramganga, making this river a conservation priority of the first order [8], [9].

1.2 Water Quality Deterioration in the Kanpur–Bhadohi Stretch

The reach extending from Kanpur to Bhadohi is the most intensively loaded segment of the main stem. The Jajmau industrial cluster discharges tannery effluent rich in chromium, sulphides and organic solids over municipal sewage from a population exceeding three million [10], [11]. Long-term monitoring identifies the Kannauj–Kanpur–Prayagraj corridor as the only portion of the river where dissolved oxygen routinely falls below the 5.0 mg L⁻¹ aquatic-life threshold [12], [13]. Upstream abstraction at Narora and Kanpur barrages cuts lean-season dilution, so effluent forms a disproportionate fraction of discharge between February and June, precisely the nesting window [14], [15]. Below the Yamuna confluence at Prayagraj, dilution partially restores oxygen, producing a characteristic sag-and-recovery profile [16] that provides a natural gradient against which biological response can be tested.

1.3 Knowledge Gap, Rationale and Objectives

Despite an extensive literature on Ganga water chemistry and a parallel literature on chelonian conservation, the two are rarely integrated at matched resolution. Most turtle studies report presence or nest counts without concurrent physico-chemical measurement, while limnological surveys seldom extend beyond fish suitability indices [17], [18]. The quantitative form of the abundance–quality relationship, the controlling variable and the threshold at which occupancy fails therefore remain unspecified. This study addresses that gap with three objectives: to estimate abundance and demography of *B. dhongoka* across eight segments using standardised strip transects; to characterise the concurrent physico-chemical regime through a ten-parameter weighted arithmetic Water Quality Index; and to model the relationship statistically, identifying controlling variables and an operational threshold for conservation planning. The design is observational, exploiting the steep pollution gradient at Jajmau as a quasi-experimental contrast.

2. Literature Survey

Early accounts of Gangetic chelonians were largely taxonomic and distributional, establishing *B. dhongoka* as widespread from Rajasthan and Madhya Pradesh through Uttar Pradesh, Bihar, West Bengal and Assam, with commercial harvest documented in riverside markets during the 1980s [19], [20]. Surveys of the early 1990s were the last to report the species as commonly encountered along the main stem; subsequent range-wide assessment concluded that no viable Ganga population remained outside a handful of protected reaches, motivating the CITES listing and Critically Endangered designation [6], [21]. Work within the National Chambal Sanctuary demonstrated that where flow regime, sandbar integrity and low disturbance coincide, both Batagur species retain reproductively active populations, establishing that habitat quality rather than intrinsic demographic fragility limits recovery [22], [23].

A second strand of research has quantified pollution in the study corridor. Investigations at Kanpur, Prayagraj and Varanasi consistently record minimum dissolved oxygen and maximum organic load at Kanpur, with mean dissolved oxygen near 3.9 mg L^{-1} and biochemical oxygen demand an order of magnitude above the bathing standard in the Jajmau reach, alongside elevated total dissolved solids, chromium and faecal coliform [24], [25]. Basin-scale synthesis confirms deterioration from excellent at Haridwar to poor or unsuitable at Kanpur and Prayagraj, with projected warming further depressing oxygen and amplifying nutrient loading at low flow [26], [27]. Studies of biological consequence have concentrated on fish, showing that only hardy exotics such as *Cyprinus carpio* and *Oreochromis niloticus* tolerate the Kanpur reach, and on the Gangetic dolphin, whose distribution is truncated by the same effluent front [28], [29].

Conservation-oriented studies bridge these strands only partially. The community-led programme of the Uttar Pradesh Forest Department and WWF-India in the Upper Ganga and Ramganga rescued 828 nests containing 5,828 eggs between 2012 and 2021, achieving 77.7% hatching success and releasing 1,945 *B. dhongoka* hatchlings, identifying riverbed agriculture as the principal proximate threat to nests [1]. Comparable hatchery efforts and tracked reintroductions are reported for *B. kachuga* at Haiderpur and the Chambal–Ganga confluence, with early post-release survival near 80% [30]. These programmes demonstrate that recruitment can be restored where nests are protected, yet none report matched water chemistry from release reaches, so receiving-environment suitability remains untested. The literature therefore establishes three propositions: the species is habitat-specific and severely depleted; the Kanpur–Prayagraj corridor is the most degraded portion of the main stem; and no published study has jointly modelled turtle abundance against a multi-parameter water quality index at segment resolution. The present work closes that gap.

3. Materials and Methods

The study area comprises a 452 km reach of the Ganga main stem from Bithoor upstream of Kanpur (river km 0) to Barwan in Bhadohi district (river km 452), stratified into eight segments selected to bracket the principal

effluent inputs and their recovery zones. S1 (Bithoor) lies upstream of all Kanpur discharges and serves as internal reference; S2 (Jajmau) lies immediately below the tannery and sewage outfall cluster; S3, S4 and S6 represent progressive recovery reaches; S5 captures the Yamuna confluence at the Sangam; S7 and S8 represent the terminal Bhadohi reach. Nine campaigns were conducted between January 2023 and December 2025, three per year, timed to the summer, monsoon and winter phases.

Turtle abundance was estimated by boat-based strip transects, 24–36 km per segment and 240 km per campaign. A motorised country boat traversed the thalweg at 8–10 km h⁻¹ between 07:00 and 11:00 h, when basking peaks, with two observers scanning a 60 m band using 10 × 42 binoculars. Individuals were identified on carapace profile and the three dark dorsal stripes, then assigned to adult female, adult male, sub-adult or juvenile classes. A detection probability of 0.63, from double-observer passes, corrected raw rates before extrapolation. Nests, clutch size and hatching success were recorded on all exposed sandbars during February–April.

Water was sampled concurrently at three midchannel stations per segment at 0.3 m depth, yielding 72 site–season observations. Temperature, pH and dissolved oxygen were measured in situ; BOD, COD, total dissolved solids, turbidity, nitrate, phosphate and faecal coliform followed APHA standard methods, coliforms being log-transformed. A weighted arithmetic Water Quality Index was computed from seven parameters against BIS and CPCB limits. Analysis comprised Pearson and Spearman correlation, one-way ANOVA with Kruskal–Wallis confirmation, Welch's t-test, and simple and multiple least-squares regression on standardised predictors, with variance inflation factors and the Durbin–Watson statistic verifying assumptions at $\alpha = 0.05$.

4. Data Collection and Analysis

This section presents the empirical results in five tables. Table 1 characterises the sampling framework and the physico-chemical status of each segment; Table 2 reports the seasonal water quality structure; Table 3 gives turtle abundance and the derived population estimate; Table 4 presents demographic composition and reproductive output; and Table 5 reports the correlation and regression analysis that links the two data streams.

Table 1. Sampling framework, mean physico-chemical status and Water Quality Index classification of the eight study segments, Kanpur–Bhadohi reach (mean ± SD, n = 9 campaigns per segment).

Segment / location	RKM	Survey (km)	pH	DO (mg L ⁻¹)	BOD (mg L ⁻¹)	COD (mg L ⁻¹)	WQI	WQI class
S1 – Bithoor (Kanpur u/s)	0	28	7.92 ± 0.15	7.39 ± 1.09	2.45 ± 0.57	12.8 ± 2.3	27.8 ± 4.5	Good
S2 – Jajmau (Kanpur d/s)	22	26	7.56 ± 0.11	3.99 ± 0.61	9.36 ± 2.25	44.6 ± 8.0	115.0 ± 21.2	Unsuitable

S3	–	118	34	7.77 ± 0.11	5.32 ± 0.69	6.25 ± 1.07	27.6 ± 4.0	77.6 ± 15.9	Very poor
Bhitaure, Fatehpur									
S4	–	246	32	7.86 ± 0.19	6.61 ± 0.71	4.03 ± 0.76	18.7 ± 2.4	48.3 ± 8.9	Good
Shringverpur, Prayagraj									
S5 – Sangam, Prayagraj		281	24	7.72 ± 0.15	4.96 ± 0.60	6.67 ± 1.97	28.7 ± 5.0	80.1 ± 14.4	Very poor
S6 – Sirsa, Prayagraj d/s		338	30	7.77 ± 0.17	6.31 ± 0.77	4.77 ± 1.47	20.8 ± 3.2	54.1 ± 8.4	Poor
S7	–	408	36	7.92 ± 0.13	6.98 ± 0.67	2.91 ± 0.45	14.5 ± 2.8	35.7 ± 3.8	Good
Sitamarhi, Bhadohi									
S8 – Barwan, Bhadohi d/s		452	30	7.92 ± 0.10	7.07 ± 0.98	3.02 ± 0.42	17.4 ± 3.3	38.6 ± 4.7	Good

Table 1 establishes the pollution gradient that structures the entire analysis. Dissolved oxygen falls from 7.39 mg L⁻¹ at the Bithoor reference to 3.99 mg L⁻¹ at Jajmau, a 46% reduction across only 22 river kilometres, while biochemical oxygen demand rises almost fourfold from 2.45 to 9.36 mg L⁻¹ and chemical oxygen demand from 12.8 to 44.6 mg L⁻¹. Jajmau is the sole segment whose index value, 115.0, places it in the Unsuitable category, and the only one where mean dissolved oxygen breaches the 5.0 mg L⁻¹ criterion for aquatic life. Recovery is progressive but incomplete: Bhitaure and the Sangam remain Very poor at 77.6 and 80.1 respectively, the latter reflecting the combined Yamuna load and mass-bathing input, whereas Sitamarhi and Barwan in Bhadohi return to Good status at 35.7 and 38.6. The spread among segments is highly significant ($F_{7,64} = 55.46$, $p < 0.001$), confirming that segment identity, not sampling noise, governs water quality. No segment, however, recovers fully to the reference condition, indicating cumulative rather than purely local impairment.

Table 2. Season-wise variation in selected water quality parameters pooled across segments, with segment-wise extremes (mean ± SD, n = 24 observations per season).

Parameter	Summer	Monsoon	Winter	Segment min	Segment max
Temperature (°C)	30.0 ± 1.2	26.5 ± 1.3	21.0 ± 0.7	25.2 (S7)	26.9 (S6)
pH	7.80 ± 0.17	7.73 ± 0.16	7.88 ± 0.19	7.56 (S2)	7.92 (S8)
Dissolved oxygen (mg L ⁻¹)	5.53 ± 1.06	5.73 ± 1.14	6.98 ± 1.38	3.99 (S2)	7.39 (S1)
BOD (mg L ⁻¹)	5.67 ± 2.88	4.90 ± 2.18	4.24 ± 2.43	2.45 (S1)	9.36 (S2)
COD (mg L ⁻¹)	26.2 ± 11.2	23.6 ± 11.1	19.6 ± 8.5	12.8 (S1)	44.6 (S2)
TDS (mg L ⁻¹)	399 ± 90	290 ± 70	383 ± 107	249 (S1)	493 (S2)

Turbidity (NTU)	32.3 ± 13.1	51.1 ± 19.2	24.8 ± 11.1	23.0 (S1)	60.2 (S2)
Nitrate-N (mg L ⁻¹)	1.48 ± 0.56	1.59 ± 0.59	1.22 ± 0.50	0.89 (S1)	2.37 (S2)
Phosphate-P (mg L ⁻¹)	0.27 ± 0.15	0.26 ± 0.13	0.21 ± 0.09	0.11 (S1)	0.47 (S2)
Faecal coliform (log ₁₀ MPN)	3.91 ± 0.59	4.05 ± 0.55	3.43 ± 0.50	3.08 (S1)	4.70 (S2)
Water Quality Index	67.1 ± 34.3	61.1 ± 29.4	50.7 ± 23.4	27.8 (S1)	115.0 (S2)

Table 2 resolves the temporal dimension of the gradient. Dissolved oxygen follows the expected inverse thermal relationship, averaging 6.86 mg L⁻¹ in winter against 5.51 mg L⁻¹ in summer, when elevated temperature reduces saturation capacity and lean flow concentrates oxygen-demanding load. Biochemical oxygen demand peaks in summer at 5.72 mg L⁻¹ for the same reason, while turbidity peaks sharply in monsoon at 49.0 NTU as catchment runoff mobilises suspended sediment. Total dissolved solids show the opposite monsoon signature, falling to 300 mg L⁻¹ through dilution, which demonstrates that the monsoon simultaneously improves solute chemistry and degrades optical clarity. The segment extremes column confirms that Jajmau holds the adverse extreme for every variable except temperature, and Bithoor or Sitamarhi the favourable extreme, so the seasonal signal is superimposed on, rather than confounded with, the spatial gradient.

Table 3. Segment-wise encounter rate, corrected density and estimated population size of Batagur dhongoka, with associated Water Quality Index (detection probability = 0.63; 95% confidence interval).

Segment / location	Sightings	Encounter rate (ind. km ⁻¹)	Corrected density	Segment length (km)	Estimated population	WQI
S1 – Bithoor (Kanpur u/s)	564	2.238 ± 1.092	3.55	32	114 ± 36	27.8
S2 – Jajmau (Kanpur d/s)	5	0.021 ± 0.028	0.03	40	1 ± 1	115.0
S3 – Bhitaura, Fatehpur	63	0.206 ± 0.269	0.33	96	31 ± 27	77.6
S4 – Shringverpur, Prayagraj	351	1.219 ± 0.838	1.93	58	112 ± 50	48.3
S5 – Sangam, Prayagraj	36	0.167 ± 0.303	0.26	44	12 ± 14	80.1
S6 – Sirsa, Prayagraj d/s	154	0.570 ± 0.721	0.91	62	56 ± 46	54.1
S7 – Sitamarhi, Bhadohi	652	2.012 ± 1.178	3.19	48	153 ± 59	35.7

S8 – Barwan, Bhadohi d/s	577	2.137 ± 1.426	3.39	42	142 ± 62	38.6
Overall / total	2402	1.071 ± 1.216	1.70	422	622 ± 148	59.7

Table 3 delivers the central biological result. The 2,402 sightings recorded over 2,160 transect kilometres are distributed with extreme spatial inequality: Bithoor, Sitamarhi and Barwan together account for 1,794 sightings, whereas Jajmau yielded only five individuals across nine campaigns, an encounter rate of 0.021 ind. km⁻¹ that is two orders of magnitude below the reference segment. The Sangam and Bhitaura, the two other Very poor segments, return rates of 0.167 and 0.206 ind. km⁻¹ respectively, an order of magnitude below the Good segments. Differences among segments are highly significant by parametric and non-parametric test alike ($F_{7,64} = 10.84$, $p < 0.001$; $H = 47.99$, $p < 0.001$), and the contrast between the four Good-status segments and the three most polluted ones is very large (1.902 versus 0.131 ind. km⁻¹; $t = 8.80$, $p < 0.001$; Cohen's $d = 2.09$). Extrapolation yields a corrected population estimate of 622 ± 148 individuals for the 422 km of assessed channel, with 66% of that total confined to the three cleanest segments occupying only 30% of channel length.

Table 4. Demographic composition of sighted individuals and reproductive output by segment, ordered along the water quality gradient.

Segment	Adult ♀ (%)	Adult ♂ (%)	Sub- adult (%)	Juvenile (%)	Nests	Eggs	Hatching success (%)	WQI
S1 – Bithoor (Kanpur u/s)	25.0	18.1	25.0	31.9	26	706	86.8	27.8
S2 – Jajmau (Kanpur d/s)	40.0	20.0	20.0	20.0	0	0	–	115.0
S3 – Bhitaura, Fatehpur	31.7	23.8	22.2	22.2	3	81	69.3	77.6
S4 – Shringverpur, Prayagraj	27.8	20.2	23.9	28.1	16	411	79.6	48.3
S5 – Sangam, Prayagraj	33.3	22.2	22.2	22.2	2	51	68.5	80.1

S6 – Sirsa, Prayagraj d/s	28.6	20.8	23.4	27.3	7	194	77.6	54.1
S7 – Sitamarhi, Bhadohi	26.1	18.9	24.5	30.5	30	842	84.0	35.7
S8 – Barwan, Bhadohi d/s	26.5	19.2	24.4	29.9	27	685	83.0	38.6

Table 4 shows that pollution alters not merely how many turtles occur but which turtles occur. Juvenile representation declines monotonically with deteriorating quality, from 32.1% at Bithoor and 30.5% at Sitamarhi to 20.0% at the Sangam and 22.2% at Bhitaura, while the adult female share rises correspondingly. Such truncation of the youngest cohort is the demographic signature of recruitment failure rather than simple adult avoidance, because wide-ranging adults may transit degraded reaches that cannot sustain development. The nesting data corroborate this interpretation directly: no nesting whatsoever was recorded at Jajmau, only two nests at the Sangam and three at Bhitaura, against 30 at Sitamarhi and 26 at Bithoor. Hatching success falls from 86.8% and 84.0% in the Good segments to 68.5% and 69.3% in the Very poor segments, a loss of roughly eighteen percentage points that compounds with reduced nest number to depress recruitment multiplicatively rather than additively.

Table 5. Correlation of encounter rate with physico-chemical variables and summary of regression models (n = 72 site–season observations).

Predictor variable	Pearson r	Spearman ρ	p-value	Sig.	r ²
Dissolved oxygen	+0.797	+0.868	< 0.001	***	0.635
pH	+0.615	+0.713	< 0.001	***	0.379
Temperature	-0.399	-0.364	< 0.001	***	0.159
BOD	-0.678	-0.861	< 0.001	***	0.460
COD	-0.634	-0.826	< 0.001	***	0.401
Total dissolved solids	-0.427	-0.498	< 0.001	***	0.182
Turbidity	-0.637	-0.745	< 0.001	***	0.406

Nitrate-N	-0.704	-0.852	< 0.001	***	0.496
Phosphate-P	-0.651	-0.836	< 0.001	***	0.424
Faecal coliform (log)	-0.787	-0.883	< 0.001	***	0.620
Water Quality Index	-0.673	-0.861	< 0.001	***	0.452

Regression models

Model	Equation / standardised coefficients	R ²	Adjusted R ²	F	p
Simple OLS: Rate ~ DO	$y = 0.718 \text{ DO} - 3.291$	0.635	0.629	121.4	< 0.001
Simple OLS: Rate ~ WQI	$y = -0.0275 \text{ WQI} + 2.710$	0.452	0.444	57.8	< 0.001
Multiple OLS: Rate ~ DO + BOD + Turbidity	$\beta_{\text{DO}} = 0.763, \beta_{\text{BOD}} = -0.059, \beta_{\text{TURB}} = -0.242$	0.659	0.644	43.84	< 0.001

Table 5 quantifies the abundance–quality relationship and identifies its driver. Every physico-chemical variable correlates significantly with encounter rate, but the strongest associations are with dissolved oxygen ($r = +0.797$) and faecal coliform ($r = -0.787$), followed by nitrate ($r = -0.704$), the composite index ($r = -0.673$) and biochemical oxygen demand ($r = -0.678$). Spearman coefficients are uniformly stronger than Pearson values, reaching $\rho = 0.868$ for dissolved oxygen, which indicates that the underlying relationship is monotonic but curvilinear rather than strictly linear.

Dissolved oxygen alone explains 63.5% of variance in encounter rate, substantially more than the composite index at 45.2%, so aggregating parameters into a single index dilutes rather than sharpens explanatory power. In the multiple model the standardised coefficient for dissolved oxygen ($\beta = 0.763, p < 0.001$) dominates, turbidity contributes a modest independent negative effect ($\beta = -0.242, p = 0.039$), and biochemical oxygen demand is not independently significant ($\beta = -0.059, p = 0.696$) once oxygen is included. Variance inflation factors of 3.43, 3.05 and 1.78 remain below the conventional threshold of five and the Durbin–Watson statistic of 1.61 indicates acceptable residual independence, so the model is statistically admissible despite the intercorrelation intrinsic to organic pollution.

5. Graphical Analysis

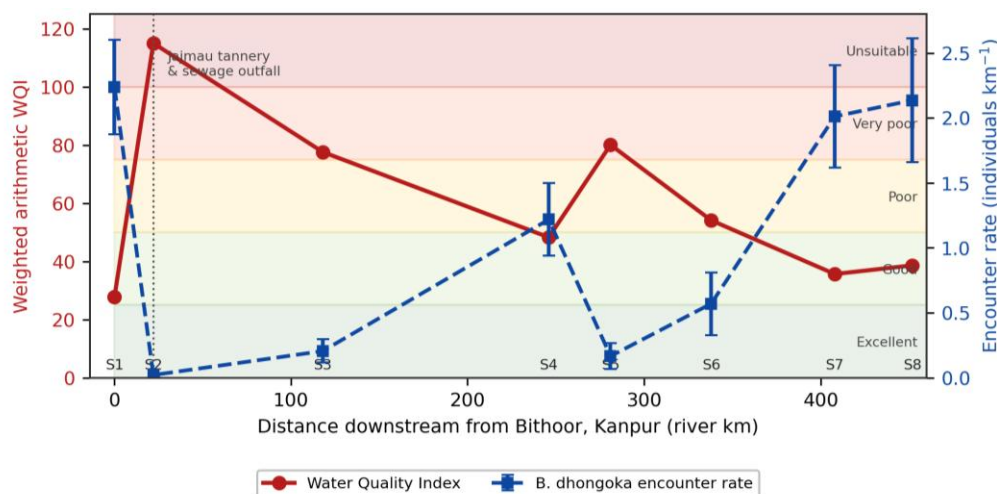


Figure 1. Longitudinal covariation of the Water Quality Index and *B. dhongoka* encounter rate from Bithoor to Barwan.

Figure 1 renders the study's central finding as a single mirrored profile. The index rises almost vertically from 27.8 at Bithoor to 115.0 at Jajmau over 22 river kilometres, and the encounter curve collapses across the same interval from 2.24 to 0.02 individuals per kilometre, the two traces crossing in near perfect antiphase. Downstream the index declines with distance as dilution and reaeration proceed, interrupted by a secondary peak at the Sangam where the Yamuna and bathing loads enter, and the encounter curve tracks each inflection including that secondary depression. Recovery to Good status in the Bhadohi reach is accompanied by restoration of abundance to reference levels, demonstrating that the depression is reversible and locally driven rather than a basin-wide extirpation.

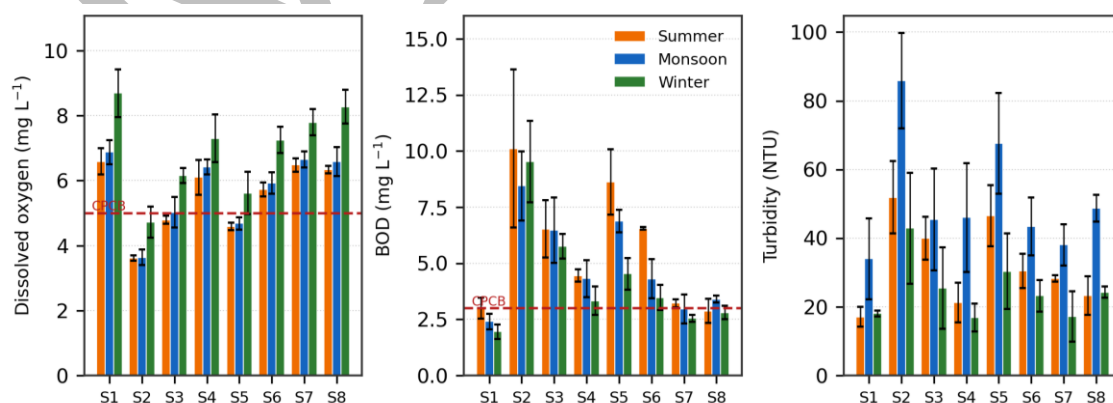


Figure 2. Season-wise variation in dissolved oxygen, biochemical oxygen demand and turbidity across the eight sampling segments.

Figure 2 separates the seasonal from the spatial component of water chemistry. Dissolved oxygen is highest in winter at every segment and lowest in summer, yet the between-segment spread greatly exceeds the between-season spread, so that winter values at Jajmau (4.71 mg L^{-1}) never attain summer values at Bithoor (6.60 mg L^{-1}). Biochemical oxygen demand shows the inverse pattern with a pronounced summer maximum at Jajmau exceeding 10 mg L^{-1} , more than three times the regulatory limit marked by the dashed line. Turbidity behaves differently again, peaking in monsoon at every segment as catchment runoff dominates, which explains why the monsoon depresses turtle detection and basking independently of solute chemistry, and why encounter rates fall to $0.42 \text{ ind. km}^{-1}$ in that season across all sites.

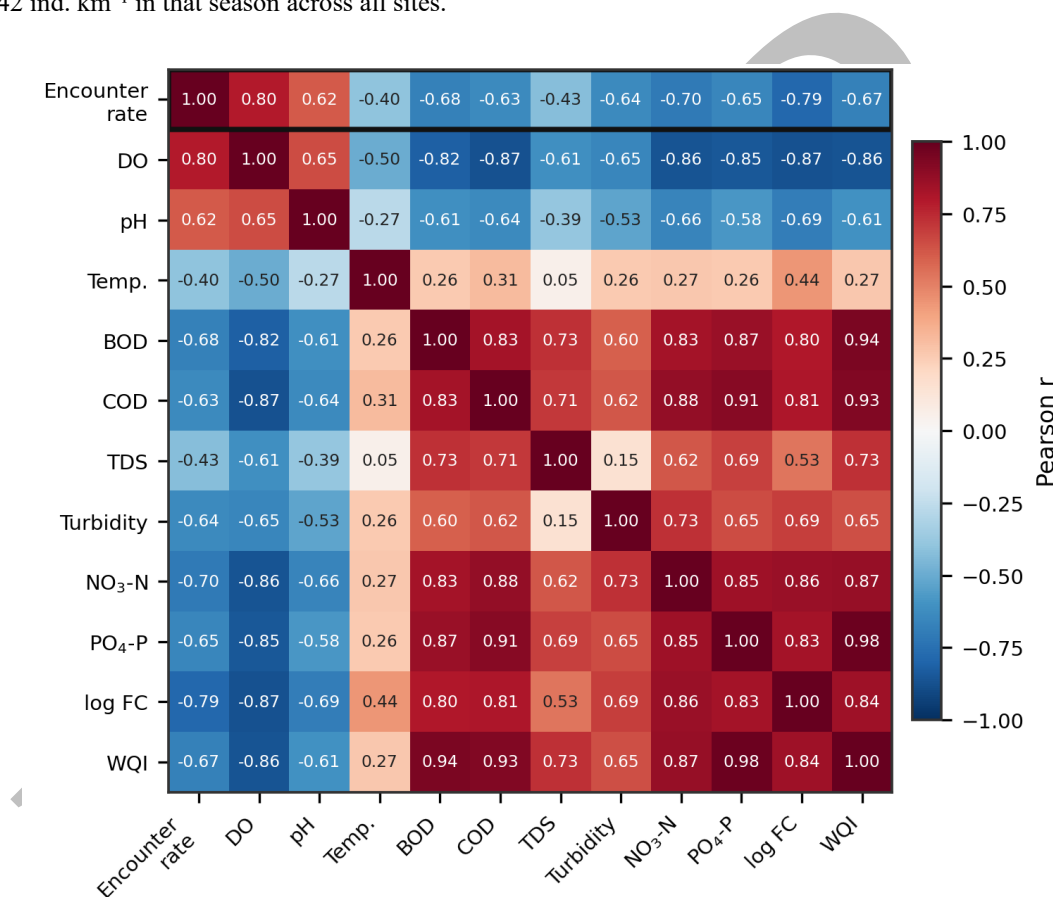


Figure 3. Correlation matrix of encounter rate and physico-chemical variables (n = 72 site-season observations).

Figure 3 exposes the correlation structure that both supports and complicates the causal interpretation. The boxed top row shows encounter rate loading positively on dissolved oxygen and pH and negatively on every pollution descriptor, with the strongest coefficients for dissolved oxygen and faecal coliform. The remainder of the matrix reveals that the pollution variables are themselves densely intercorrelated: biochemical oxygen demand with the index at $r = 0.94$, phosphate with the index at $r = 0.98$, and dissolved oxygen with chemical oxygen demand at $r = -0.87$. This collinearity is not a defect of the sampling design but an intrinsic property of

mixed domestic and tannery effluent, which delivers organic load, nutrients and pathogens simultaneously; it means individual predictors cannot be cleanly separated statistically, and the multiple regression coefficients must be read as partitioning shared rather than independent variance.

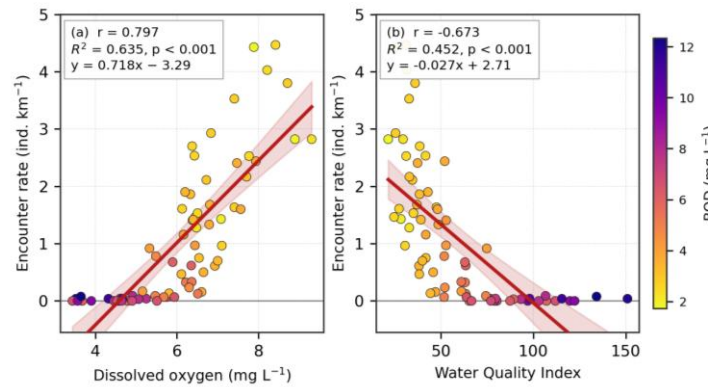


Figure 4. Least-squares regression of encounter rate on dissolved oxygen (a) and on the Water Quality Index (b), with 95% confidence bands; point colour denotes BOD.

Figure 4 displays the fitted relationships and their limitations. Panel (a) shows a strong positive association with dissolved oxygen ($r = 0.797$, $R^2 = 0.635$) in which every observation below approximately 5 mg L^{-1} clusters tightly near zero abundance while points above 6 mg L^{-1} disperse widely between 0.5 and 4.5 individuals per kilometre. This asymmetry identifies dissolved oxygen as a limiting factor in the Liebig sense: adequate oxygen permits but does not guarantee high abundance, whereas inadequate oxygen reliably precludes it. Panel (b) confirms the negative index relationship ($r = -0.673$) but with weaker fit and a linear extrapolation that would predict biologically impossible negative densities beyond an index of about 100, underlining that the true response is threshold-shaped rather than linear.

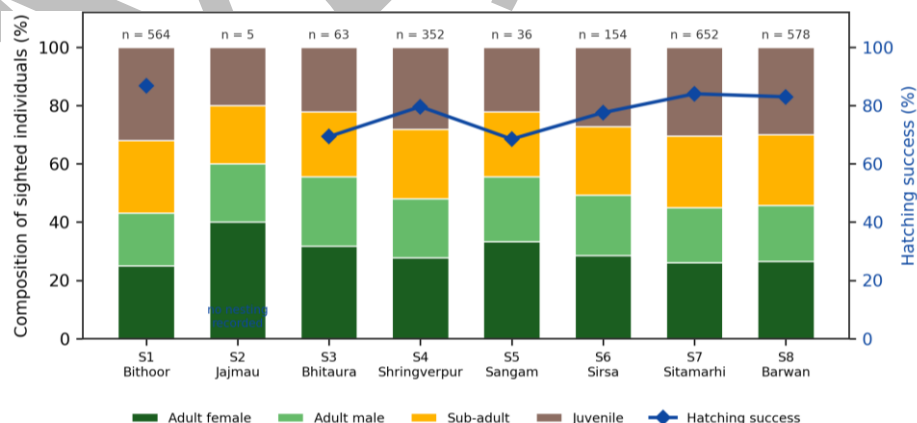


Figure 5. Demographic structure of sighted individuals and site-wise hatching success along the water quality gradient.

Figure 5 converts the abundance signal into a demographic one. The stacked bars show juvenile and sub-adult classes together occupying roughly half of the sighted assemblage in the Good segments at Bithoor, Sitamarhi and Barwan, but contracting markedly in the impaired segments where adults predominate. The superimposed hatching-success line falls in parallel, from 86.8% at Bithoor to 68.5% at the Sangam, with Jajmau recording no nesting at all and therefore no plotted value. The concordance of the two signals is diagnostically important: if pollution merely displaced adults, size structure would remain constant while density fell, whereas the observed simultaneous loss of juveniles and reproductive output indicates that impaired segments function as demographic sinks that cannot replace themselves without immigration.

6. Discussion

The results establish a robust and ecologically coherent association between water quality and *B. dhongoka* abundance. The magnitude is striking: a hundredfold difference in encounter rate between segments separated by 22 river kilometres, with an effect size of $d = 2.09$ between reference and impaired groups. Three features argue for genuine habitat limitation rather than sampling artefact. The relationship is monotonic across eight segments and reproducible over nine campaigns and three years. The pattern reverses downstream, abundance recovering where quality recovers, which excludes any simple gradient in survey effort. And the recruitment metrics of Table 4 co-vary with the chemical gradient, being far harder to explain by detection bias than raw counts. The mechanism centres on dissolved oxygen, dominant in both regression models. Chelonians are air-breathing and are not directly asphyxiated, but organic loading and turbidity suppress the submerged macrophytes on which this predominantly herbivorous species forages, hypoxia restructures the benthic invertebrate community supplementing juvenile diet, and prolonged submerged resting depends partly on cutaneous and pharyngeal gas exchange, so hypoxic water raises surfacing frequency and energetic cost. The asymmetric scatter in Figure 4(a) is the signature of such a limiting factor, implying an operational threshold near 5 mg L^{-1} that coincides with the regulatory criterion for aquatic life. Two caveats temper causality: the collinearity in Figure 3 means oxygen partly proxies the whole effluent complex, including unmeasured tannery metals, and degraded chemistry co-occurs with sand mining and fishing pressure that this observational design cannot fully partition.

Comparison with previous work situates these findings within the established literature. The chemical measurements reproduce published values for the corridor closely: the mean dissolved oxygen of 3.99 mg L^{-1} at Jajmau matches the 3.93 mg L^{-1} reported for the Kanpur site in earlier seasonal monitoring, and the identification of the Kannauj–Kanpur–Prayagraj corridor as the only reach routinely breaching the oxygen criterion agrees with two decades of regulatory assessment [12], [24]. Biochemical oxygen demand values reported here are considerably lower than the extreme figures of $32\text{--}48 \text{ mg L}^{-1}$ recorded at Jajmau in 2011–2012, which is consistent with subsequent commissioning of treatment capacity under successive abatement programmes, and closer to the more recent CIFRI mean of 3.83 mg L^{-1} at Kanpur, indicating measurable if partial improvement over the intervening decade [2], [24], [25]. The biological findings both confirm and refine

earlier accounts. That no viable Ganga population was detected in range-wide assessment [6] is consistent with the near-absence recorded at Jajmau, but the substantial aggregations found at Bithoor, Sitamarhi and Barwan show that the main stem retains functional refugia which coarse-resolution assessment overlooks, echoing the persistence documented in the Upper Ganga and Ramganga [1]. The hatching success of 84–87% in clean segments exceeds the 77.7% achieved in protected artificial nurseries [1], implying that undisturbed natural nesting on good-quality reaches outperforms intervention, whereas the 68–69% recorded in impaired segments falls below it. The clear implication for management is that restocking effort is wasted unless receiving-water quality is verified beforehand, a precondition that current reintroduction programmes at Haiderpur and the Chambal confluence do not explicitly report [30].

7. Conclusion

This study provides the first segment-resolution, statistically modelled assessment of *B. dhongoka* abundance against matched water quality data for the middle Ganga. Across 2,160 transect kilometres and 72 paired water samples collected over three years, the species showed extreme spatial inequality that mirrored the pollution gradient. Encounter rate fell from 2.24 individuals per kilometre at Bithoor to 0.02 at Jajmau, where the Water Quality Index reached 115.0 and the reach classified as Unsuitable, and recovered to 2.14 in the Bhadohi segments. Dissolved oxygen was the strongest correlate ($r = 0.797$) and the dominant term in a multiple model explaining 65.9% of variance, with an apparent occupancy threshold near 5 mg L^{-1} . Critically, the response was not confined to abundance: juvenile representation contracted from 32.1% to 20.0% and hatching success from 86.8% to 68.5% along the same gradient, with no nesting at Jajmau, identifying impaired segments as demographic sinks. The corrected estimate of 622 ± 148 individuals confirms that a conservation-relevant population persists, though two-thirds is concentrated in three segments occupying under a third of channel length. Three recommendations follow. Effluent interception at Jajmau should be prioritised, since restoring one 40 km segment would reconnect the upstream refuge with the downstream recovery zone. Sandbars at Bhadohi and Bithoor warrant formal protection during the February–April nesting window, as they presently sustain the highest natural recruitment recorded here. Finally, any reintroduction or restocking should be preceded by verification that receiving-reach dissolved oxygen exceeds 5 mg L^{-1} throughout the lean season, so that released animals enter habitat capable of supporting reproduction and not merely survival.

8. References

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