Conservation implications of the channel changes in Sharda River on endangered swamp deer population and floodplain ecosystem in Kishanpur Wildlife Sanctuary, Uttar Pradesh, India

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One surviving stronghold of endangered Northern swamp deer is Jhadi *taal* (lake) in Kishanpur Wildlife Sanctuary on the floodplains of Sharda River. Changes in channel characteristics and land use/cover in a stretch of the river were detected during 1948–2001 and their impact on deer habitat was assessed. Analyses revealed consistent shift of west bank line towards *taal*, moving to within 100 m in 2001 and reducing further, posing threat of inundation. Other results included loss of sal forest and grasslands owing to shifts in the river course and encroachment of newly deposits. Threat to *taal* was confirmed by a probability model.

Keywords: Channel changes, conservation, locational probability model, Sharda River, swamp deer.

RIVER dynamics in alluvial floodplains, viz. channel changes, erosion, sedimentation and water-table fluctuations constitute the natural disturbance regime. The result is a complex floodplain pattern and a high level of biodiversity[1,2]. Rapid land-use changes and river management are two factors responsible for alteration in the river dynamics and consequent changes in habitat heterogeneity and successional trajectories during the last few decades[2–5]. Understanding the nature, extent, rates and causes of altered river dynamics is critical, especially for priority conservation areas. Changes from equilibrium could cause the loss of permanent or transient habitats for many faunal species leading to their dispersal, population decline or even extinction. Thus, assessment of altered river dynamics and its effect is vital for management, mitigation and restoration of wildlife habitat and populations[2,6].

The northern swamp deer (*Cervus duvauceli duvauceli* Cuvier) is endemic to the Indian subcontinent and is listed in the IUCN Red Data Book of threatened species as endangered. It was once abundant throughout the tall wet grasslands of the northern Indian and Nepalese Terai at the base of the Himalayan range. Factors implicated in its decline include loss of habitat due to the conversion of grasslands into agricultural land and relentless hunting[7]. Currently, the northern swamp deer is found in isolated pockets in few well-protected national parks and wildlife sanctuaries in India and Nepal. In Nepal, about 2000 animals occur in Suklaphanta Wildlife Reserve and Bardia National Park. On the Indian side, Dudhwa Tiger Reserve (DTR) in Uttar Pradesh supports a single large population of 1200–1400 animals[7]. Within DTR, Jhadi *taal* (lake) is a stronghold of about 400 animals and key to the survival of northern swamp deer in India today.

Jhadi *taal* is a pocket of tall grassland around a shallow seasonal lake within the sal (*Shorea robusta*) forest of Kishanpur Wildlife Sanctuary (KWLS), which is a part of the DTR. The *taal* area is typical of the woodland–grassland–wetland complex characteristic of the Terai ecosystem. It is located on the floodplain of Sharda River, which forms the northern border of KWLS. The river descends from the Himalayan borderland of Nepal and India, on to the Gangetic floodplain of India where it follows a meandering pattern. High run-off and siltation rates have been observed in the Sharda River during the last 40 years, primarily due to massive conversion of forest to agriculture for resettlement of people in Nepal in the upper reaches during the 1960s and 1970s (refs 8 and 9). These changing patterns have led to frequent and sudden changes in the river course and in the last few years, the river channel has come dangerously close to Jhadi *taal*. If the changing course and erosion continue, Jhadi *taal* will be inundated or drained by the Sharda River, destroying this prime habitat of swamp deer and likely leading to their local extirpation in the KWLS portion of the DTR.

In this article, we evaluate channel changes in the Sharda River and their implications on an area of high biodiversity value and conservation significance, i.e.

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Jhadi *taal*. We also describe river channel changes and determine their effects on swamp deer habitat and on floodplain pattern from 1948 to 2001, and construct a probability model of channel configuration during the timeframe of the assessment period to assist managers in assessing channel stability in the study area and risk of channel encroachment to Jhadi *taal*.

Study area

An approximately 10 km stretch of the Sharda River along the northern boundary of KWLS, including Jhadi *taal*, was selected as the study site (Figure 1). The study area lies between lat. 28°22′–28°26′N and long. 80°26′–80°30′E and covers an area of 55.3 sq. km. The tract very gently slopes to the south-east. The average elevation is 165 m above mean sea level. The soil consists of Gangetic alluvial formations. The sanctuary is a mosaic of moist and dry deciduous sal forests, riparian forest, and plantations of khair (*Acacia catechu*), sissoo (*Dalbergia sissoo*) and *Tectona grandis*. These wooded areas are interspersed by extensive tall grasslands and wetlands (*taal*) and are maintained by annual flooding and prescribed grassland burning. Jhadi *taal* is surrounded by one such tall grassland.

KWLS and Jhadi *taal* have also been recognized as important bird areas[10] and placed under A1 category, i.e. holding species classified as globally threatened with extinction. In addition, KWLS and Jhadi *taal* support a large population of *Panthera tigris tigris* due to abundant prey that includes swamp deer, *Cervus porcinus* and *Sus scrofa*[8].

Outside the sanctuary and along the Sharda River, swamps and grasslands created in abandoned channel areas (old channels, oxbow lakes and vast alluvuim deposits by migrating river) are encroached and reclaimed into agricultural lands[8,9].

Methodology

Data acquisition and image processing

We used Survey of India toposheets for 1948 (1 : 63,360) and 1965 (1 : 50,000) and satellite images for 1977 (Landsat MSS – resolution 80 m), 1990 (Landsat TM – resolution 30 m), 1999 (Landsat ETM+ – resolution 30 m) and 2001 (IRS 1D, LISS III – resolution 23.5 m). We geometrically corrected and resampled all datasets to bring to the same scale. After extracting the study area from each dataset, a fragment of floodplain (41.3 sq. km) was delineated for assessing the effect of channel changes on vegetation development. All images were from October except the 1977 image, which was from March and thus was not used for preparation of a land use/cover to avoid classification errors. Also, the 1965 toposheet was not available for the entire study area, so we extrapolated channel boundaries to estimate channel length and area[11]. The land use/cover map could not be prepared for 1965 too.

Channel characteristics

We digitized the river channel in GIS as one continuous polygon for each year at a scale of 1 : 50,000. River chan-

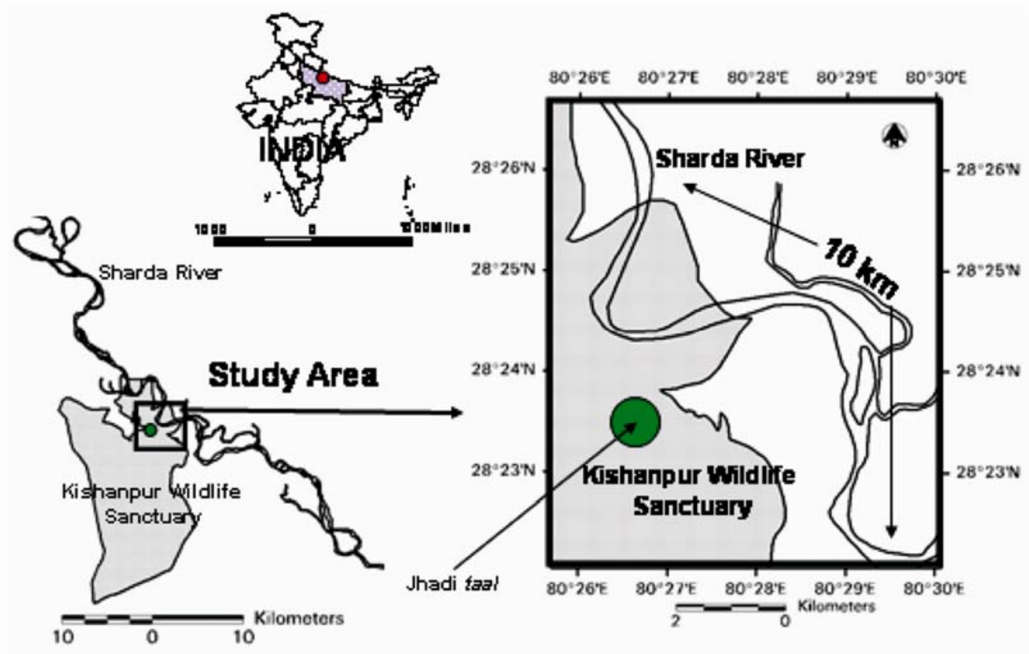

Figure 1. Locations of Jhadi *taal* in Kishanpur Wildlife Sanctuary and the adjacent Sharda River in Uttar Pradesh, India.

nel was defined as an elongated area where streamflow occurred with sufficient frequency, force and duration to preclude the presence of vegetation[11,12]. To describe and compare the channel characteristics (change in bank line position, length, area and sinuosity), we divided the studied section of channel into three segments named 'A', 'B' and 'C' (Figure 2).

Change in bank line position: To assess change in bank line positipon, we measured distances from the common reference point on Jhadi *taal* to west and east bank line for each assessment year.

Changes in channel length, area and sinuosity: We measured channel length along the line equidistant and parallel to left and right banks of the channel polygon. Active channel area was determined for each polygon, excluding mid-channel islands >1 sq. km (ref. 11). Sinuosity is the measure of intensity of meanders in a river channel and is measured as channel length divided by straight valley length[11].

Vegetation development on the floodplain

We collected data on the dominant plant life form at 250 point locations during the winter of 2005 to validate maps. Land use/cover of the years 1948, 1990 and 2001 were prepared through visual interpretation at 1 : 50,000 scale. Finally, overall accuracy and Kappa statistics were calculated[13]. The classified images were overlaid to quantify changes in land use/cover categories.

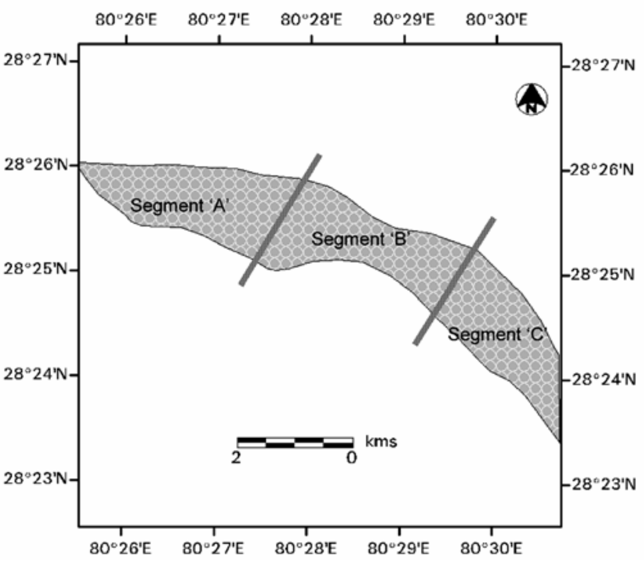

Figure 2. Channel sections of the Sharda River where changes in channel location and pattern from 1948 to 2001 were studied.

Locational probability model

We developed a locational probability model (LPM)[14] that depicts the most likely location and configuration of the channel in any randomly selected year. The LPM is estimated by overlaying channel area polygons (GIS coverages) where numerical weight (W_n) was assigned to each polygon. We converted GIS coverages for each year to a raster-based format and assigned each cell a value of 1 or 0, where 1 indicated channel presence and 0 indicated no channel.

The weights were assigned to each polygon according to weighting method followed by Graf[15]:

$$W_n = t_n/m,$$

where W_n is the weighting value assigned to map n, t_n the number of years separating given map from preceding map, and m the total number of years for the historic record. Weights were determined from a random year of 2004.

The final map was generated by combining all coverages consisting of a value for occurrence and non-occurrence of river channel and weight assigned. Each value of cell (p) of final locational probability map was based on the algebraic equation developed by Graf[15] and modified by Wasklewicz *et al.*[14]. Accordingly,

$$p = (W_1F_1) + (W_2F_2) + \cdots + (W_nF_n),$$

where p is the final locational probability, W_n the weight assigned to map n and F_n the channel occurrence or non-occurrence. p value of final map was distributed in probability classes. Low probability indicates 'instability' whereas high probability indicates 'stability' of the channel. Based on this, low probability class (1 to <33%) occupied area was designated as unstable area, >33–66% class occupied area was referred as moderately stable, and high probability (>66–100%) occupied area was classified as stable.

Results

Channel characteristics

Changes in bank line position: The west bank line shifted by 3.1 km south-west towards Jhadi *taal* during the assessment period (1948–2001). The maximum shift of 1.5 km occurred between 1948 and 1965 (Table 1, Figure 3). In 2001, the distance of the west bank line from Jhadi *taal* was reduced to only 100 m (Figures 3 and 4). In contrast, the east bank line remained more stable during the assessment period.

Changes in channel length and sinuosity: The length and sinuosity oscillated considerably from 1948 to 2001

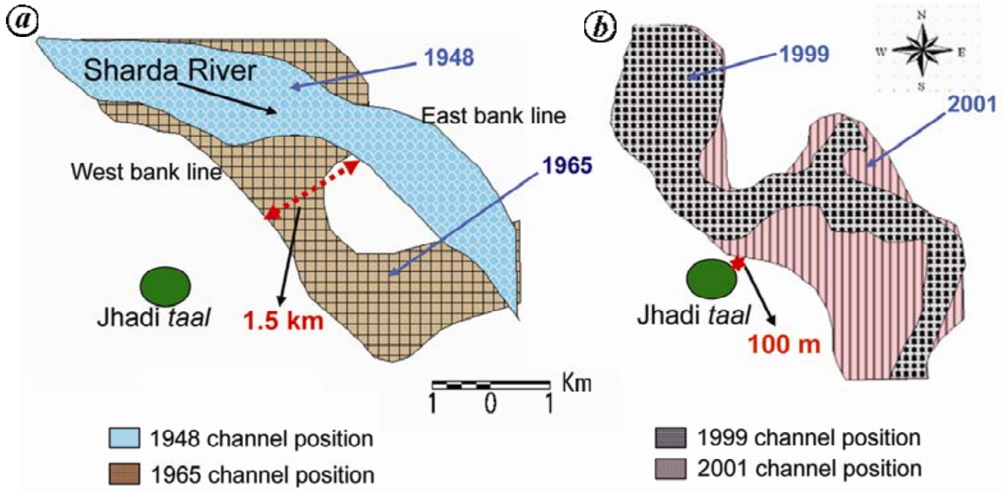

Figure 3. Notable periods of channel shift that brought the west bank line of Sharda River close to Jhadi *taal* during (***a***) 1948–65 and (***b***) 1999–2001.

Table 1. Distance of Jhadi *taal* from the west and east banks of the Sharda River channel from 1948 to 2001

Year	West bank line (km)	East bank line (km)
1948 (base year)	3.2	4.1
1965	1.7 (–1.5)	4.6 (+0.5)
1977	1.2 (–0.5)	2.9 (–1.7)
1990	1.6 (+0.4)	2.5 (–0.4)
1999	1.1 (–0.5)	3.2 (+0.7)
2001	0.1 (–1)	3.2 (0)
1948–2001 (overall change)	(–3.1)	(–0.9)

The number in parentheses indicates the change in distance in relation to preceding year.

with an overall increase in length by 3% and consequent increase in sinuosity by 15% (Table 2).

Changes in channel area: Channel area also oscillated during the study period with a significant net gain of 96% (Table 2). The maximum gain occurred during the period 1948–1965 when the channel area increased by more than double (55%).

Changes in island number and area: The net loss of six islands and 29% in their area occurred during the entire assessment period (Table 2).

Changes in floodplain vegetation

The following land use/cover categories were identified: sal forest with an overstory of *Terminalia alata*, *Lagerstromia speciosa* and *Mallotus philippensis*; mixed deciduous forest dominated by *Mallotus philippensis*, *Syzygium cumini* and *Trewia nudiflora*; Grasslands in low lying water logged areas with *Saccharum spontaneum*, *Sclerostachya fusca* and *Phragmites karka* grasses; khair and sissoo forests on new sandy alluvium; agriculture and habitation. Sand bars on newly created silt deposits and water. The overall accuracy was 80% and overall Kappa statistics was 0.7.

Changes in woodland (sal forest, mixed deciduous forest and khair–sissoo forests): Due to the shift of entire channel towards south-west during the 42 years separating 1948 and 1990, complete loss of 4.8 sq. km area of sal forest on the north-eastern boundary of KWLS was registered resulting in disappearance of this category (Table 3, Figure 5). New land cover categories of mixed deciduous forest, and khair and sissoo forests were noticed in 1990 in the channel abandoned area.

Changes in grassland, sand bar and water: Grasslands suffered a net loss of 3% during entire assessment period of 53 years (Table 3). The sand bar and water increased by about 3% and 7% respectively, during entire assessment period. There was continuous increase of water during entire assessment period (Table 3).

Changes in agriculture and habitation: The considerable shift of channel towards south-west during 1948–1990 led to loss of large area of habitation and agriculture along KWLS boundry (Figure 5). The abandoned area formed on north-east side experienced the expansion of agriculture to make the net gain to the extent of 12% (Table 3, Figure 5). During 1990–2001, there was loss along both east and west bank line, leading to net loss. Despite the loss, the net gain during entire assessment period was about 5%.

Locational probability model

The LPM revealed that 51% of the study area had a low probability of the channel remaining in that

Table 2. Channel length, sinuosity, area, and island number and area in the Sharda River from 1948 to 2001

				Islands	
Year	Length (km)	Sinuosity	Area (sq. km)	No.	Area (sq. km)
1948 (base year)	8.83	1.02	5.7	7	5.5
1965	8.10 (–8)	0.93 (–9)	12.3 (+55)	5	5 (–9)
1977	11.14 (+37)	1.29 (+39)	12.1 (–15)	4	3 (–40)
1990	9.69 (–13)	1.26 (–2)	9.4 (–22.3)	1	0.8 (–73)
1999	10.11 (+4)	1.31 (+4)	10.4 (+11)	1	0.4 (–50)
2001	9.06 (–10)	1.17 (–11)	11.2 (+8)	1	3.9 (+875)
Difference 1948–2001	0.23 (+3)	0.15 (+15)	5.5 (+96)	6	1.6 (–29)

Values in parentheses are the percentage change in relation to the preceding year.

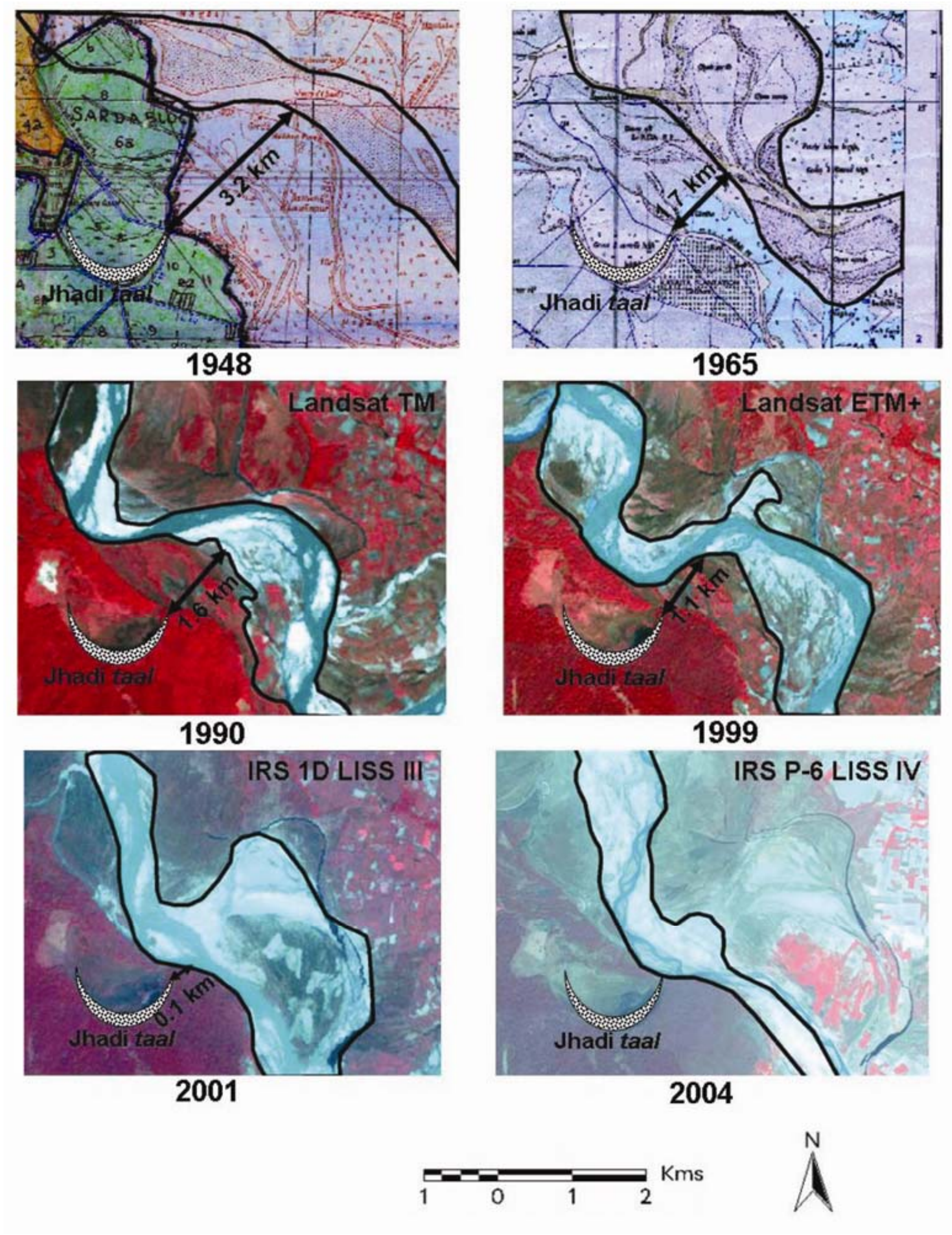

Figure 4. Toposheets (1948 and 1965) and digital images (1990, 1999, 2001 and 2004) of the study area showing consistent shift of Sharda River towards Jhadi *taal*.

Table 3. Areal and percentage (parentheses) of changes in land use/cover categories in a 41.3 sq. km area of the Sharda River floodplain

Land use/cover categories	Change in area 1948–1990 (sq. km)	1990–2001 (sq. km)	1948–2001 (sq. km)
Sal forest	4.8 (–12)	*	4.8 (–12)
Mixed deciduous forest	2.7 (+7)	2.1 (–5)	0.6 (+2)
Grassland	3.0 (–7)	1.8 (+4)	1.2 (–3)
Khair and sissoo forests	1.8 (+4)	1.2 (–3)	0.5 (+1)
Agriculture and habitation	5.1 (+12)	3.1 (–8)	2.0 (+5)
Sand bar	2.3 (+6)	1.0 (–3)	1.2 (+3)
Water	0.8 (+2)	2.0 (+5)	2.9 (+7)

*Absence of category.

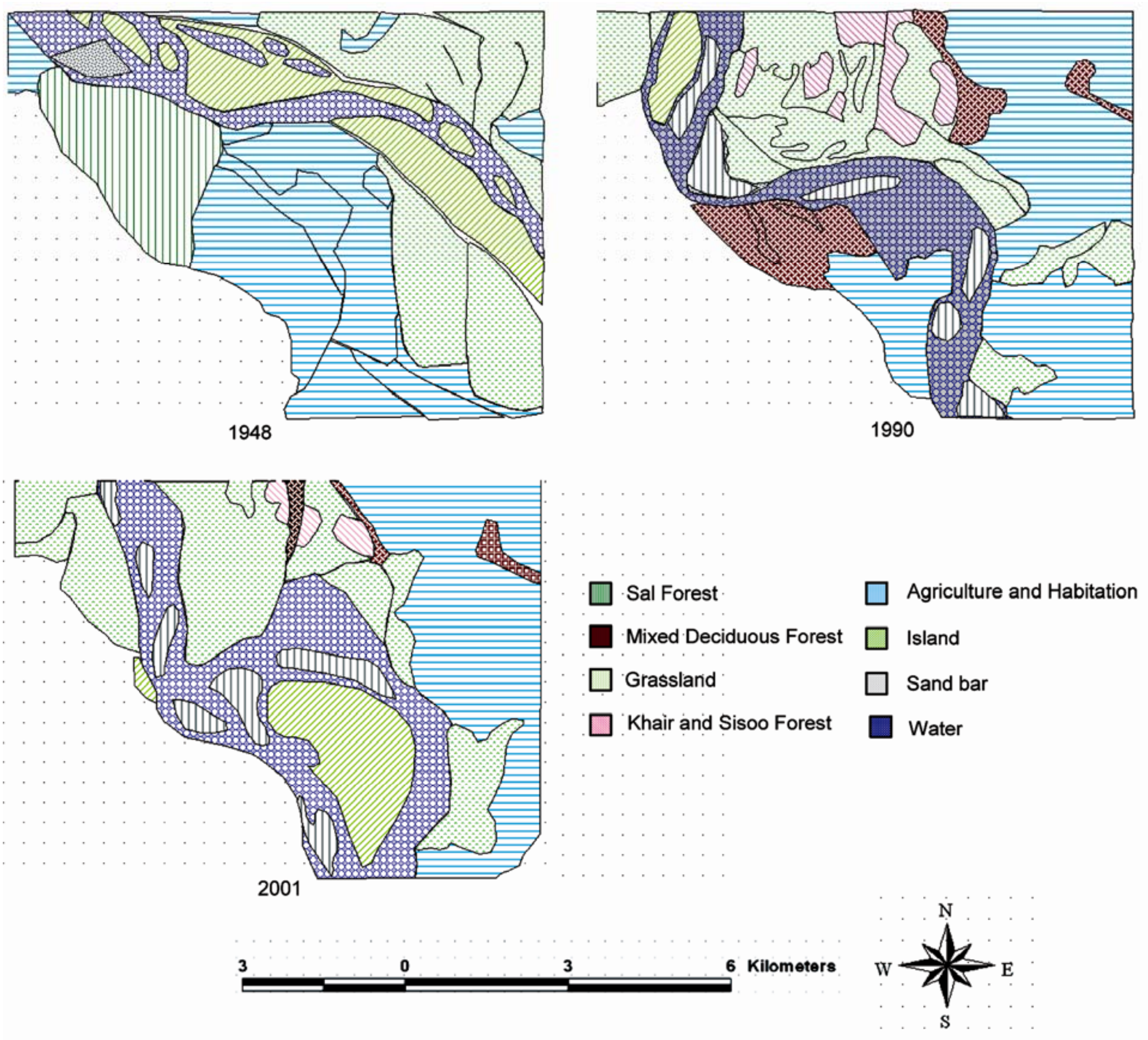

Figure 5. Land use/cover patterns in the floodplain of the Sharda River near Jhadi *taal* during 1948, 1990 and 2001.

location, indicating channel instability. Forty-five per cent of the study area had moderate probability of being continuously occupied by the river channel, thus moderate stability. Only 4% of the area had a high probability of being continuously occupied by river channel, indicating channel stability.

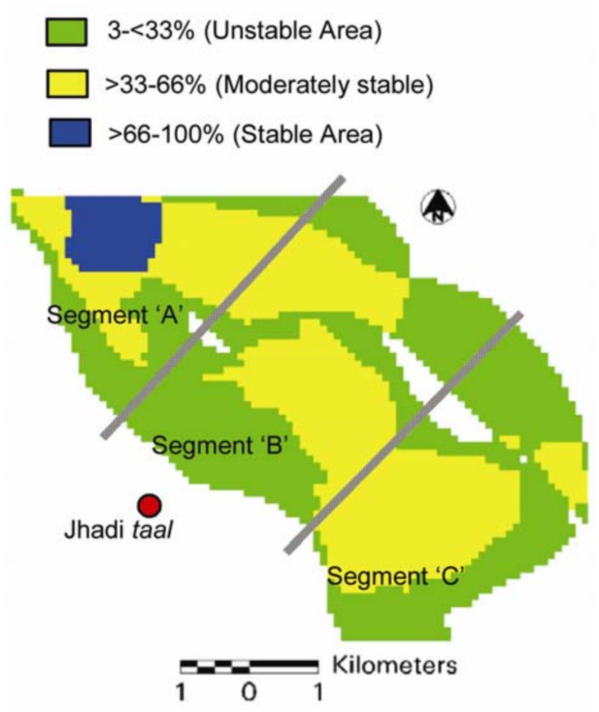

Figure 6. Probabilities of channel stability based on a locational probability model for the Sharda River channel adjacent to Jhadi *taal*.

The only stable area of river channel was in segment 'A' upstream from Jhadi *taal* (Figure 6). Segment B was closest to Jhadi *taal*, the unstable area was found to be maximum in this segment and indicated continuing instability. Segment 'C' had its maximum area under moderately stable category.

Discussion and conclusion

Channel migration of the Sharda River is one of the drivers of the dynamic Terai ecosystem in DTR that maintains its unique woodland–grassland–wetland complex. However, rapid river channel changes have made future of Jhadi *taal* and swamp deer precarious.

Results showed the instability and continuous shift of Sharda River channel towards Jhadi *taal*. This instability brought the west bank line closer to Jhadi *taal* by 100 m in 2001 and is posing a potential threat to it. It was accompanied by net gain in both length and sinuosity which pointed towards increased meandering. The first prominent alteration took place during 1948–65 when area of the channel got double and west bank line shifted towards *taal* by 1.5 km. The second major alteration took place during 1999–2001, again when west bank line moved towards *taal* with massive 1 km shift, channel area also increased but as a new island was formed during this period, only 8% of increase in channel area got registered (see subsection on changes in channel length, area and sinuosity).

One interesting fact that was revealed is that east bank line remained more stable during the assessment period. Probable reasons could be local altitudinal variation as evident in toposheets of 1948 and 1965, the presence of agricultural lands and habitations along the western bank of the Sharda River might have posed the least resistance to bank erosion and channel expansion. Raj *et al.*[16] also observed that the course of the Vishwamitri River, a meandering river of Gujarat has shifted towards east between 1969 and 2003. They inferred that eastward tilting of the area is responsible for eastward migration of the river.

Thus, the results showed that the west bank line of the Sharda River in the studied section had been relatively unstable as compared to the east bank line, meandering was increasing and drastic increase in channel area led to major shifts in the west bank line. Marston *et al.*[3] found that changes in the water release schedule of Jackson Lake Dam on the Snake River near Grand Teton National Park, USA, triggered changes in river channel sinuosity and rate of lateral channel migration. Similarly, Mount[17] also associated increasing instability towards increase in sudden water discharge from upstream. He elucidated that with the increase in the frequency of flooding, depositional, rather than erosional processes act to expand the channel capacity and when discharge exceeds the channel capacity of the river, there is a dramatic increase in cross-sectional area associated onto the floodplain. In the context of Sharda River, increasing trend in water and net gain in sand bar also pointed towards enhanced flooding and more silt from upstream. The net gain of 96% in channel area again supported the results.

Net loss of valuable sal forest along KWLS and important habitat of grassland owing to the relocation of Sharda River channel occurred during 53-year of the assessment period. The sal was the victim of major alternation of 1948–65 period. In subsequent years, the presence of mixed deciduous forest, khair and sissoo forests in the abandoned areas after the shift indicated progression of natural succession. To avoid encroachment of this land, the Forest department sometime undertakes plantations of khair and sissoo. Despite this, the abandoned areas outside the sanctuary are encroached, as evidenced by net gain in agriculture and habitation despite significant loss along both east and west bank line. These areas were otherwise supposed to undergo natural succession to develop new habitats for faunal species.

The LPM supported our observation of threat to Jhadi *taal* in the near future by showing the presence of unstable area in segment 'B' which was nearest to Jhadi *taal*. Tiegs and Pohl[11] viewed LPM as a disturbance probability model because it depicts how frequently an area is cleared of its vegetation. Thus, the channel would again shift from this area and chances are that it will shift towards Jhadi *taal*.

Implications for conservation

At present, the population of swamp deer in Jhadi *taal* is surviving. If the *taal* gets flooded, it will be total loss of habitat for swamp deer, even if it gets only inundated or drained by cutting of bank by river, it would lead to sedimentation and siltation that would choke the lake. Ultimately, swamp deer would be forced to migrate in search for new suitable habitat. This population will become vulnerable to poaching, if it moves for habitat outside the protected area. Several workers have recognized poaching as the main cause of decline in swamp deer population in Dudhwa National Park, a part of DTR[7,18].

Another mooted issue is that a new suitable habitat eventually may be formed, just as Jhadi *taal* was created as an oxbow lake several years ago by channel migration. However, it may take several years for habitat to develop around a new *taal* and for the recovery of the lost faunal population. In one such case, Hastie *et al.*[19] reported decline of endangered freshwater pearl mussel (*Margaritifera margaritifera*) population in the Kerry River, Scotland by 4–8% after the major flood of 1998, and that the mussel population may now be at a greater risk of extinction.

The increasing instability, widened channel area, enhanced water and silt pointed towards the changing flow regime and sediment dynamics in the upstream region of the Sharda River. The probable reasons could be incessant land-use changes and river engineering works upstream[8,9]. The relative importance and effect of these man-made activities with respect to the channel dynamics require attention.

The distance between *taal* and river channel is further reducing (Figure 4) and it has reduced to less than 10 m as observed in 2008. For a critically endangered species like the swamp deer, this risk could prove fatal. Thus, it is hoped that the authorities will take some mitigation measures to save this remnant population from extinction.

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ACKNOWLEDGEMENTS. We thank Mr P. R. Sinha, Director, WII and Dr V. B. Mathur, Dean, WII for advice and support. We also thank Dr Manoj Agarwal for technical support in GIS work and senior forest officials of Uttar Pradesh Forest Department for their help in field logistics. Dr John Lehmkuhl, US Forest Service, provided valuable comments on the manuscript.

Received 3 April 2009; revised accepted 11 January 2010