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ORIGINAL ARTICLE

Fish community and habitat diversity profiling of Luni, an ephemeral saline river from Thar Desert of India for conservation and management

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Abstract
'Luni' is an ecologically fragile and ephemeral saline river of socio-economic significance for indigenous peoples of the Thar Desert, India. The present study aims for mapping the ichthyofaunal diversity of an unexplored river Luni and its relationship with habitat parameters based on field surveys conducted from October, 2018 to November, 2019. The diverse habitats of river Luni support 27 fish species and the highest diversity was recorded from midstream segment (19 species) followed by downstream (14 species). The index of diversity ($H' = 2.35$) and dominance ($D = 0.133$) indicated rich fish diversity and even distribution. The relational analysis of habitat variables with abundance of cyprinids revealed, altitude and oxidation reduction potential as the key drivers for its distribution in the upstream segment of the river. This study provides an evidence for establishment of invasive species especially *Oreochromis mossambicus* and its impact on the fish assemblage structure of arid river Luni. The major anthropogenic factors threatening biodiversity and pristine habitats are mining, release of effluents and excess canal water, unplanned developmental activities in the riparian corridor and establishment of non-native species. The baseline information generated on fish assemblage pattern and habitat status of the river Luni can assist in formulating strategies for the conservation and management of this riverine ecosystem to support the livelihood of local communities.

Keywords Ephemeral river · Fish diversity · Invasive species · Luni River · River habitat · Rajasthan

Introduction

Luni River is the only integrated river in the Thar region, the great desert of the Indian subcontinent and receives drainage from the west of Aravalli ranges (Laity 2009). The river flows restricted and is mostly dry, except the rainy season (Banyal and Kumar 2014). Occasionally the river has caused catastrophic floods as in 1979, widening from 40–500 to 500–1360 m (Dhir et al. 1982). The river derives its name from word 'Lun' meaning salt and therefore termed as 'Salt River'. Irrespective of high salinity, this river serves as a primary source of irrigation for cultivable and culturable command areas (1.66 million ha) in western Rajasthan (Bohra 2007). The spatial variation in the salinity gradient of the river Luni attributes it a unique habitat for its biodiversity. Amarasinghe et al. (2004) classified Luni river basin as a physically water scarce and food deficit basin. The changing climatic conditions and anthropogenic activities pose multiple challenges to such tropical arid intermittent riverine ecosystems and the diversity they harbour. Good scientific ecological understanding of such systems are needed to implement adequate management practices (Datry et al. 2014). The major threats associated with the Luni river basin are extraction of surface and ground water, mixing of industrial effluents along with other wastes in the river water, change in the land use land cover pattern, destruction of riparian vegetation, siltation and sedimentation due to river bank erosion, change in the river bed ecology and invasion

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of non-native species (Singh et al. 1988; Vats and Singh 1991; Bohra 2007; Rathore 2011; Mohan and Ramkishor 2013; Banyal and Kumar 2014).

Studies on fish diversity patterns, connectivity of populations and their determining factors are useful to understand ecosystems and their functioning and the arid zone rivers often have fragmented populations and diversity (Murphy et al. 2015). India has diverse ecological and biological diversity and reports about 9.5% of global fish diversity (AqGRISI 2019; Froese and Pauly 2019). The state of Rajasthan which is an arid region of India has four major river basins viz, Chambal, Mahi, Luni and Ghaggar. River Chambal flows east to Ganga river basin and rest three are west flowing rivers and Luni is the only ephemeral system. Majority of the reports on fish diversity are checklists for the rivers of Rajasthan, including Luni, for the number of species found. A survey report of Zoological Survey of India lists 75 fishes from the Rajasthan state (Datta and Majumdar 1970). Thereafter, many workers have updated the fish diversity of this region and few of them are: 95 fish species (Johal et al. 1993); 145 species (Srivastava 2007) and 146 species (Sharma and Choudhary 2007). A comprehensive checklist by Mohan and Ramkishor (2013) reports the occurrence of 160 fish species from various aquatic systems of Rajasthan. The river Luni has been studied extensively for various geological and climatological aspects including the occurrence of flash flood events (Sharma 1997; Dhir et al. 1982; Moharana and Kar 2013). The fish diversity of Thar Desert is an admixture of Western Himalaya, Aravalli hills, Peninsular India and the Middle East components (Yazdani 1996).

The Luni river basin is known for its diverse freshwater and brackishwater ecosystems comprising of rivulet, stream, reservoir, lake, seasonal pools, saline and marshy wetlands etc. (Jain et al. 2007; Bohra 2007). The keyword search (Luni *AND* Fish) in '*TOPIC*' field of 'basic search' in Web of Science (https://apps.webofknowledge.com/), a database of indexed journal revealed that the river Luni was not studied for its fish diversity at least for the past 20 years (1999–2019). However, a few reports on fish diversity of this river are available from some selected locations, which documented a total of 8 fish species (Banyal 2012a, b; Banyal and Kumar 2014). All these studies oblige the importance of a comprehensive study on fish and habitat diversity of river Luni and their association by field surveys and explorations. The studies and documentation of this river ecosystem also deserve attention as it receives intermittently excess water from the Narmada River, since a decade, through a man-made canal and can risk by changing the unique natural ecosystem. Furthermore, the proposed inter basin water transfer project *i.e.* Rajasthan-Sabarmati Link Project will cross the river Luni and its tributaries upon its implementation (HWRISI n.d.). The base line data on habitat status and fish diversity of a riverine ecosystem is a prerequisite for the future impact assessment of any river projects which is anticipated to change the habitat ecology and fish assemblage (Joshi et al. 2017).

Considering the growing anthropogenic threats to the fish diversity of this unique river system and its ecological and socio-economic significance to the Indian arid zone, the present study was done with objectives; to characterize the unique habitats of river Luni along with its land use pattern; record the diversity, distribution pattern and conservation status of fish communities and its association with habitat parameters; assess the occurrence of non-native fish species and other associated threats in the Luni river basin for conservation and management.

Materials and methods

Study area

The Luni river basin including west flowing rivers of Kutch and Saurashtra extends from 20° 53′ to 26° 57′ N latitude and 67° 52′ to 75° 19′ E longitude in which the upper Luni basin covers 70,202 km^2 area (Fig. 1). The river Luni is originating from Pushkar valley, Rajasthan and the total length is 462.5 km. The spatial difference in the salinity gradient of the river Luni provides a unique habitat to its biodiversity. Luni often termed as 'salt river' because of increased salinity in the middle and downstream of the river course than the upstream region (Hunter 1908; GWDR 2013). The banks of the river Luni are highly loose and easily erodible, thus the width of the river increases during the peak flood flow period (Singh et al. 1988; Banyal and Kumar 2014). The main left bank tributaries of this ephemeral river are Lilari, Guhiya, Bandi, Sukri, Hemawas, Mithri, Jawai, Bandi and Sugi, while Jojari joins on the right bank (MoWR 2014). The river water from the upper basin gets bifurcated into several small streamlets before it spread out into the head region of Rann of Kutch (*i.e.* Luni lower basin), though the delta formation is defunct (GWDR 2013). The topography of this basin is highly varying and major part falls under the elevation range 10–300 m above the mean sea level. The climate in the basin is semi-arid and the temperature ranges from 2 to 46 °C. The rainfall pattern is erratic (300–500 mm) and shows uneven spatio-temporal distribution, which means that 90% of the rainfall is received during monsoon season. The entire Luni basin falls under Hot arid ecoregion with desert and saline soils prone to moderate-severe erosion, and thus it exports huge sediment to the downstream area (MoWR 2014).

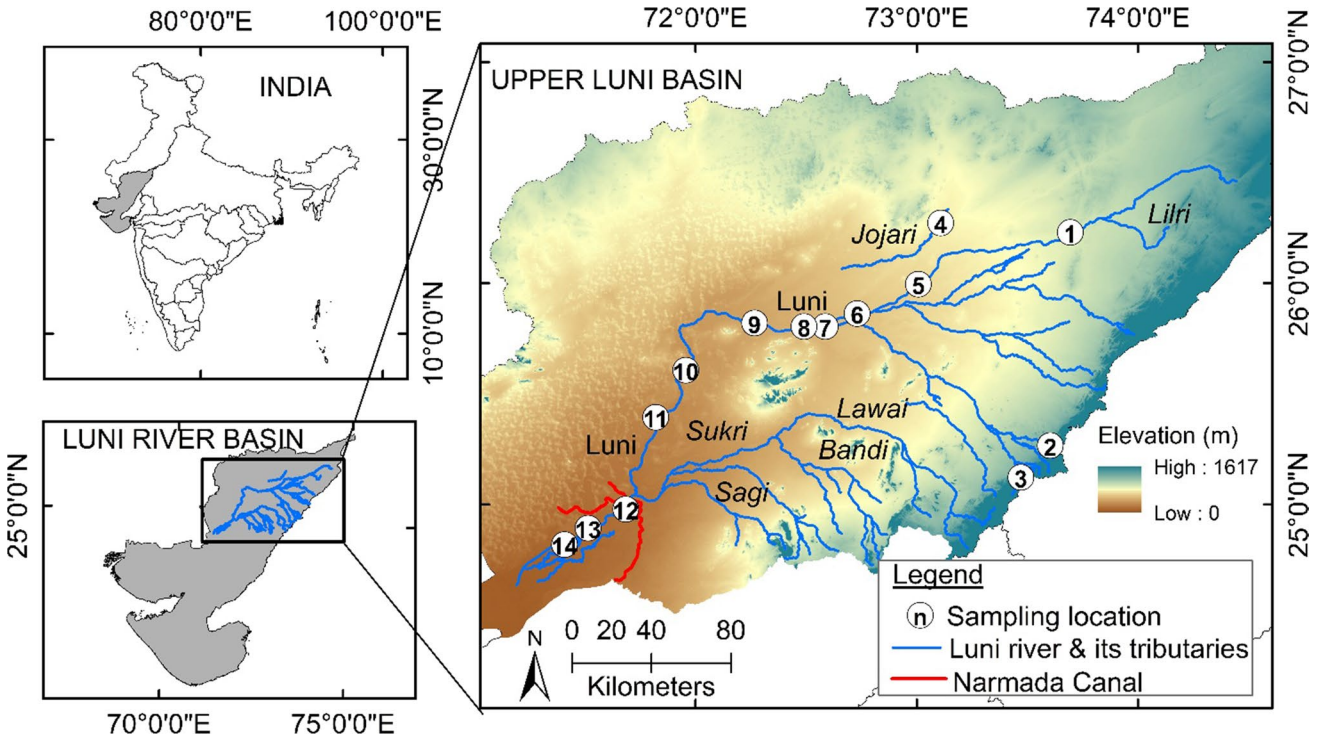

Fig. 1 Map showing the sampling sites in the Luni river basin, India. [Details of the sampling locations: Upstream: (1) Jaswant Sagar Dam, (2) Desuri, (3) Ranakpur; Midstream: (4) Jodhpur (Jojariya river), (5) Luni village, (6) Dundhara, (7) Samdhari, (8) Jethantri, (9) Balotra, (10) Nakora, (11) Bhatala; Downstream: (12) Gandhav, (13) Doodhwa, (14) Surachand]

Data collection

The present study covers the entire stretch of the river Luni from origin at Pushkar valley to the confluence at Rann of Kutch for survey and sampling. After preliminary survey based on the dissimilarity in the habitat pattern and accessibility, the whole stretch of this river was divided into three different zones for sampling and data collection purposes (1) Upstream zone: Pushkar to Luni; (2) Midstream zone: Luni to Gandhav; (3) Downstream zone: Gandhav to Rann of Kutch (Fig. 1). A total of 14 sampling sites were selected in all the zones by taking into the consideration of equal representation from each habitat type. Field surveys were conducted during the monsoon season from October, 2018 to November, 2019. The geographical coordinates of the sampling sites were collected using the handheld Global Positioning System (eTrex Vista HCx, Garmin, USA). The elevation map of this basin was created in ArcMap 9.3 platform using the SRTM DEM datasets (30 m) downloaded from USGS Earth Explorer (https://earthexplorer.usgs.gov/). The river network shape file has been prepared using satellite images of Google Earth platform, and river basin shape file was obtained from NRSC India-Water Resource Information System (https://indiawris.gov.in/wris/).

During the fish sampling, physical and chemical parameters of water such as temperature (°C), pH, salinity (ppt), oxidation–reduction potential (mv), dissolved oxygen (ppm), conductivity (mS/cm), total dissolved solids (ppm) were recorded using the sensor-based multi-parameter equipment (Hanna instruments Ltd., UK). These parameters were recorded for each site in a standard data collection sheet prepared by ICAR-NBFGR, Lucknow, which includes wetted area, channel width, water substrate, aquatic as well as riparian vegetation characteristics and water depth. The characteristics of substrate materials and water depth for each sampling site were determined by inspection and striking the river bottom with a wooden pole.

Experimental fishing was done in all selected sampling sites along the river stretch by hiring the local fishermen. Fishing was done during day time (08:00 h–17:30 h) by using various fishing gears like gill nets of different mesh sizes (2.5 × 2.5, 4 × 4, 7.5 × 7.5 cm), cast nets (1 × 1, 2.5 × 2.5 cm), hapa and push nets. Each gear was operated at least 5 times in each sampling site covering different habitats like river margin, pools and marshy areas.

Data analyses

All the specimens collected by experimental fishing were identified using standard taxonomical guides like Jayaram (1981, 1999). The numerical and biological parameters such as species-wise specimen count, and length and weight of

specimens were recorded in the field, respectively. The representative specimens of each species were preserved using 10% formalin and brought to the laboratory for further confirmation. Fish species nomenclature was confirmed using Fishbase (Froese and Pauly 2019), and the conservation status of the reported species was assessed using the IUCN Red List of Threatened Species—Version 2019-3 (IUCN 2020). The information on utilization of fishes were collected from interaction with fishermen during the field survey and online databases like IUCN and Fishbase.

The univariate measures viz, Shannon and Wiener diversity index (H') (Shannon and Wiener 1963), Margalef's species richness (d) (Margalef 1978), Pielou's evenness index (J') (Pielou 1966) and Simpson's dominance index (D) (Simpson 1949) were calculated to analyse fish species diversity at each site in the river Luni. The variation in the fish structure assemblage for each site was evaluated by a dendrogram constructed using the presence–absence and abundance matrix of the fish species. This was done by using the multivariate clustering method as a grouping analysis based on the Bray–Curtis similarity index. Canonical Correspondence Analysis (CCA) is a multivariate method, which helps in understanding the differential habitat preferences of a biota and environmental parameters that influences the abundance through an ordination diagram (ter Braak 1986; ter Braak and Verdonschot 1995). Both univariate and multivariate analysis on the fish and habitat data were performed using the PAST programme (v. 3.26) following Hammer et al. (2001).

Results

Habitat characterization

The habitat characteristics and associated land use patterns of the sampling sites located in various zones of the river Luni are presented in Table 1.

The water flow in the upstream zone of the river Luni entirely depends on the rainfall. The shallow water pools and slow water riffles are the most commonly observed habitat types in the hilly upstream region. The substrate is dominated by boulders, cobbles and pebbles. The wetted channel width of the river ranged between 4 and 15 m and depth from 0.3 to 0.8 m. The habitat in the midstream segment of the river is characterized by slow moving water and the presence of shallow and deep water pools while the substrate is dominated mostly by sand and gravels. The land use patterns are mainly semiurban, agriculture, shrub land, saline areas and industrial activities like textile processing, dyeing and printing industries. The wetted width of the river bed ranged between 5 and 250 m. The downstream segment of the river is characterized by shallow and slow moving water with fewer pools. The dominant substrate categories in the downstream are silt and clay and the land use pattern is mainly dominated by agriculture and shrub lands. Moreover, divergence of the river into small streamlets with decrease in the width of channel was noticed after Gandhav.

A high degree of variation in the salinity of water was reported across different zones of this river. The salinity of river water in the upstream zone was reported < 0.5 ppt and thereafter a rapid rise in the salinity were observed in the midstream region, where water reaches to the plain area. The highest salinity was observed at Luni village (9.15 ppt) followed by Dundhara (7.41 ppt) (Table 2). The water salinity in the downstream was reported between 2.42 to 5 ppt. pH of the river water ranged from 6.65 to 9.25 and the lowest value was reported from the upstream segment. The dissolved oxygen was observed higher in the sampling sites of midstream and downstream zones than the upstream of the river. The lowest dissolved oxygen was found at Jodhpur (1.85 mg/l) in the Jojaria River, which is a right bank tributary of the river Luni. The higher values of water conductivity (15,700 mS/cm) and total dissolved solids (TDS) (7833 ppm) were reported from the sampling sites of the middle (Luni village) and downstream zones of the river. The oxidation reduction potential (ORP) (mv) value was found to be higher in the sampling sites located in the upstream zone ranging from 145.3 to 247.6 mv while the lowest value was recorded at Jodhpur (midstream).

Habitat use pattern by fish assemblage

Fishes of Cyprinidae were taken for plotting species abundance-environmental variables biplot ordinance diagram because of the highest dominance of the species of this family for 13 sites (except Jodhpur). Eigenvalues of axis 1 and 2 derived from the Canonical Correspondence Analysis (CCA) from the data of the environmental variables and fish species abundance accounted to 0.77 and 0.51, respectively. The biplot thus constructed by CCA indicates that altitude and oxidation reduction potential (ORP) are the influencing variables for the axis 1 while water temperature and conductivity are the influencing factors for the axis 2. The abundance of cyprinid fishes in relation to environmental variables in the ordinance space is depicted in Fig. 2. This indicates that abundance and distribution of cyprinids in the sampling sites of the upstream zone viz., Desuri (2) and Ranakpur (3) are influenced by altitude and ORP.

Fish species assemblage and distribution

Fish diversity assessment

The fish diversity assessment of an ephemeral river Luni, revealed a distribution of 27 species belonging to 22 genera

Table 1 Details of the sampling sites of Luni River, India along with its habitat parameters and associated land use patterns

Stream segment	Sampling site	Geographical coordinates	Altitude (m)	Land use type	Habitat type and depth (m)	Dominant substrate type	Actual and wetted Width of river channel (m)
Upstream	Jaswant sagar	26° 13′ 30.4212″N 73° 41′ 25.3536″E	272	Reservoir-water body; agriculture land; small dam/ weir; fishing	Shallow water, pool type; 0.2	Silt & Clay > Gravel	–
	Desuri	25° 15′ 49.0212″N 73° 36′ 9.0612″E	428	Forest area; small check dam	Riffle, slow water; 0.3	Boulders > Cobbles > Pebbles	45/4
	Ranakpur	25° 7′ 1.6032″N 73° 28′ 13.926″E	427	Wildlife sanctuary; protected area; forest; no fishing activities	Riffle, slow water; 0.8	Boulders > Cobbles > Pebbles	75/15
Midstream	Jodhpur	26° 16′ 12.0648″N 73° 6′ 27.9648″″E	204	Urban area; industrial effluents and sewage	Shallow water pool; no water flow; 0.8	–	–
	Luni village	25° 59′ 44.4444″N 73° 0′ 43.884″E	175	Semi urban area; agriculture area; Saline area	Shallow water, slow water; 0.6	Cobbles > Gravel > Sand	250/150
	Dundhara	25° 51′ 30.8988″N 72° 44′ 42.54″E	144	Rural; agriculture area; no fishing activities	Riffle, slow water; Pool; 0.2	Sand > Gravels	600/10
	Samdhari	25° 48′ 1.6812″N 72° 34′ 42.5388″E	129	Semi urban; agriculture area; shrub land; water extraction; fishing	Shallow water pool; slow water; 2	Sand > Gravel > Pebble	450/250
	Jethantri	25° 47′ 50.32″N 72° 29′ 27.88″E	124	Rural; agriculture area; wasteland; shrub area; fishing	Shallow water pool; 1	Sand > Silt & Clay	450-550/water only in pools
	Balotra	25° 48′ 53.7624″N 72° 15′ 56.5992″E	118	Semi urban; agriculture area; shrub land; industrial activities; fishing;	Deep water pool; slow water; 1.25	Silt & Clay > Sand	350/200
	Nakora	25° 36′ 8.2836″N 71° 57′ 16.0704″E	71	Rural; agriculture area; wasteland; shrub area;	Shallow water; Riffle; 0.5 m	Sand > Pebble > Gravel	80/5
	Bhatala	25° 23′ 22.2108″N 71° 49′ 35.1408″E	50	Rural; agriculture area; wasteland; shrub area;	Shallow water; pool; 0.6 m	Sand > Gravel	350; water only in pools

Table 1 (continued)

Stream segment	Sampling site	Geographical coordinates	Altitude (m)	Land use type	Habitat type and depth (m)	Dominant substrate type	Actual and wetted Width of river channel (m)
Downstream	Gandhav	24° 59′ 15.612″N 71° 40′ 47.5176″E	32	Rural; agriculture area; shrub area	Deep water pool; slow water; 2.25	Silt & Clay	450/250
	Doothwa	24° 53′ 15.8388″N 71° 30′ 36.2412″E	20	Rural; agriculture area; shrub area	Shallow water; slow water; 0.7	Silt & Clay	120/70
	Surachand	24° 48′ 55.26″N 71° 25′ 8.8788″E	18	Rural; agriculture area; shrub area	Bifurcated small stream; slow water; 0.5	Silt & Clay > Gravel	70/35

Table 2 Physico-chemical parameters of water quality in surveyed sites during monsoon season along the Luni River, India

Stream segment	Sampling site	Water Temp. (°C)	Salinity (ppt)	pH	DO (mg/l)	Conductivity (mS/cm)	TDS (ppm)	ORP (mv)
Upstream	Jaswant sagar	31.51	0.06	7.85	3.4	142	71	145.3
	Desuri	24.81	0.27	6.65	2.97	570	284	247.6
	Ranakpur	24.41	0.25	7.34	5.6	529	263	237.6
Midstream	Jodhpur	31.55	1.35	7.74	1.85	2651	1325	-310.9
	Luni village	24.66	9.15	8.82	8.25	15,700	7833	105.6
	Dundhara	24.58	7.41	8.74	8.1	12,900	6450	112.6
	Samdhari	25.67	4.73	8.49	5.71	8490	4253	141.4
	Jethantri	22.22	1.41	8.17	4.99	2717	1357	87.7
	Balotra	24.55	2.87	9.25	6.58	5346	2664	93.5
	Nakora	23.07	7.40	7.95	4.56	4697	6433	155.6
	Bhatala	21.65	3.09	8.6	6.74	5689	2848	124.1
Downstream	Gandhav	28.24	2.42	8.38	8.22	4439	2292	140.1
	Doothwa	28.98	3.13	8.50	9.2	5816	2908	121.4
	Surachand	25.59	5.00	8.43	6.36	8858	4495	118.4

of 12 families. Cyprinidae is the richest family in terms of species diversity (12 species) followed by Ambassidae (3 species). Family-wise distribution of fish species reported from the river Luni in the present study is depicted in Fig. 3. The number of species in the sampling locations ranged from 0 (Jodhpur) to 12 (Samdhari and Gandhav). The highest species diversity was reported in the midstream (19 species) followed by the downstream zone (14 species) of the river (Table 3). The estimated diversity index (H') and dominance index (d) value of the river Luni were 2.35 and 0.13, respectively. Among the sampling sites, high value of the diversity and richness index was reported in the midstream ($H' = 1.95$; $d = 2.81$) followed by the downstream ($H' = 1.86$; $d = 2.51$). The distribution of fish species was found to be more even in the upstream ($J' = 0.79$) than mid and downstream zones. The dominance index was estimated lowest in the upstream ($D = 0.179$). The higher values of diversity index (H') were reported from midstream at locations Bhatala (1.87) and Samdhari (1.62) than downstream at Gandhav (1.56). The site-wise fish assemblage structure details are given in Table 3.

Fish species distribution and Conservation status

The commonly distributed species are *Gibelion catla* and *Systomus sarana*, while the most abundantly distributed species are *Aphanius dispar* and *Salmostoma bacaila* (Table 3). The species like *Rasbora daniconius*, *Garra gotyla* and *Acanthocobitis botia* are restricted to the upstream zone. Similarly, the catfish species such as *Sperata seenghala*, *Mystus gulio*, *Wallago attu* and snakehead (*Channa punctata* and *C. marulius*) are distributed

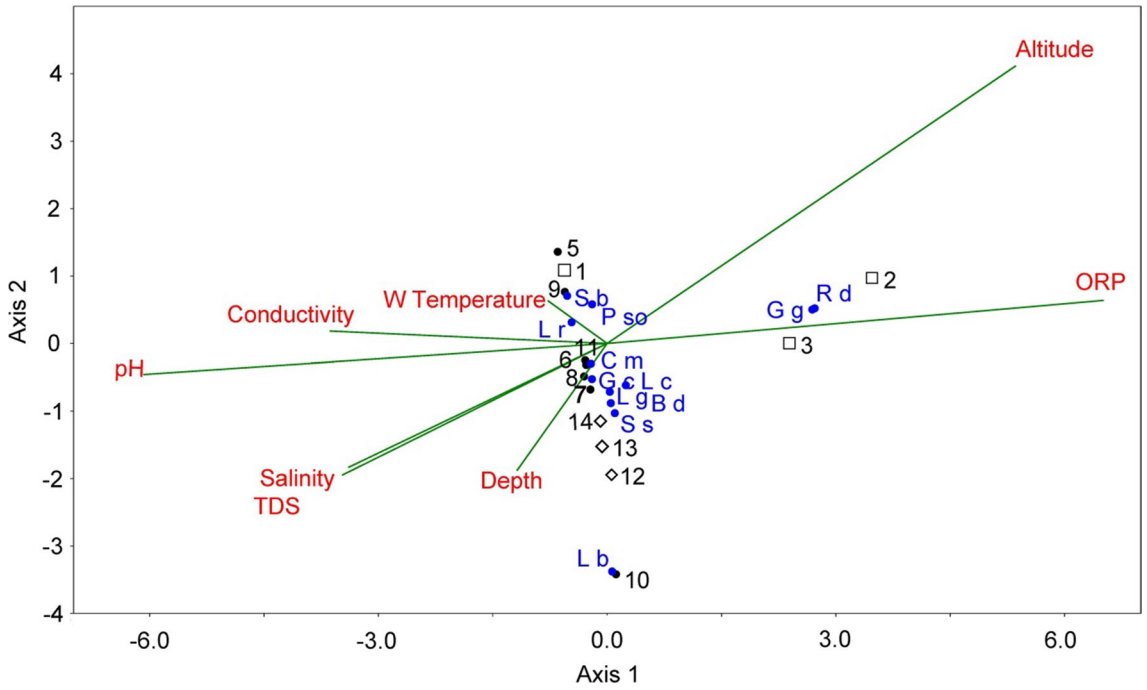

Fig. 2 Canonical corresponding analysis (CCA) ordination diagram displaying the effect of significant environmental factors on cyprinid fishes in 13 sampling sites in Luni river basin, India. [Site labels: Upstream: Square shape: 1-Jaswant sagar Dam; 2-Desuri; 3-Ranakpur; Midstream: Black Dot shape: 4-Jodhpur; 5-Luni village; 6-Dundhara; 7-Samdhari; 8-Jethantri; 9-Balotra; 10-Nakora; 11-Bhatala; Downstream: Diamond shape: 12-Gandhav, 13-Doothwa; 14-Surachand. Species codes: B.d—*Bangana dero*; C.m—*Cirrhinus mrigala*; G.c—*Gibelion catla*; G.g—*Garra gotyla*; L.b—*Labeo boggut;* L.c—*Labeo calbasu*; L.g—*Labeo gonius;* L.r—*Labeo rohita*; R.d—*Rasbora daniconius*; P.s—*Puntius sophore*; S.s—*Systomus sarana*; S.b—*Salmostoma bacaila*]

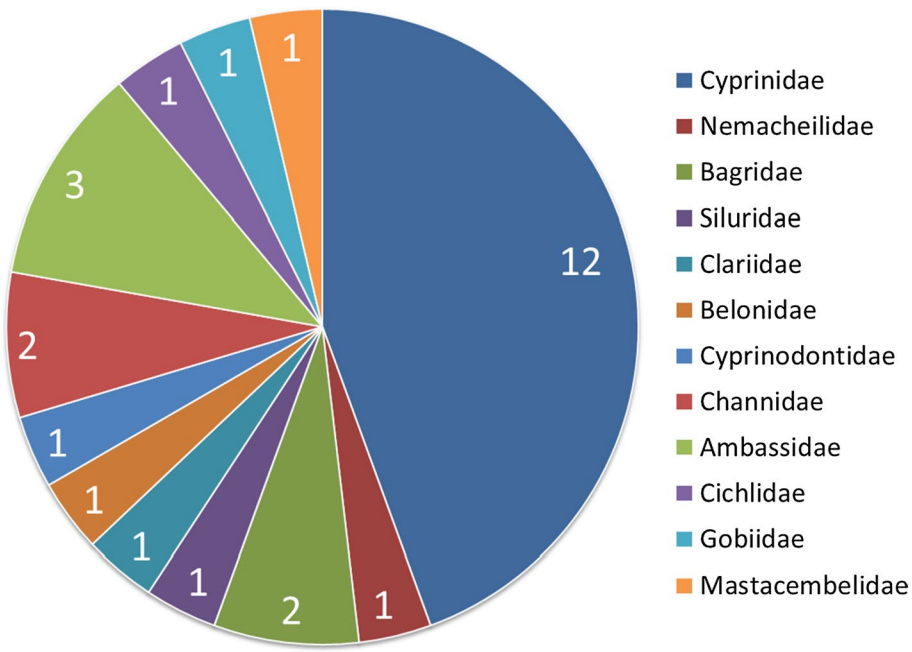

Fig. 3 Family-wise distribution of number of fish species reported from the Luni River, India in the present study

only in the mid and downstream zones. Arabian toothcarp *Aphanius dispar*, which is a killifish species, was recorded abundantly in the pools of Luni village, Dundhara, Balotra and Nakora in the midstream zone. In the present study, it was also observed that some of the freshwater species such as *Gibelion catla, Cirrhinus mrigala*, *Puntius sophore*, *Systomus sarana*, *Labeo boggut*, *L. calbasu*, *Bangana dero*, *L. gonius*, *L. rohita*, *Sperata seenghala* and *Wallago*

Table 3 Zone-wise fish assemblage structures of survey sites along the Luni River, India

Stream segment	Sampling site	No. of species	Abundant fish species	Diversity (H′)	Richness (d)	Evenness (J′)	Dominance (D)
	Jaswant sagar	4	*Salmostoma bacaila, Puntius sophore*	1.04	0.80	0.71	0.41
	Desuri	3	*Rasbora daniconius, Garra gotyla*	0.84	0.63	0.77	0.5
	Ranakpur	4	*R. daniconius, G. gotyla*	1.33	0.86	0.95	0.27
Upstream		8	*R. daniconius, S. bacaila*	1.85	1.53	0.79	0.17
	Jodhpur	0	–	–	–	–	–
	Luni village	5	*S. bacaila, Aphanius dispar*	0.98	0.89	0.53	0.45
	Dundhara	5	*A. dispar,*	0.95	1.05	0.52	0.53
	Samdhari	12	*Cirrhinus mrigala, Mystus gulio*	1.62	2.35	0.42	0.29
	Jethantri	3	*C. mrigala*	0.52	0.49	0.56	0.72
	Balotra	7	*S. bacaila*	1.32	1.37	0.53	0.39
	Nakora	5	*A. dispar, Oreochromis mossambicus*	0.81	0.77	0.45	0.61
	Bhatala	10	*S. bacaila, C. mrigala,*	1.87	2.28	0.64	0.20
Midstream		19	*A. dispar, C. mrigala*	1.95	2.81	0.37	0.19
	Gandhav	12	*O. mossambicus, Systomus sarana*	1.56	2.24	0.39	0.31
	Doothwa	3	NA	0.93	0.91	0.85	0.43
	Surachand	6	*A. dispar*	1.53	1.41	0.77	0.26
Downstream		14	*O. mossambicus, S. sarana*	1.86	2.51	0.46	0.22
Luni River		27	*A. dispar, S. bacaila*	2.35	3.83	0.39	0.13

NA not available

attu can tolerate moderate salinity (varies in the range of 2.8–9.1 ppt). Table 4 presents the distribution pattern of the fish species reported from the river Luni.

The cluster analysis based on the Bray–Curtis similarity revealed that the fish assemblages of the river Luni has five distinct clusters at 0.15 index level based on the fish species abundance (Fig. 4). The mixture of sampling sites in the down and midstream zones except at Gandhav form two cluster and show similarity in its faunal assemblage. The sampling sites at Desuri and Ranakpur in the upstream hilly range and the important tributary confluence point at Gandhav in the midstream zone form another distinct set of clusters. No fish species were reported at Jodhpur from Jojaria stream of the river Luni that forms an utterly distinct cluster. To know the extent of non-native species impact, similarity analysis was performed using only the native fish species abundance data *i.e.* not including *Oreochromis mossambicus* and *Clarias gariepinus*, which has resulted in the formation of four distinct cluster merging Gandhav with other downstream sampling sites (Fig. S1).

The assessment of the conservation status of the fish species was done using the IUCN Red List of Threatened Species 2019, which indicated 25 species under least concern (LC), 1 under vulnerable (VU) (*Wallago attu*) and 1 under near-threatened (NT) (*Parambassis lala*) categories (Table 4).

Invasion of non-native fishes

Invasion of the non-native fish is considered as one of a major threat to the biodiversity of an aquatic ecosystem. The widespread invasion of non-native species such as, African Catfish (*Clarias gariepinus*) and Mozambique tilapia (*Oreochromis mossambicus*) of different life stages were reported from the mid and downstream segment of the river Luni. The presence of tilapia in different sizes (6.1 cm/4 g to 26.5 cm/235 g) indicates the recruitment of young ones by the established breeding population of *O. mossambicus* in the river. African catfish of the maximum length of 0.9 m and weight of 6.5 kg was caught from the water pools at Bhatala in the midstream zone of the river.

Table 4 Distribution and IUCN status of fish species identified in the present study

Sl. No.	Name of the species	IUCN status	Utilization	Distribution pattern		
				Upstream	Midstream	Downstream
Cypriniformes						
Cyprinidae						
1	*Salmostoma bacaila* (Hamilton, 1822)	LC	FF	+	+	–
2	*Rasbora daniconius* (Hamilton, 1822)	LC	FF + OF	+	–	–
3	*Gibelion catla* (Hamilton, 1822)	LC	FF	+	+	+
4	*Cirrhinus mrigala* (Hamilton, 1822)	LC	FF + GF	–	+	+
5	*Garra gotyla* (Gray, 1830)	LC	FF	+	–	–
6	*Bangana dero* (Hamilton, 1822)	LC	FF + GF	–	+	+
7	*Labeo boggut* (Sykes, 1839)	LC	FF	–	+	–
8	*Labeo calbasu* (Hamilton, 1822)	LC	FF + GF	–	+	–
9	*Labeo gonius* (Hamilton, 1822)	LC	FF	–	+	–
10	*Labeo rohita* (Hamilton, 1822)	LC	FF + GF	+	+	–
11	*Systomus sarana* (Hamilton, 1822)	LC	FF	+	+	+
12	*Puntius sophore* (Hamilton, 1822)	LC	FF + GF + MV	+	+	–
	Nemacheilidae					
13	*Acanthocobitis botia* (Hamilton, 1822)	LC	MV + AT	+	–	–
Siluriformes						
Bagridae						
14	*Sperata seenghala* (Sykes, 1839)	LC	FF + AT	–	+	–
15	*Mystus gulio* (Hamilton, 1822)	LC	FF + OF	–	+	+
	Siluridae					
16	*Wallago attu* (Bloch & Schneider, 1801)	VU	FF + OF + GF	–	+	–
	Clariidae					
17	*Clarias gariepinus* (Burchell, 1822)	LC	FF	–	+	–
Beloniformes						
Belonidae						
18	*Xenentodon cancila* (Hamilton, 1822)	LC	FF + AT	–	+	–
Cyprinodontiformes						
Cyprinodontidae						
19	*Aphanius dispar* (Rüppell, 1829)	LC	FF + OF	–	+	+
Perciformes						
Channidae						
20	*Channa punctata* (Bloch, 1793)	LC	FF	–	+	–
21	*Channa marulius* (Hamilton, 1822)	LC	FF	–	–	+
	Ambassidae					
22	*Chanda nama* (Hamilton, 1822)	LC	FF + AT + BC	–	+	+
23	*Parambassis ranga* (Hamilton, 1822)	LC	FF + AT	–	–	+
24	*Parambassis lala* (Hamilton, 1822)	NT	AT	–	–	+
	Cichlidae					
25	*Oreochromis mossambicus* (Peters, 1852)	LC	FF	–	+	+
	Gobiidae					
26	*Glossogobius giuris* (Hamilton, 1822)	LC	FF + AT	–	–	+
Synbranchiformes						
Mastacembelidae						
27	*Macrognathus pancalus* (Hamilton, 1822)	LC	FF + AT	–	–	+

FF food fish; *GF* game fish; *OF* ornamental fish; *AT* aquarium trade; *BC* biological control; *LC* least concern; *NT* near threatened; *VU* vulnerable

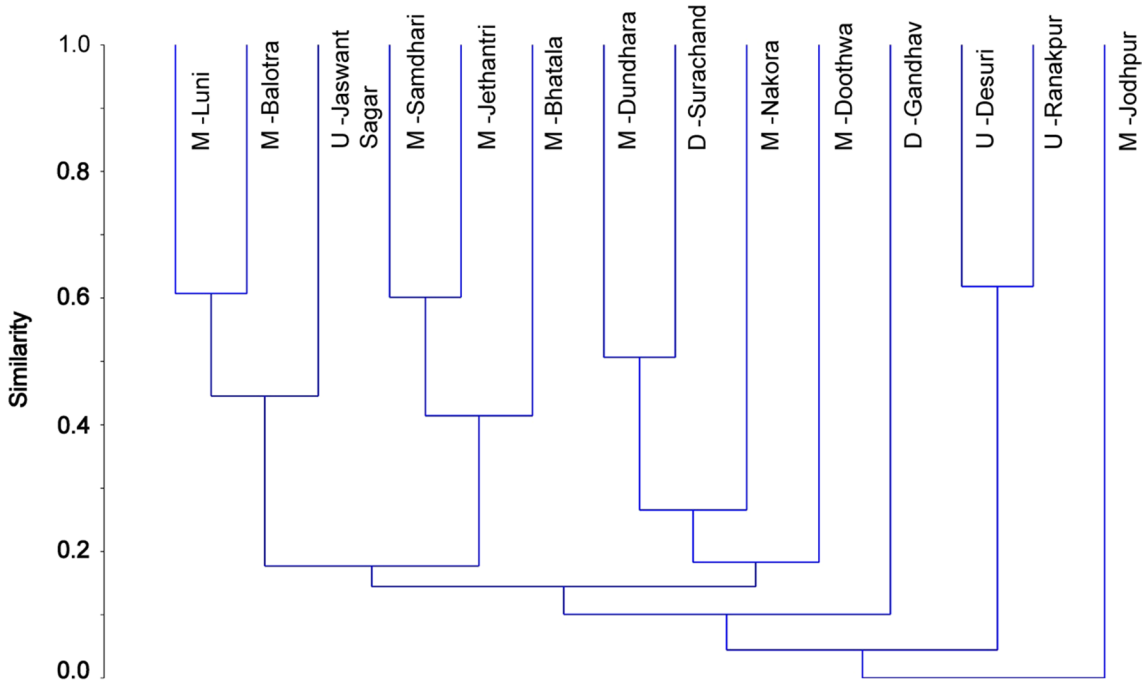

Fig. 4 Dendrogram showing Bray–Curtis similarities based on the fish species abundance data between the sampling sites along the Luni River, India [letter U, M and D denotes *U* Upstream, *M* Midstream and *D* Downstream]

Discussion

Habitat status

The Luni basin is known for its erratic and unpredictable changes in its river bank and habitat characteristics (Hunter 1908). The majority of the rocky terrain dominating upstream habitats of the river Luni is formed by its tributaries (Sukri, Lunawa, Jawai, etc.) originating from the Kumbhalgarh hills of Aravalli range (Editor-Director 2011). The flow of these ephemeral streams is restricted to the rainy season. The river Luni stretches to its full width only for a short term and the flow causes widening of the beds (up to 1.8 times from the original width from 1958 to 1986) than deepening because of the bank erosion (Singh et al. 1988). This results into the development of the shallow water pools along the midstream, which retains water for a few months. However, interaction with fishermen confirmed that certain water pools retain water for a long period depending on the intensity of rainfall in the previous rainy seasons.

During the survey, no clear pattern was observed in the salinity profile of the river Luni. Hunter (1908) reported the distribution of freshwater (sweet) up to Balotra. On the contrary, the current study reports highest salinity in the Luni village (9.15 ppt) followed by Dundhara (7.41 ppt) which are located in the upstream of Balotra (Fig. 1). This indicates the change in habitat profile of the river Luni, which is attributed to the presence of saline depressions and salt affected land in the catchment area as well as other prevailing geological and climatic factors pertaining to the arid zone (Sharma 1997; Mandal et al. 2009). The irregular pattern in the salinity might be due to the confluence of few tributaries *i.e.* Bandi, Sukri and Sagi in the midstream of the river Luni that reduces the salinity by diluting the river water at places like Dundhara, Samdari and Gandhav (Jain et al. 2007). During the study, the highest pH was reported at Balotra (9.25), which might be due to the release of effluents from dyeing industries into the river water (Vats and Singh 1991; Meghwal and Parihar 2017). The oxidation reduction potential (ORP) that characterizes the redox reactions is important for the nutrient cycling in the rivers and wetlands. The sampling locations with low (less than 100 mv) and negative ORP value (− 310.9 mv at Jodhpur) indicates the prevailing anaerobic conditions in the river system (Søndergaard 2009; Goncharuk et al. 2010).

Habitat use pattern by fish assemblage

CCA analysis of fish abundance in relation to environmental variables revealed that altitude and ORP substantially influences cyprinid fish assemblage in the upstream of Luni river basin. Johnson et al. (2012) highlighted that the most influencing environmental variables for cyprinids in Ken River are stream order, deeper habitat, flow and water temperature. In the present study, cyprinid species such as *Garra gotyla* and *Rasbora daniconius* were reported only from sampling

sites located at the highly elevated Aravalli range. In general, the headwater streams have been known for harbouring few species of restricted distribution (Zbinden and Matthews 2017; Richardson 2019). Other important parameters which influence the abundance of cyprinid fishes in Luni village and Balotra along the midstream of the river Luni are conductivity and water temperature (Fig. 2). Kollaus and Bonner (2012) found water temperature as the most influencing factor for seasonal movement of fish species in semi-arid to arid environments. It is pertinent to mention here that one among the Indian Major Carp *i.e. Cirrhinus mrigala* was reported in abundance with other brackishwater fish species from midstream locations (salinity: 1.41–4.7 ppt) at Jethantri, Bhatala and Samdhari (Table 2 and 3). Kasim (1983) reported the salinity tolerance level of *C. mrigala* as 3.54 ppt which was found to be lesser than other carps such as *Cyprinus carpio* and *Labeo fimbriatus*.

Fish species assemblage and distribution

Fish diversity

The field survey in the present study revealed the distribution of 27 fish species from the river Luni. The other workers like Banyal (2012a, 2012b) and Banyal and Kumar (2014) have recorded 3 fish species near Jodhpur, 5 species from Jaswant sagar and 8 species from Sanchore region, respectively. Mohan and Ramkishor (2013) found Cyprinidae family as the dominant fish group in the entire Rajasthan state including Luni river basin. The highest species diversity reported from the mid and downstream of the river Luni might be attributed to its habitat characteristics. Being an ephemeral river, the water flow in the Luni depends on the rainfall (Jain et al. 2007). This was clearly evident in the present study as little water was observed in the Jaswant sagar dam with nil downstream flow even during the monsoon season (September, 2019). However, formation of deep pools in the riverbeds were commonly observed along the midstream of the river especially near Samdhari and Balotra, which holds water for relatively longer period. Earlier to that, Banyal and Kumar (2014) reported formation of the water pools near Sanchore region in midstream of the river Luni due to the intermittent release of surplus water from Narmada canal. The Shannon–Wiener diversity index (H') considers both species richness and evenness of a particular habitat usually ranges between 1.5 and 3.5 (Margalef 1972). The diversity index value reported in the present study from all the three segments of the river Luni indicates that it falls in the normal range and represents even distribution of fish species (Table 2). The locations reported with highest fish diversity are essentially the confluence of various tributaries of the river Luni that justifies the studies done by Falke and Gido (2006) and Johnson et al. (2012) who have reported rich fish diversity in the confluence points of river stream.

Fish species distribution and conservation status

The present study exhibits a peculiar fish distribution pattern in the river Luni. The hilly upstream region supports fishes like *Rasbora daniconius*, *Garra gotyla* and *Acanthocobitis botia.* The distribution of few brackishwater fishes such as *Mystus gulio*, *Aphanius dispar* is mainly from the midstream region, which is mainly attributed because of ability of fishes to withstand in the prevailing high salinity of water. The separation of Gandhav from other sampling sites of mid and downstream in respect of fish assemblage-based Bray–Curtis Similarity Index indicates threat to this river system due to the establishment and spread of non-native species (Fig. 4 and Table 3). This is confirmed by the analysis performed using native fish species abundance data (Fig. S1). Clavero et al. (2015) reported the colonization of invasive species and its relationship with dams in the modified downstream stretches of arid rivers in Morocco. Likewise, distinct cluster formation by the Jojaria stream at Jodhpur might be attributed to its degraded water quality (Table 2). Banyal and Kumar (2014) reported the occurrence of established fish communities of few species in the water pools of mid and downstream section of the river Luni which are linked to the release of excess water from Narmada canal. The present study reports high fish diversity and dominance of non-native fish *O. mossambicus* in Gandhav which is located near to Narmada canal (Table 3; Fig. 1). The abundant occurrence of a euryhaline fish, *A. dispar* along the midstream of the river supports the entry of this fish species from the Middle East coastal zones as reported by Yazdani (1996). The prevailing saline conditions in the river Luni might have facilitated the distribution of this species even to the interior locations extended up to the Luni village, which is located about 300 km away from the Great Rann of Kutch. The discontinuity in the distribution and presence of this fish at few isolated locations with high salinity illustrate the importance of dry season refuges and hydrological connectivity in the arid river system (Kerezsy et al. 2017). However, the ongoing habitat change and river flow modification may affect the indigenous fish diversity of river Luni.

Invasion of non-native fishes

The impact of invasive species abundance especially *Oreochromis mossambicus* on the fish assemblage structure of riverine habitat of Luni is highly evident (Fig. 4 and S1). Clavero et al. (2015) reported a change in fish assemblage structure of arid Moroccan rivers due to the adverse effect of non-native species distribution. Earlier, Mohan and Ramkishor (2013) reported the occurrence of 10 non-native fishes

from the Rajasthan state and authors highlighted widespread distribution of *O. mossambicus* in the rivers, lakes and ponds. The authors also emphasized that few of these fishes are competing with the native fish fauna of this state. In the present study, the extensive distribution of *Clarias gariepinus* and established breeding populations of *O. mossambicus* were observed in the river Luni. This might be due to the on-going change in the river bed ecology (Banyal and Kumar 2014) and other anthropogenic factors such as release of wastewater effluents and sedimentation changing the original habitats of the river Luni (Vats and Singh 1991; Bohra 2007; Mohan and Ramkishor 2013; Meghwal and Parihar 2017). Earlier to this study, Sharma and Choudhary (2007) had already mentioned the occurrence of *C. gariepinus* in all major river basins of Rajasthan including the river Luni. Gavioli et al. (2018) argue that the effect of non-native species on native fish diversity is more disquieting than the water quality and hydrological parameters of a riverine ecosystem.

Conclusion

The present investigation on fish diversity and habitat status of an unexplored river Luni from Thar Dessert region revealed the distribution of 27 species. The spatial variation in the water quality variables suggests that the entire Luni river basin is unique and offers vivid habitat of diverse types. Such information on fish and habitat diversity can incline people/resource managers towards valuing the river system and its biodiversity for conservation and sustainable utilization (Aichi Biodiversity Target 1).

The study reports an alarming invasion and establishment of non-native species, especially *Oreochromis mossambicus* from the highly diverse middle and downstream zones of the river. There might be negative repercussions of this species on the habitat, fish assemblage structure and survival of the threatened species reported *i.e. Wallago attu* (Vulnerable) and *Parambassis lala* (Near Threatened). This information about non-native species will assist the resource managers in implementing the control or eradication measures to prevent its establishment and spread into the upstream of this river system (Aichi Biodiversity Target 9). This study suggests for (i) targeted and selective fishing of non-native species from the locations where it is abundantly distributed and (ii) awareness among the general public about the menace of non-native species on natural habitat for preserving the uniqueness of this river system.

The deterioration in water quality and degraded river bed ecology due to discharge of waste material, release of excess canal water and invasion of non-native fish species suggests for environmental restoration, regular monitoring and inspection of critical habitats by environmental authorities. The baseline information thus generated can be used as a bench mark for planning strategy for the proposed Rajasthan-Sabarmati link canal in the light of riverine ecosystem conservation and management.

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Compliance with ethical standards

Conflicts of interest The authors declare that there is no conflict of interest.

Ethics approval The authors declare that the field study complies with the current laws of the country.

Consent to participate All co-authors of the manuscript have been consulted and obtain consent to participate.

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References

Amarasinghe, U. A., Sharma, B. R., Aloysius, N., Scott, C., Smakhtin, V., & de Fraiture, C. (2004). Spatial variation in water supply and demand across river basins of India. Research Report 83. Colombo: International Water Management Institute.

AqGRISI. (2019). Aquatic Genetic Resource Information System of India. Available at: http://mail.nbfgr.res.in/agrisi/index.php. Accessed: 16 January, 2020.

Banyal, H. S. (2012a). Exploration of fish diversity in Luni river at Kankani village near Jodhpur, Rajasthan. *Journal of Environment and Bio-Sciences, 26,* 141–142.

Banyal, H. S. (2012b). Ichthyo faunal diversity in Jaswant sagar reservior near Bilara Region of Jodhpur district, Rajasthan. *Journal of Environment and Bio-Sciences, 26,* 151–152.

Banyal, H. S., & Kumar, S. (2014). New record of fish diversity in the Luni river at Sanchore region of Rajasthan state. *Journal of Environment and Bio-Sciences, 28,* 45–46.

Bohra, N. K. (2007). Ecological studies on Luni river basin. *Nature, Environment and Pollution Technology, 6,* 29–35.

Clavero, M., Esquivias, J., Qninba, A., Riesco, M., Calzada, J., Ribeiro, F., et al. (2015). Fish invading deserts: Non-native species in arid Moroccan rivers. *Aquatic Conservation: Marine and Freshwater Ecosystems, 25,* 49–60. https://doi.org/10.1002/aqc.2487.

Datry, T., Larned, S. T., & Tockner, K. (2014). Intermittent rivers: A challenge for freshwater ecology. *BioScience, 64,* 229–235. https://doi.org/10.1093/biosci/bit027.

Datta, A. K., & Majumdar, N. (1970). Fauna of Rajasthan, India. Part 7. Fishes. *Records of the Zoological Survey of India, 62,* 83–85.

Dhir, R. P., Kolarkar, A. S., Sharma, K. D., Vangani, N. S., Saxena, S. K., Sen, A. K., Ramakrishna, Y. S., Murthy, K. N. K., Singh, N., & Tak, B. L. (1982). July 1979-Flash flood in the Luni. Technical Bulletin No. 6, Jodhpur: Central Arid Zone Research Institute.

Editor-Director (2011). Faunal exploration of Kumbhalgarh Wildlife Sanctuary, Rajasthan. *Conservation Area Series, 47*, 1–118. Kolkata: Zoological Survey of India.

Falke, J. A., & Gido, K. B. (2006). Effects of reservoir connectivity on stream fish assemblages in the Great Plains. *Canadian Journal of Fisheries and Aquatic Sciences, 63,* 480–493. https://doi.org/10.1139/f05-233.

Froese, R., Pauly, D. (2019). FishBase. World Wide Web electronic publication. www.fishbase.org, version (08/2019).

Gavioli, A., Mancini, M., Milardi, M., Aschonitis, V., Racchetti, E., Viaroli, P., et al. (2018). Exotic species, rather than low flow, negatively affect native fish in the Oglio River, Northern Italy. *River Research and Applications, 34,* 887–897. https://doi.org/10.1002/rra.3324.

Goncharuk, V. V., Bagrii, V. A., Melnik, L. A., Chebotareva, R. D., & Bashtan, S. Y. (2010). The use of redox potential in water treatment processes. *Journal of Water Chemistry and Technology, 32,* 1–9. https://doi.org/10.3103/S1063455X10010017.

GWDR (2013). Hydrogeological Atlas of Rajasthan - Luni River Basin. Ground Water Department of Rajasthan, Govt. of Rajasthan. Available: https://phedwater.rajasthan.gov.in/content/dam/doitassets/water/Ground%20Water/Pdf/PublicReports/Groundwater_Atlas/Basinwise/Luni%20River%20basin.pdf. Accessed: January 17, 2020.

Hammer, Ø., Harper, D. A., & Ryan, P. D. (2001). PAST: paleontological statistics software package for education and data analysis. *Palaeontologia Electronica, 4,* 9.

Hunter, W. W. (1908). Luni—Ludhiana Tahsil to Madhi. *The Imperial Gazetteer of India, 16,* 211–212.

HWRISI (n.d.). Proposed Inter Basin Water Transfer Links. Hydrology and Water Resources Information System for India. Available: http://117.252.14.242/rbis/india_information/interlinking.htm. Accessed: May 13, 2020.

IUCN. (2020). The IUCN Red List of Threatened Species. Version 2019-3. https://www.iucnredlist.org. Accessed: January 14, 2020.

Jain, S. K., Agarwal, P. K., & Singh, V. P. (2007). Other Basins and Islands. In *Hydrology and Water Resources of India* (pp. 743–795). Dordrecht: Water Science and Technology Library-57, Springer. https://doi.org/10.1007/1-4020-5180-8_16.

Jayaram, K. C. (1981). *The freshwater fishes of India. A handbook*. Kolkata: Zoological Survey of India.

Jayaram, K. C. (1999). *The freshwater fishes of the Indian region*. New Delhi: Narendra Publishing House.

Johal, M. S., Chahal, I. S., & Tandon, K. K. (1993). Ichthyofauna of Rajasthan State. *Journal of the Bombay Natural History Society, 90,* 404–411.

Johnson, J. A., Parmar, R., Ramesh, K., Sen, S., & Murthy, R. S. (2012). Fish diversity and assemblage structure in Ken river of Panna landscape, central India. *Journal of Threatened Taxa, 4*, 3161–3172. https://threatenedtaxa.org/index.php/JoTT/article/view/811/1457.

Joshi, K. D., Alam, M. A., Jha, D. N., Srivastava, K., Srivastava, S. K., Kumar, V., et al. (2017). Studies on ecology, fish diversity and fisheries of Ken-Betwa Rivers (India): Proposed for inter-linking. *Aquatic Ecosystem Health & Management, 20,* 71–85. https://doi.org/10.1080/14634988.2017.1261576.

Kasim, H. M. (1983). Salinity tolerance of certain freshwater fishes. *Indian Journal of Fisheries, 30,* 46–54.

Kerezsy, A., Gido, K., Magalhães, M. F., & Skelton, P. H. (2017). The Biota of Intermittent Rivers and Ephemeral Streams: Fishes. In T. Datry., N. Bonada., A. Boulton (Eds.), *Intermittent Rivers and Ephemeral Streams* (pp. 273–298). Burlington: Academic Press. https://doi.org/10.1016/B978-0-12-803835-2.00010-3.

Kollaus, K. A., & Bonner, T. H. (2012). Habitat associations of a semi-arid fish community in a karst spring-fed stream. *Journal of Arid Environments, 76,* 72–79. https://doi.org/10.1016/j.jaridenv.2011.08.013.

Laity, J. J. (2009). *Deserts and desert environments*. Chichester: John Wiley & Sons.

Mandal, A. K., Sharma, R. C., & Singh, G. (2009). Assessment of salt affected soils in India using GIS. *Geocarto International, 24,* 437–456. https://doi.org/10.1080/10106040902781002.

Margalef, R. (1972). Homage to Evelyn Hutchinson, why there is an upper limit in diversity. In Deevey, E. S (Ed.), *Growth by Intussusceptions, Ecological Essays in Honor of G. Evelyn Hutchinson* (pp. 211–235). Connecticut: The Connecticut Academy of Arts and Sciences.

Margalef, R. D. (1978). Information theory in ecology. *International Journal of General Systems, 3,* 36–71.

Meghwal, D. R., & Parihar, R. (2017). Curative measures for the polluted Luni River and alternatives for textile industries at Balotara, North Western Rajasthan, India. *International Research Journal of Earth Sciences, 5,* 23–26.

Mohan, D., & Ramkishor, S. (2013). Ichthyofauna of Rajasthan. In B. K. Sharma, S. Kulshreshtha, & A. Rafi Rahmani (Eds.), *Faunal Heritage of Rajasthan, India* (pp. 257–277). Berlin: Springer Publications.

Moharana, P. C., & Kar, A. (2013). Fluvial process measurement of arid ephemeral channels in western Rajasthan. In G. Mahesh (Ed.), *Remote sensing applications in dryland natural resource management* (pp. 37–51). New Delhi: New India Publishing Agency.

MoWR (2014). West Flowing Rivers of Kutch and Saurashtra including Luni Basin Report. Ministry of Water Resources, Govt. of India. Available at: http://indiawris.gov.in/wris/#/Basin.

Murphy, A. L., Pavlova, A., Thompson, R., Davis, J., & Sunnucks, P. (2015). Swimming through sand: connectivity of aquatic fauna in deserts. *Ecology and Evolution, 5,* 5252–5264. https://doi.org/10.1002/ece3.1741.

Pielou, E. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology, 13,* 131–144.

Rathore, J. (2011). Assessment of water quality of River Bandi affected by textile dyeing and printing effluents, Pali, Western Rajasthan, India. *International Journal of Environmental Science and Technology, 2,* 560.

Richardson, J. S. (2019). Biological diversity in headwater streams. *Water, 11,* 366.

Shannon, C. E., & Wiener, W. (1963). *The mathematical theory of communication*. Ilinois: University of Illinois Press.

Sharma, K. D. (1997). Integrated and sustainable development of water resources of the Luni basin in the Indian arid zone (pp. 385–394). IAHS Publications-Series of Proceedings and Reports, 240, Wallingford: International Association of Hydrological Sciences.

Sharma, L. L., & Choudhary, C. S. (2007). Conservation and management of fish diversity in Rajasthan. In W. S. Lakra & U. K. Sarkar (Eds.), *Fresh water fish diversity of Central India* (pp. 110–117). Lucknow: ICAR-National Bureau of Fish Genetic Resources.

Simpson, E. H. (1949). Measurement of diversity. *Nature, 163,* 688.

Singh, S., Sharma, K. D., Singh, N., & Bohra, D. N. (1988). Temporal change detection in river courses and flood plains in an arid environment through satellite remote sensing. *Journal of the Indian Society of Remote Sensing, 16,* 53–56. https://doi.org/10.1007/BF02991878.

Søndergaard, M. (2009). Redox potential. *Encyclopedia of Inland Waters* (pp. 852–859). Oxford: Pergamon Press.

Srivastava, N. (2007). Freshwater fish diversity in Rajasthan. In W. S. Lakra & U. K. Sarkar (Eds.), *Fresh water fish diversity of Central India* (pp. 142–155). Lucknow: ICAR-National Bureau of Fish Genetic Resources.

ter Braak, C. J. F. (1986). Canonical correspondence analysis: A new eigenvector technique for multivariate direct gradient analysis. *Ecology, 67,* 1167–1179. https://doi.org/10.2307/1938672.

ter Braak, C. J. F., & Verdonschot, P. F. M. (1995). Canonical correspondence analysis and related multivariate methods in aquatic ecology. *Aquatic Science, 57,* 255–289. https://doi.org/10.1007/BF00877430.

USGS Earth Explorer https://earthexplorer.usgs.gov/. Accessed: 05 February 2020.

Vats, P. C., & Singh, S. (1991). Ecosystems and Environmental hazards of an arid environment: A case study. In H. S. Sharma (Ed.), *Indian Geomorphology* (pp. 45–56). New Delhi: Concept Publishing Company.

Web of science https://apps.webofknowledge.com. Accessed: 02 May 2020.

India-WRIS (n.d.). India – Water Resource Information System. Available at: https://indiawris.gov.in/wris/.

Yazdani, G. M. (1996). Fish diversity in Thar Desert. In A. K. Ghosh, Q. H. Baqri, & I. Prakash (Eds.), *Faunal diversity in the Thar-Desert - Gaps in Research* (pp. 285–295). Jodhpur: Scientific Publication.

Zbinden, Z. D., & Matthews, W. J. (2017). Beta diversity of stream fish assemblages: Partitioning variation between spatial and environmental factors. *Freshwater Biology, 62,* 1460–1471.