Diatom distribution and its relationship with water quality in the Mahi River Basin

Diatoms are sensitive to environmental conditions in aquatic ecosystems and their distribution is mainly governed by the physicochemical composition of the water and wet sediments which are a function of regional lithology, topography, relief, climate, vegetation, tectonic activity and anthropogenic influences. The influence of rock weathering in the catchment regions on the cation–anion chemistry, including trace elements of river, lake waters and sediments has been discussed by many workers[1–4]. The chemistry of large rivers of India and its relationship with weathering and exogenic cycling of elements have also been described fairly well[5–8]. However, relatively smaller rivers have been paid little attention, more so in terms of understanding the physicochemical parameters and microorganisms, particularly the diatom distribution and its interrelationship[9]. Diatoms are unicellular photosynthetic algae having a siliceous exoskeleton called frustule. The frustule is composed of opaline silica and its morphology determines the taxonomic classification[10]. Diatoms are distributed in all waters, except the hottest and the most hypersaline environment. They normally occur as phytoplankton or phytobenthos in marine as well as in freshwater of all latitudes[11] and play a major role in determining the biological productivity. Diatoms are not only the nutritional source for themselves and other living things in the water, but also increase the rate of dissolved oxygen in water[12]. The composition, density, seasonal changes and ecological conditions like physical and chemical factors play a guiding role in the distribution patterns and assemblages of the diatoms[13] and therefore have a complex pattern of spatial and temporal variability[14]. Diatoms are studied as sensitive indicators for environmental conditions and have also been used effectively in the pollution-related studies[15,16]. Diatom existence and distribution patterns are used effectively for understanding the palaeomonsoon, sea-level fluctuation, palaeoenvironmental and palaeoclimatic conditions during the Quaternary period over diverse regions of the globe[17–19]. The water resources are the ultimate source for survival of the entire biological world; however, our present-day water systems are experiencing rapid changes due to different anthropogenic influences. Therefore, there is a need to study the water chemistry and its impact/relation to the diatom distribution.

The present study aims to understand the diatom distribution pattern with changing physicochemical environment in the Mahi River Basin of western India (Figure 1). The Mahi River Basin occupies a large area (32,000 sq. km) comprising parts of Madhya Pradesh (MP), Rajasthan and Gujarat. It originates at Minda village, Sardarpur District, MP and starts flowing in the NW direction till it enters into southern Rajasthan. From here the river course suddenly takes a SW turn and finally debouches into the Gulf of Cambay (Figure 1). In the upper reaches, the river largely flows over the Deccan Traps (basalts), sedimentary and metasedimentary rocks of the Middle Proterozoic Vindhyan Supergroup, the ~2.5 Ga Aravalli Supergroup rocks (mafic volcanics with leucogranite intrusions, metasediments, granites, minor komatiites, amphibolites) and still older (~3.5 Ga) banded gneissic complex rocks (Figure 1). The rocks encountered in the upland zone largely belong to the Jharol Group (phyllite, chlorite–schist and quartzites), Rakhabdev ultramafic suite (talc and serpentine and chlorite–schist), Lunavada Group (phyllite, mica–schist and carbonates) and Champaner Group (granites and gneisses with/without metasediments) of the Aravalli Supergroup[20] (Figure 1). In the middle and lower reaches the river flows across Mainland Gujarat, which is geomorphologically

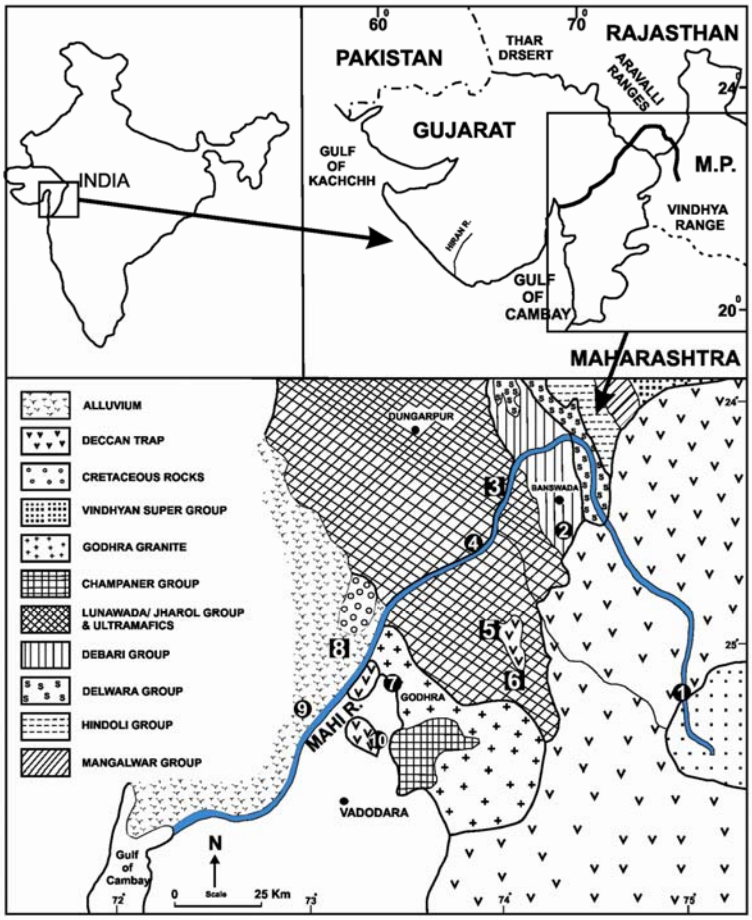

Figure 1. Map showing the study area and water sampling locations in the Mahi River Basin. Filled circle (•) indicates the main river channel or its tributaries and filled square (■) indicates ponds in the area (based on Merh and Chamyal[22]).

Table 1. Physical and chemical characteristics of water samples collected from different locations in the Mahi River Basin

Sample No	Temperature (°C)	PH	EC (μs cm^{-1})	TDS (ppm)	Salinity (ppt)	HCO_3 (ppm)	F (ppm)	Cl (ppm)	NO_3 (ppm)	SO_4 (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Si (ppm)	Mn (ppm)	Fe (ppm)	Ni (ppb)	Region
● 1	15.0	7.36	443	314	0.23	250	0.3	17.5	12.0	15.6	48	19	19	0.9	15.2	0.03	0.35	1.6	M P Region
● 2	14.4	7.26	261	215	0.14	128	0.2	7.50	5.30	6.90	20	7.1	7.3	0.9	8.6	0.03	0.41	2.4	M P Region
■ 3	14.6	7.94	475	323	0.24	237	0.11	36.6	3.80	13.0	27	22	39	1.5	8.10	0.12	0.30	1.5	Rajasthan Region
● 4	17.6	7.22	409	306	0.23	207	0.5	30.4	3.20	14.6	56	18	33	1.2	10.3	0.012	0.18	1.2	Rajasthan Region
■ 5	17.1	7.43	322	235	0.17	170	0.3	16.8	1.70	4.00	30	08	19	2.5	6.40	0.12	0.87	4.0	Gujarat region – Upper Reaches
■ 6	17.1	7.82	429	317	0.24	183	0.4	37.4	1.60	16.9	25	09	47	1.7	10.7	0.09	1.32	5.0	Gujarat region – Upper Reaches
● 7	19.5	6.79	653	463	0.40	225	0.4	32.8	1.60	39.2	27	18	46	4.2	8.20	0.04	0.13	1.0	Gujarat region – Lower Reaches
■ 8	18.9	7.11	249	181	0.14	120	0.3	10.3	0.80	3.00	16	04	10	3.9	1.90	0.07	0.26	2.0	Gujarat region – Lower Reaches
● 9	17.5	7.97	851	544	0.47	152	0.4	41.0	3.90	31.3	28	14	56	1.6	9.70	0.08	0.17	2.0	Gujarat region – Lower Reaches
● 10	16.0	7.45	494	355	0.25	219	0.34	39.5	6.70	18.4	25	20	43	1.8	11.3	0.012	0.14	1.0	Gujarat region – Lower Reaches

• River water sample; ■ Pond water sample.

divided into four broad zones – the eastern upland zone, the shallow buried pediment zone, the alluvial zone and the coastal zone[21]. However, in the lower reaches the river forms fertile alluvial plains with frequent development of ravines comprised of Late Pleistocene to Middle Holocene sedimentary deposits[22].

The climate of the basin, in general, is dry except for the monsoon season. The entire region falls within the arid–semi-arid zone. The temperature during summer (March–June) remains ~40°C; however, it touches 44–48°C for a few days almost every year. Similarly, the winter (December–February) temperature remains ~14°C, but drops to 3–4°C occasionally. The region receives rainfall mainly during the SW monsoon (mid June–September), with the annual rainfall varying between 33 and 152 cm. However, records of the past few years show a substantial increase in the rainfall. The vegetation cover varies widely due to varying nature of climate and lithologies in the basin.

A total of ten surface-water samples, four (sample nos 3, 5, 6 and 8) from ponds in the basin area and six (sample nos 1, 2, 4, 7, 9 and 10) from the main channel of the Mahi River or its tributaries, as marked in Figure 1, were collected. Samples for the diatom study were collected using planktonic net (silk bottling cloth of 25 μm mesh size) and preserved in the field itself using formaldehyde solution. Samples for chemical analysis were collected generally from midstream in pre-cleaned 1 litre polyethylene bottles, so that they represent diverse lithology of the catchment. Temperature, pH, electrical conductivity (EC), salinity, total dissolved solids (TDS) (measured by microprocessor (μp)-based Water and Soil Analysis Kit, Model No-1160E) and bicarbonate (HCO_3^-) were measured at the sampling site immediately after collection using standard methods. A part of each sample was acidified with ultra pure concentrated nitric acid (for cation measurement), while the rest was stored in pre-cleaned bottles and brought to laboratory for further chemical analysis. Both anions and cations were analysed using Ion Chromatograph (Dionex 500) and ICP–MS (Perkin Elmer) respectively, installed at the Geochemical Division of the Wadia Institute of Himalayan Geology, Dehradun. To cross-check the reproducibility of the analysis, repeat analysis was carried out and precision was within 5%. In the diatom study, the samples collected using planktic net were initially centrifuged at 1000 rpm to concentrate them further in the sample. The supernatant was discarded and then treated with acetolytic mixture (9 : 1 acetic anhydride and conc. H_2SO_4) and kept for 5 min at 100°C on a hot plate and then allowed to cool at room temperature. The samples were washed three times with distilled water. After washing, a thin smear was prepared on glass slides by tapping one drop of sample on the slide. The slide was kept on a hot plate till it dried completely and was mounted using Canada balsam. The scanning and counting were done using the Leitz microscope under 100× (oil) objective at the Birbal Sahni Institute of Palaeobotany. Canonical correspondence analysis (CCA) was performed using XLSSTAT in Windows. CCA is basically a weighted average regression method in which all species are assumed to have a unimodal response surface and all the axes are constrained to be a linear combination of environmental variables. The variables with significance of $P \leq 0.05$ were selected for CCA analysis.

All physical and chemical analysis results and diatom assemblages for the analysed samples are given in Tables 1 and 2 respectively. Table 1 reveals significant variations in the physical parameters (EC, salinity and TDS) and cation–anion concentrations in the samples, probably due to the different lithologies of the sampling region. It was also observed from the literature that the ionic composition of surface water of Mahi Basin is significantly high compared to the average of Indian rivers as well as that of the world rivers[5,23]. This is attributed to the dominance of basalt rock-type and subtropical climate in the study area. Overall,

Table 2. Diatom distribution (in percentage range) in the samples studied from the Mahi River Basin

Sample no.	Pond/river	*Navicula viridula*	*Navicula* spp.	*Cymbella* spp.	*Pinnularia* spp.	*Gyrosigma* sp.	*Nitzchia* sp.	*Synedra capitata*	*Stauroneis* spp.	*Cocconeis* sp.	*Amphora* sp.	*Rhopalodia* spp.	*Cyclotella* sp.
1	River	–	++++	+++	+	+	+	+++	–	+	–	–	–
2	River	++++++	+	+	+	++	+	+	–	+	+	–	–
3	Pond	++	++	+++	++	++	+	+	+	–	+	+	–
4	River	++	+++++	++	+	–	–	+++	+	–	–	–	–
5	Pond	++	+++	+	++	++	+	++	+	–	+	–	+
6	Pond	++	++	+	+++	+++	+	-	+	++	–	–	–
7	River	+	+++	+++++	+	–	+	++	+	+	–	–	–
8	Pond	++++++	++++	–	–	–	–	–	–	–	–	–	–
9	River	+	++	–	+	++	+	+++++	+	–	+	–	+
10	River	–	–	–	–	–	++++	++++++	–	–	–	–	–

<10% +, 10–20% ++, 20–30% +++, 30–40% ++++, 40–50% +++++, >50% ++++++, (–) indicates absence of genera/species. Note that pennate forms are high in abundance compared to centric forms.

the values of EC, TDS, salinity and thereby chloride ion (Cl^-) concentration are directly proportional to each other (Table 1). In general, the salinity varies between 0.14 and 0.47 ppt, with the lowest value of 0.14 ppt in sample no. 8 (pond sample) and the highest value of 0.47 ppt recorded in sample no. 9 (river sample). TDS and EC values also show a similar trend at the locations. Among anions, NO_3^- varies from 0.8 to 12 ppm showing a decreasing trend from sample no. 1 to sample no. 8, but it increases in sample nos 9 and 10. SO_4^{--} and F^- content vary between 4 and 40 ppm and 0.1 and 0.5 ppm respectively. The cation concentration varies over wider ranges: Ca (16–56 ppm), Mg (4–22 ppm), Na (7.3–56 ppm), K (0.86–4.2 ppm), Fe (0.126–1.314 ppm), Mn (0.012–0.116 ppm) and Ni (1.2–5.0 ppb) in the studied samples (Table 1). Relatively higher Na values compared to other cations may be a result of salt contribution from the catchment area.

In general, the diatoms are high in abundance in river water compared to pond water, but low in diversity indicating that nutrient availability plays an important role in diatom distribution[10]. The overall diatom distribution is highly biased towards the freshwater pennate forms (>90%) and only a small section is represented by centric forms, i.e. *Cyclotella* sp. (sample nos 5 and 9). Most of the pinnate-form diatoms, being benthic in nature, flourish at the bottom of the water bodies. But interestingly, they contribute maximum in the present study on surface waters of all sampling sites. Their presence in the Mahi River Basin is marked by the abundance of *Navicula* spp., *Navicula viridula* in all samples, except sample no. 10. *Cymbella* spp. occur in high frequency in sample no. 7, while in other samples the counts are low and absent in sample nos 8–10. *Synedra capitata* marks its presence with maximum abundance in sample nos 9 and 10, low counts in other samples and is absent in sample nos 6 and 8. *Pinnularia* spp. and *Gyrosigma* sp. occur in low counts in most of the samples, except sample nos 9 and 10. *Nitzchia recta* shows maximum count in sample no. 10 and is negligible in other samples. *Cocconeis* sp. is reported only from sample nos 1, 2, 6 and 7, and is not present in other stations (Table 2). The presence of *Stauroneis* sp., *Amphora* sp. and *Rhopalodia* spp. is also observed in a few stations (Table 2).

In order to observe relationship between physicochemical parameters and diatom population, if any, CCA was performed. Two eigen values (0.364 and 0.043) were found suitable as these satisfy more than 92% of the entire event. The CCA test shows that EC, HCO_3^-, K^+, NO_3^- and F^- are the major components which play a vital role in governing the diatom assemblage in the region (Figure 2). EC and HCO_3^- show direct relation with *Navicula* spp., *S. capitata*, *Pinnularia* spp. and *Stauroneis* spp. (Figure 2). NO_3^- and F^- in CCA correlate well with *Cymbella* spp., *Navicula* spp. and *S. capitata* (Figure 2).

The absolute TDS and other cation–anion concentrations in an individual sample, and the observed variations among the studied samples indicate lithological control. However, at places signatures of anthropogenic activities are also discernible resulting into variation in diatom assemblages. For example, in sample nos 1, 2, 5 and 6, K^+, F^- and NO_3^- are controlled by the regional geology predominantly containing rocks (phyllite, mica schist, chlorite, schist, etc.) of the Jharol and Lunavada Groups and weathering of these leads to increase in the aforesaid components. The diatom assemblages *N. viridula*, *Navicula* sp., *S. capitata* and *Cymbella* spp. show positive relation with K^+, F^- and NO_3^- elements in the CCA test. *Pinnularia* spp., *Gyrosigma* sp., *Stauroneis* spp. and *Cocconeis* sp. are not correlated with K^+, Na^+ and Mg^{++}, but their presence in the assemblage shows their preference to neutral and low-alkali water. This may be attributed to other components affecting the alkalinity (i.e. pH and salinity).

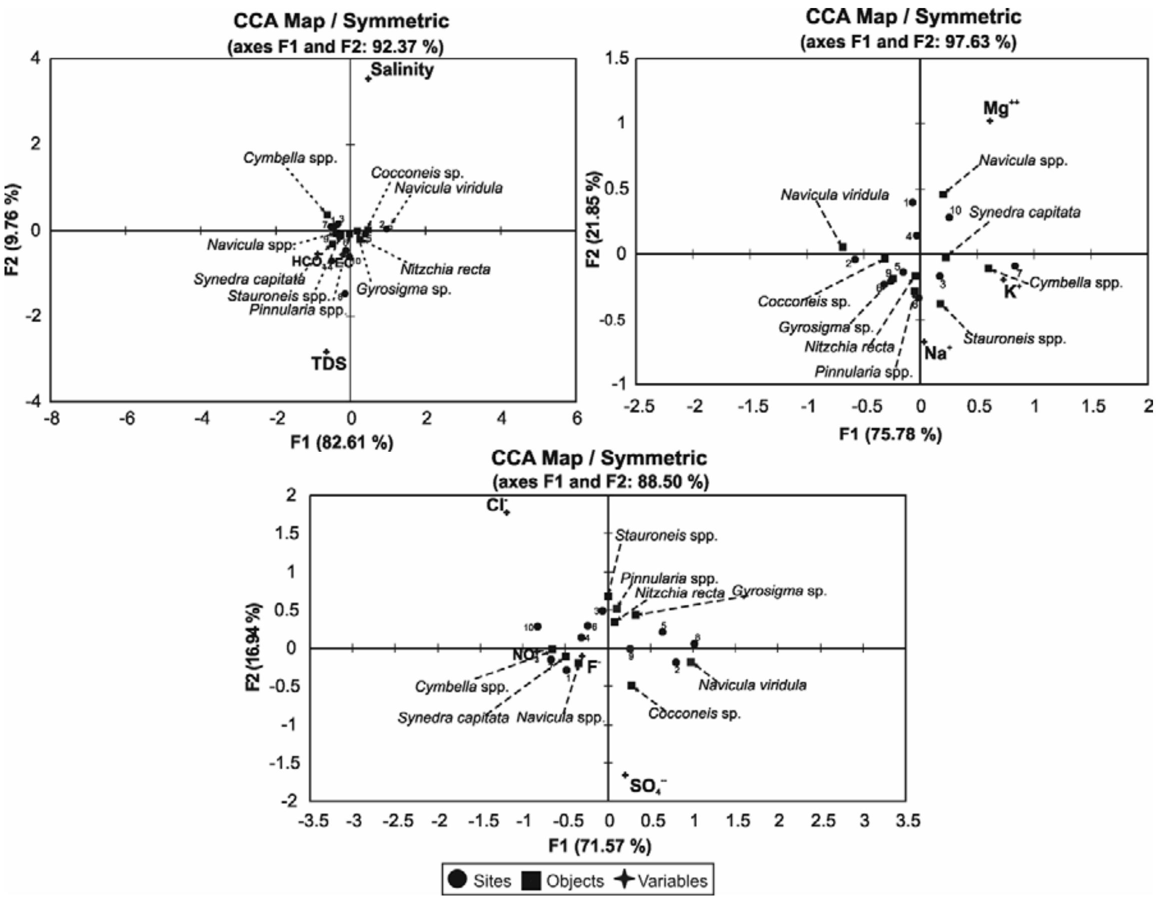

Figure 2. Statistical relationship between diatom assemblages and environmental variables using multivariate canonical correspondence analysis.

The presence of *Gyrosigma* sp., *Pinnularia* spp. and *Stauroneis* spp. favours stagnant conditions where the water movement is relatively steady. These conditions are generally met in ponds and river flowing in flat terrains. Presence of *Gyrosigma* sp., *Pinnularia* spp. and *Stauroneis* spp. in sample nos 3, 5 and 6 testifies it. However, sample no. 8 (also a pond sample) does not show their presence, which is otherwise related to low nutrient availability in this sample (Table 1). The low abundance of diatom in sample no. 4 could be an effect of high F^- content in the water, which readily dissolves the siliceous frustule of diatoms. During the collection of samples, it was also observed that the region has much higher F^- concentration in groundwater. Also, a large community of people had brown–blackish teeth indicating that they were suffering from fluorosis and suggesting[24] that the fluoride concentration in the water is above the permissible limit of <1.5 ppm.

In the lowermost reaches of the Mahi river, where it flows in the incised valley cutting through the 30–40 m thick alluvium, the diatom assemblage is dominated by *Cymbella* spp., *Navicula* sp., *S. capitata*, with lower counts of *N. recta*, *Gyrosigma* sp. and *Pinnularia* spp. The higher count of *Cymbella* spp. at station no. 7 shows tolerance for higher concentration of SO_4^{--}, which may be attributed to the effluents added by the industrial units related to chemicals, refining and fertilizer production in the adjoining region. Relatively higher concentration of SO_4^{--} give rise to reducing conditions which help *Cymbella* spp. to flourish. The high NO_3^- values in sample nos 7 and 9 support the increased counts of *S. capitata*, indicating an increase in eutrophic conditions[25,26].

The present study is a preliminary work. However, it clearly shows the following: (1) The dominance of bottom-dwelling pennate forms of diatoms over floating centric forms in surface waters, which otherwise prefer pond water, suggesting control of physicochemical conditions which further is a function of local lithology. (2) The lower reaches of the Mahi Basin, where mixing through industrial effluents is significant, show higher frequency of *Cymbella* spp. and *S. capitata* suggesting slightly increased eutrophic conditions. This can also be used effectively as a tool for monitoring ecological/environmental conditions. (3) The CCA test in most cases confirms the direct relation of physico-chemical components with the diatom population. (4) The cotemporary diatom assemblages of different water bodies of the upper and lower Mahi River Basin provide recent analog which can be further applied on much older successions for precise palaeoenvironmental and palaeoclimatic interpretation. However, this would require a more detailed study.

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A new caecilian *Ichthyophis davidi* sp. nov. (Gymnophiona: Ichthyophiidae): the largest striped caecilian from the Western Ghats

The Western Ghats, a hill chain of 1600 km running parallel to the west coast of India, is one of the amphibian hotspots. Gymnophiona in the Western Ghats is represented by 23 species[1], of which 12 belong to Ichthyophiidae and 11 species to Caeciliidae. Under Ichthyophiidae, *Ichthyophis* and *Uraeotyphlus* are the two genera containing five and seven species respectively. In the genus *Ichthyophis*, two forms of species are categorized: monocoloured species and species with yellow stripes. A total of four striped caecilians, namely *Ichthyophis beddomei* Peters, 1879 (Karnataka, Kerala and Tamil Nadu), *Ichthyophis tricolor* Annandale, 1909 (Kerala), *Ichthyophis longicephalus* Pillai, 1986 (Kerala) and *Ichthyophis kodaguensis* Wilkinson, Gower, Govindappa and Venkatachalaiah, 2007 (Karnataka and Kerala), and a monocoloured species *Ichthyophis bombayensis* Taylor, 1960 (Gujarat, Maharashtra, Goa, Karnataka and Kerala) were described from the Western Ghats.

During our search for these subterranean, secretive vertebrates in the North Karnataka parts of the Western Ghats, we collected five specimens resembling each other which fit the generic diagnosis by Pillai and Ravichandran[2] for *Ichthyophis*, but differ from all known striped caecilians of the Western Ghats, including the recent description by Wilkinson *et al.*[3]. Our collections from northern Karnataka have a distinctive combination of features that distinguish them from all other described striped *Ichthyophis*, and here we describe this form as a new species.

Ichthyophis davidi sp. nov. (Table 1; Figures 1–3).

Holotype: Zoological Survey of India, Calicut (ZSI/WGRC/V/A/776), an adult female, collected on 7 September 2010 from Chorla village (15°39′N, 74°08′E), Khanapur Taluk, Belgaum District, Karnataka.

Paratypes: ZSI/WGRC/V/A/792, an adult female collected with holotype; ZSI/WGRC/V/A/850 and ZSI A 11327 adult males were collected in July 2010 from the surrounding Chorla village; Bombay Natural History Society, Mumbai, India (BNHS 5535), adult male collected from Chorla Ghats in August 2008.

Diagnosis: Largest among the known striped *Ichthyophis* from the Western Ghats, lateral yellow stripe wider (4.05 mm), stripe extending from tentacle to the tail tip with an incurvature (not broken) across the collars, strongly indicated on the lower jaw from the level of tentacle, body uniform brown above and light below. Known range in total length of metamorphosed animals 268–370 mm,