practices could explain the variation in yield of sorghum and castor up to 20% and 28% respectively.

To summarize, minimum tillage, surface application of GL @ 2 t ha^{-1} and N @ 90 kg ha^{-1} were found to be superior in positively influencing the activity of arylsulphatase, urease, dehydrogenase enzymes as well as MBC and LC. Enzyme concentrations significantly correlated with MBC, LC and OC. Addition of organic amendments and adoption of management practices that increase soil organic matter led to increased enzyme activity. The present study clearly indicates that conservation agriculture practices have significantly contributed in influencing soil enzyme activities and labile pools of carbon, which in turn have played an important part in influencing the biological soil quality, expressed as GMeanBSQI. Thus, the information generated in the present study would be useful in influencing the biological soil quality indicators, indices and corresponding biological soil functions which help in improving the productivity of crops such as sorghum and castor in these abiotically stressed soils.

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Multi-pronged search for palaeo-channels near Konark Temple, Odisha – implications for the mythical river Chandrabhaga

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The 13th century CE Sun Temple at Konark in Odisha, India, is believed to have been built at the mouth of an ancient river named Chandrabhaga. This mythical river figures prominently in ancient literature, although at present no river exists in the proximity of the Konark Sun Temple. This study investigates the possibility of existence of a 'lost' river system near Konark through integrated geological and geophysical exploration in conjunction with historical evidence. Landsat, Aster Terra Look and Shuttle Radar Topographic Mission images have been used to identify and delineate the channel of an ancient

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river. A number of thematic maps have been generated and analysed in analytical hierarchy process and later integrated on a GIS platform to delineate the most probable trace of a palaeo-channel. The existence of a palaeo-channel at some locations is further corroborated through shallow surface geophysics using ground penetrating radar. The identified palaeo-channel passes north of the Konark Sun Temple, extending approximately parallel to the coast.

Keywords: Analytical hierarchy process, mythical river, palaeo-channel, shallow surface geophysics, world heritage sites.

THE east coast of peninsular India stretching from Tamil Nadu in the south to Bengal in the north is a passive continental margin that formed during the rifting of India from Antarctica to Australia during the Mesozoic. The peninsula is drained by a number of river systems such as the Mahanadi, Krishna, Godavari and Kaveri, and the coastal area hosts numerous world heritage sites. The Konark Sun Temple, a UNESCO world heritage site in Odisha, India, built in the 13th century CE, is reported to have been originally located along the coast of the Bay of Bengal (Figure 1). At that time, a mythical river called Chandrabhaga is believed to have existed at a distance of approximately 2 km from the temple. However, no trace of any water body is visible in the proximity of the present temple, although associated myths strongly suggest the presence of water nearby. Preserved palm-leaf drawings, sketches and rare old photographs also suggest the existence of water bodies proximal to the temple in the past[1]. At present, a swampy area, believed to be a remnant of the ancient river, has been cordoned-off and enclosed by the Government of Odisha for the ritualistic holy bath during the festival of *Magha Saptami*. Thus, while there is no physical evidence of a river at present, it continues to exist in the minds of the devotees. It is therefore of obvious interest to determine if such a river (Chandrabhaga) really existed in the past, or if it is entirely mythical.

With this background, the present study investigates the existence of any palaeo-channel in the vicinity of the present-day temple, which can be related to the name ‘Chandrabhaga’, from satellite imagery in coordination with geological and geophysical studies. Identification of such a palaeo-channel may additionally lead to the delineation of pockets of freshwater zones within a dominantly saline water environment, and may even partially alleviate the drinking water problem along the Odisha coast.

The region lies within the Mahanadi delta, geologically part of a Palaeo- to Mesozoic era Gondwana basin that is at present covered with recent alluvium. On the western side, Lower Gondwana rocks overlie vast tracts of high-grade Proterozoic metamorphic rocks like khondalites, charnockites and migmatitic gneisses which belong to the Eastern Ghats Province[2]. The region has undergone several stages of rifting, subsidence, sedimentation and uplift in its geological history. The area today is characterized by a number of depressions such as the Cuttack Depression (3000 m), Paradip Depression (1400 m) and Puri–Konark Depression (2500 m), which alternate with ridges[3,4]. Fuloria[5] has shown that the basement of the basin is traversed by a number of major faults trending ENE–WSW, NNE–SSW and NNW–SSE. The transverse faults trending in the NNW–SSE direction are genetically older than the ENE–WSW longitudinal faults. Nayak *et al.*[3] reported three prominent sets of lineaments from aeromagnetic data, and suggested that the trends of some of the rivers in the Mahanadi delta system are controlled by these lineaments. The origin of these depressions and lineaments is not certain, but may be linked to the Mesozoic break-up of India from Antarctica to Australia and local bedrock structure.

The methodology includes satellite imagery study, field validation, subsurface study and data integration. Satellite imagery study has been conducted on the suspected palaeo-channel localities using a number of image manipulation techniques (source: www.landcover.org; http://glovis.usgs.gov). FCC (false colour composite) (Figure 2 *a*) and true colour imagery of Landsat ETM+ have been generated by taking band combinations of 4, 3 and 2 as well as 3, 2 and 1 respectively. Histogram equalization technique has also been applied on Aster Terra Look and ETM + Pan mosaic data (Figure 2 *b*) to increase the colour contrast between the palaeo-channel trace and the surrounding region[6]. As the suspected palaeo-channel is characterized by thick vegetation, the vegetation enhancement technique normalized difference vegetation index (NDVI) has been applied using ratio of Near Infrared (NIR) Band – Red Band/Near Infrared Band + Red Band to distinguish the vegetation band along the trace of the channel from that in the surrounding region. To get the topographic outline of the channel, spatial profiling technique has been applied to Shuttle Radar Topographic Mission (SRTM) data, using methods similar to that of Nandini *et al.*[6]. Spatial profiling refers to the plotting of topographic elevation against distance to obtain the topographic outline (Figure 3 *a*). Additional constraint on the palaeo-channel location was obtained from Thermal Infrared (TIR) image data using the B10 band of Landsat 8 Operational Land Imager (OLI) with wavelength 10.6–11.19 μm. Following the satellite imagery study, field survey was conducted in and around Konark along the trace of the identified channel.

In a palaeo-channel, there will also be a dielectric difference between the riverbed and the loose sediments that fill up the channel, and electromagnetic waves will be reflected back from the points of dielectric difference. Based on this principle, GPR survey was carried out in the present study in the northeast direction about 2.15 km away from Konark Sun Temple along a 150 m long profile (Figure 3 *b*). In the present work, bistatic fixed T/R

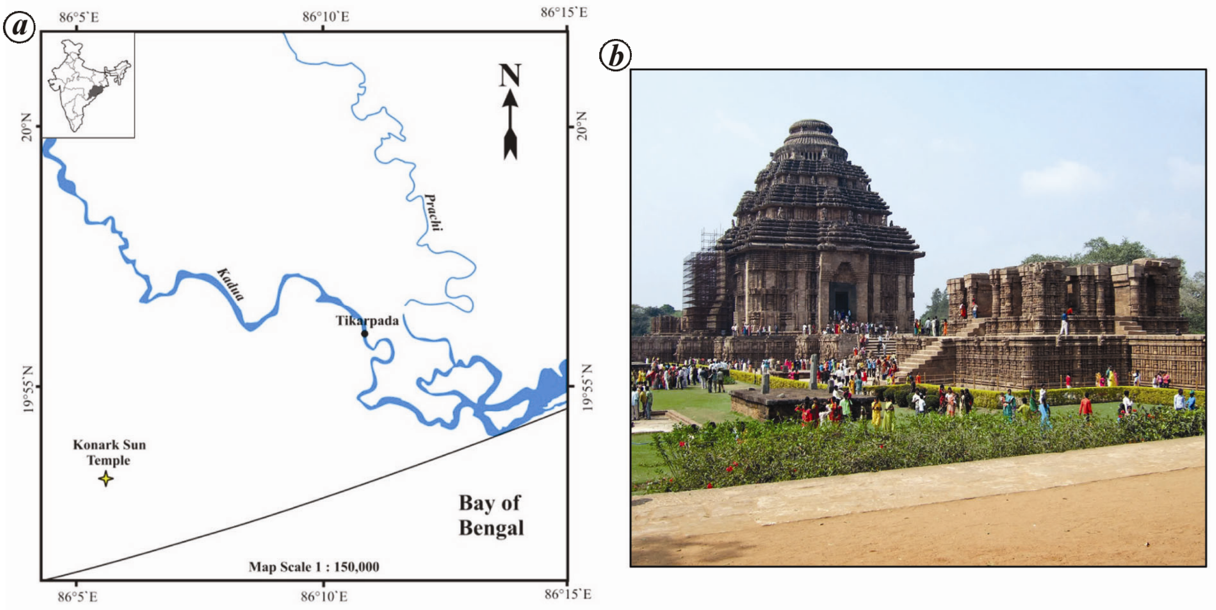

Figure 1. ***a***, Location map of the Konark region (retraced from satellite image) showing the position of Konark Sun Temple. ***b***, Photograph of the present-day Konark Sun Temple.

offset in static stacking (point collection) mode was taken with sample interval 10 cm to observe the detailed subsurface litho structure. The central frequency of the wave applied was 40 MHz and the time range was taken as 600 ns, as a result of which a profile of around 20 m depth was obtained. The collected data were processed using Radon, version 7 software provided by Geophysical Survey Systems, Inc., USA. Vertical low-pass filter and vertical high-pass filter were used to reduce the noise. Background removal tool was used to remove the horizontal bands which appear as low-frequency noise generated due to antenna ringing, and subsequently deconvolution was used to remove the noise generated due to multi-reflections from the objects such as metal piece, wet clay, etc. Finally, all the data were merged into a single file.

Thematic maps were generated on the GIS platform using thermal, elevation, NDVI, gravity, geological and tectonic data obtained from the satellite imagery as well as from published maps[4]. These were subsequently integrated using the respective weights obtained by Saaty's analytical hierarchy process (AHP)[7], a methodology successfully applied for data integration in various geophysical studies[8–10]. AHP is a multi-criteria mathematical evaluation method in the decision-making process. It uses hierarchical structures to quantify relative priorities for a given set of elements on a ratio scale, is based on the discernment of the user. From the judgments between two particular elements, a pairwise comparison matrix was constructed on a scale of 1–6 (six parameters in the present study), 1 indicating that the two elements are equally important and 6 implying that one element is more important than the other.

If an element is less significant than the others, it is indicated by reciprocals of 1–6 values (i.e. 1/1 to 1/6) (Table 1). The pairwise comparison matrix prepared was used to derive the individual normalized weights of each element. The same method has been used for integrating the selected criteria for identification of the palaeo-channel which may be related to Chandrabhaga. Each criterion used for detecting the palaeo-channel has been assigned a weight using AHP in the GIS platform and integrated to delineate the most probable location of the palaeo-channel.

Each of the thematic maps is scaled in 1 to 0 normal ratings in the GIS platform, where the high priorities are ranked as 1 and low priorities as 0 depending on their contribution to the palaeo-channel. Normalization has been carried out using the following algebraic relation

$$X_i = \frac{R_i - R_{\min}}{R_{\max} - R_{\min}},$$

where R_i is the raw rating and $R_{\max}$ and $R_{\min}$ are the maximum and minimum ratings of a particular layer[8–10].

The satellite imagery and *Google Earth* (source: Google Inc.) image show a sinusoidal trace, vegetation bands and contrast in the soil colour characteristic of a typical palaeo-channel, to the east of the Konark Sun Temple (Figure 2 *a* and *b*). The presence of dark green colour patches in the FCC image (Figure 2 *a*) is correlated with the moist region along the palaeo-channel trace[11]. After applying NDVI, the vegetation band along the channel shows brighter tone with high pixel value relative to the surrounding region. The palaeo-channel trace has a dark tone in the thermal imagery, probably resulting

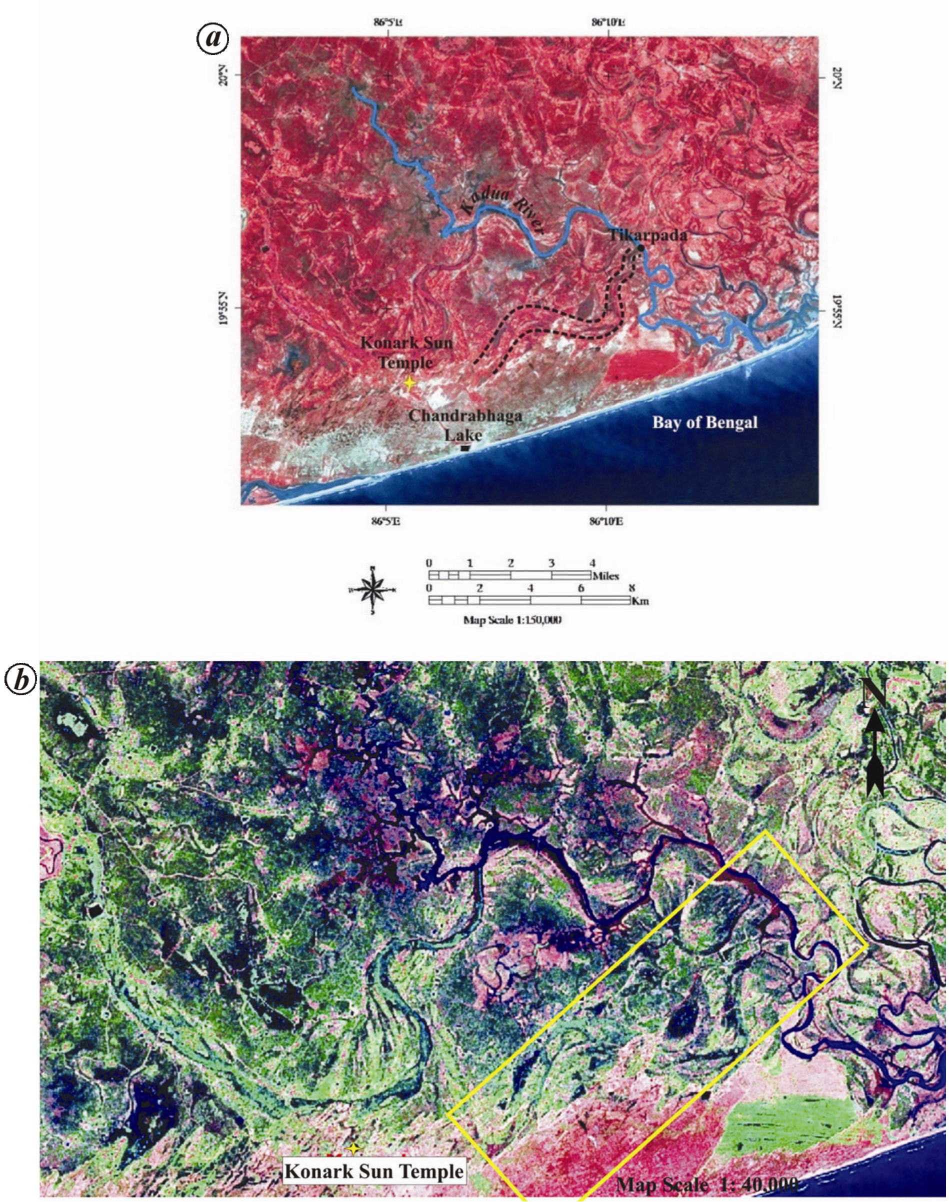

Figure 2. ***a***, False colour composite image of Konark region depicting the palaeo-channel trace (marked with dashed line) near the Sun Temple. ***b***, ETM + Pan mosaic image showing the trace of the palaeo-channel. The yellow rectangular area shows the limits of the present study.

from the presence of higher moisture content along the channel. Even when palaeo-channels are filled with sediments, they may still retain the impression of an old valley with a *V*-shaped configuration (Figure 3 *a*). GPR profiling across some regions of the identified palaeo-channel shows the existence of a *V*-shaped subsurface river valley with high-amplitude reflections along the two banks that may be caused by compacted wet clay (Figure 3 *b*). At the middle of the valley there are loose homogenous sediments; these may correspond to coarse sand identified by low reflection. However, the question that still remains to be answered is whether this delineated palaeo-channel corresponds specifically to the Chandrabhaga or not. This can be tentatively asserted by comparing the locality of the identified palaeo-channel with historical data, and even myths related to the river, as documented in the literature[1].

Field studies conducted in the identified area reveal that the suspected palaeo-channel is characterized by swampy lands covered with water hyacinth plants. The palaeo-channel of this old river can be traced to the village of Tikarpada, near the bank of River Kadua, further to the northeast.

The thematic maps generated using GIS also support the existence of the palaeo-channel identified from *Google Earth* and satellite data. The elevation data show that the palaeo-channel is characterized by a sinusoidal zone of low elevation (interpreted to be a riverbed) that

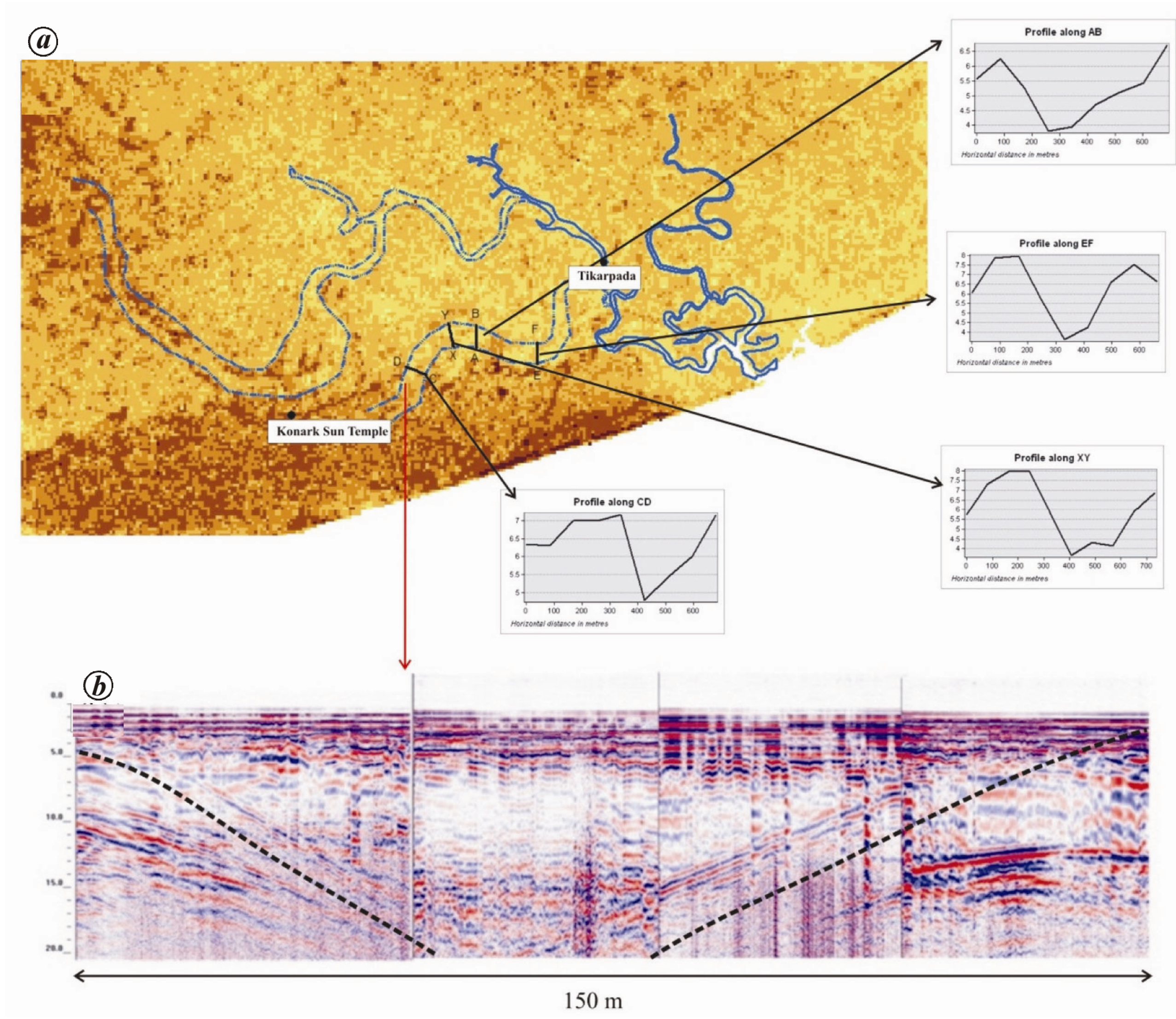

Figure 3. ***a***, Spatial profile along the selected line traverses across the suspected palaeo-channel, showing its *V*-shaped topographic outline. ***b***, Subsurface image of the river channel inferred from GPR survey along the traverse shown in (***a***).

has elevated banks. The integrated gravity anomaly map, based on gravity data collected from past sources[4], shows that a low gravity anomaly zone follows the trend of the identified palaeo-channel. Low gravity anomaly indicates the presence of low density material, which is interpreted here to represent sedimentary deposits along the depressed zone. The geological map shows that the study area is covered with alluvium, a deposit characteristic of rivers[3,4]. In addition, the tectonic map shows that the region is characterized by alternate ridges, depressions and lineaments that are almost parallel to the coast[4]. Since the trend of the delineated palaeo-channel coincides with the trend of these lineaments, it can be surmized that the palaeo-channel trend was structurally controlled. Finally, all the generated thematic maps are integrated in the GIS platform by assigning the weights to get the final output map using weighted sum algorithm which follows the algebraic expression: [Thermal] * 0.2857 + [elevation] * 0.2381 + [NDVI] * 0.1905 + [anomaly] * 0.1429 + [geology]*0.0952 + [tectonic] * 0.0476 = Weighted sum/final output map.

Each thematic map is multiplied by the respective weights obtained in AHP, and these are summed together to generate a final map in which the highest probability of existence of a palaeo-channel is indicated by 1, and the lowest by 0.115 (Figure 4). The probable trace of the palaeo-channel in the proximity of the Konark Sun Temple is found north of the site, extending towards both east and west. This trace, however, does not include the Chandrabhaga Lake, which lies south of the temple as well as the identified flow path along the coast (Figure 5). Nevertheless, the possibility of the original flow path from the identified palaeo-channel, into the Bay of Bengal through the present site of Chandrabhaga Lake cannot

Table 1. Weights assigned to the thematic maps for GIS integration

Themes	Thermal	Elevation	NDVI	Gravity anomaly	Geology	Tectonic data	Weightage
Thermal	1	6/5	6/4	6/3	6/2	6/1	0.2857
Elevation	5/6	1	5/4	5/3	5/2	5/1	0.2381
NDVI	4/6	4/5	1	4/3	4/2	4/1	0.1905
Gravity anomaly	3/6	3/5	3/4	1	3/2	3/1	0.1429
Geology	2/6	2/5	2/4	2/3	1	2/1	0.0952
Tectonic data	1/6	1/5	1/4	1/3	1/2	1	0.0476

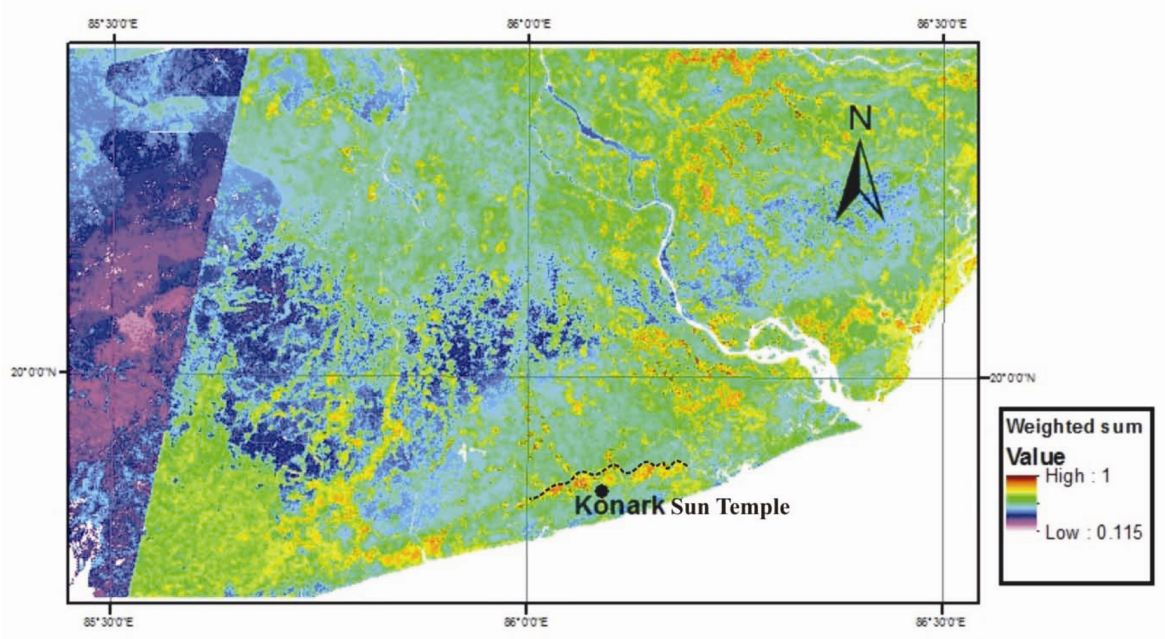

Figure 4. Final output map of the location with the highest probability of existence of a palaeo-channel near the Konark Sun Temple (marked by dashed line). Note that the identified channel passes north of the temple.

Figure 5. Probable trace of the Chandrabhaga palaeo-channel (marked as a solid line), approximately parallel to the coast as indicated by high probability zone depicted in Figure 4. The palaeo-channel marked with a dashed line and question mark shows a possible, but as yet unconfirmed flow path through the present site of Chandrabhaga Lake.

be completely overruled (dashed line in Figure 5). This intervening region, between the identified palaeo-channel and the lake, is almost completely covered with sand dunes, and therefore, the possibility of a smaller and as yet unidentified channel passing through the Lake from the main river cannot be discarded entirely. It is worthwhile to mention that near the coast, rivers change course frequently; this possibility, therefore, cannot be completely negated on the basis of the present evidence.

Most myths have their roots in some real events. Almost all myths regarding Konark are associated with a water body near to the Konark Sun Temple and indicate the presence of the Chandrabhaga river. Old illustrations and photographs also indicate the presence of water in the proximity of the temple. An aerial examination of the area through satellite imagery depicts the trail of a lost river which is otherwise difficult to identify in the field. All the evidence, including (a) sinusoidal pattern of the river as seen in *Google Earth* and Landsat imagery; (b) high NDVI indicating enhanced vegetation along the channel; (c) patches of water bodies at various locations along the channel; (d) the thermal infrared band showing darker tone within the palaeo-channel area indicating higher moisture content than the surrounding region; (e) association of the river with tectonic depressions and lineaments; (f) *V*-shaped depression seen along the elevation profile indicating a past river valley; (g) a subsurface river valley identified through shallow surface investigation, indicate the presence of a palaeo-channel near Konark, towards the north of the Sun Temple. Combining the myths with scientific and historical evidence, the identified palaeo-channel may be correlated to the lost river Chandrabhaga. What caused the extinction of this river remains a subject of further investigation.

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A student-centric research and education programme on heavy metal pollution of water bodies from selected Indian cities

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A research and education programme on environmental chemistry has been initiated to train a few selected undergraduate students so that they can take up environment-related issues and challenges for long-term sustainability of the ecosystem. The main goal of this programme is to instill 'responsible citizenship behaviour' in them in order to carry forward the huge task of environmental protection through research activities and community awareness programmes. Here we report spectrophotometer-based estimation of hexavalent chromium (9.5–337 $\mu g\ l^{-1}$), lead (20–158 $\mu g\ l^{-1}$), cadmium (from below detection limit to 34 $\mu g\ l^{-1}$) and nickel (from below detection limit to 19 $\mu g\ l^{-1}$) concentrations in different rivers, surface and groundwater bodies collected from selected cities

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