

## **A significant shift in the particulate organic matter character during flooding of the Krishna River, eastern peninsular India.**

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### **Abstract**

Extremely heavy rainfall over a small semi-arid section of the Indian Peninsula in October 2009, together with release of water from dams resulted in very severe flooding in the Krishna River. The sources and type of the organic matter during and after floods were investigated by analyzing suspended particulate matter (SPM) for organic carbon (C), total nitrogen (N) and isotopic composition of C ( $\delta^{13}\text{C}_{\text{org}}$ ). The  $\delta^{13}\text{C}_{\text{org}}$  varied from -21.4‰ during the initial heavy flood phase to -27.1‰ in the final receding phase. Discharge of terrestrial carbon (-21.4 to -23.5‰) from mixed sources with high C/N ratios (14-19) during the initial phase of the flood originated from the semi-arid section of the river. The light carbon (-25.5 to -27.1‰) with low C/N ratios (7.2-9.5) in the receding phase of the flood is from local C3 rich organic debris from the deltaic regions along with phytoplankton from aquatic sources. Since the average suspended sediment discharge of the Krishna River has decreased from 68 million tones to less than 0.1 million tones due to construction of dams and barrages, it appears that sediments and organic matter presently being delivered to the oceans are mainly during flood events and the type of organic matter delivered depends on nature of the soil where the high rainfall is received.

**Key words:** Krishna River, organic carbon sources, carbon isotopes, C3 and C4 plants, floods, extreme rain fall events.

## Introduction

Rivers play an important role in transporting sediments and organic matter from the land to the sea. Fluvial carbon is the biggest source of organic carbon in continental margin sediments. The total global fluvial carbon flux is 0.80–1.33 Pg C/y<sup>1</sup>. During the last century, most rivers of the world, including Peninsular Indian rivers, have dams built across them, resulting in significant reduction in water, sediment and organic carbon delivery to the oceans<sup>2</sup>. The Krishna River is an extreme example of this as more than 650 small and large dams have been constructed across this River during the last 60 years. Since 2002 the holding capacity of the dams by the Krishna River nearly equals or exceeds the annual runoff<sup>3-5</sup>. Understanding the amount and nature of carbon in such river basin is important as reduction in carbon supply affects the estuarine and near coastal environment.

Soil carbon, aquatic plants, agriculture, vascular plants, bacteria etc. are the main sources of terrestrial organic carbon<sup>6-8</sup>. The soil type, agriculture, vegetation, precipitation, temperature and weathering rates dictate the nature of organic matter in fluvial environment. The C/N (organic carbon/nitrogen) ratio and  $\delta^{13}\text{C}_{\text{org}}$  are commonly adopted to characterize the organic carbon sources<sup>9-12</sup>. Relatively lower  $\delta^{13}\text{C}_{\text{org}}$  ranging from -23‰ to -33‰, with an average -27‰ characterize the C3 organic matter<sup>13-15</sup> while plants employing C4 pathway are distinguished by  $\delta^{13}\text{C}_{\text{org}}$  enrichment ranging from -9‰ to -17‰<sup>13,14,16-18</sup>. Fresh water phytoplankton has  $\delta^{13}\text{C}_{\text{org}}$  values between -25‰ and -30‰ and relatively low C/N ratios (5-10)<sup>18,19</sup>. On the other hand, the soil organic matter (SOM) has high C/N ratios (>12)<sup>20</sup>.

The Krishna River, after its origin in the Western Ghats rainforests (annual rainfall >2500 mm), flows mainly through a semi-arid Deccan Plateau (<600 mm annual rainfall) for most of its length till it reaches the deltaic regions where rainfall increases to about 800 mm per year (Figure 1). Over 80% of the rainfall in the Krishna Basin occurs during the summer monsoon period (June to September). Sediments as well as organic matter in the Krishna River are discharged mainly during this period. Construction of dams and barrages along this river has altered the flow of freshwater to the Bay of Bengal (BOB), drastically. Sediment delivery has reduced from 68 million tonnes before 1960 to <0.1 million tonnes during the last decade<sup>4,21-23</sup>. A compilation of discharge for the past 50 years also shows a general decreasing trend along the Krishna River<sup>23-25</sup>. The suspended load at Wadenapalli during last decade has drastically reduced to <0.1 million tonnes<sup>26</sup> from 68 million tonnes before 1960's<sup>21</sup>..

In recent years, a number of extreme rain fall events and associated flash floods are recorded in India which includes the events of Mumbai 2005, Raichur 2009, Uttarakhand 2013 and Kashmir

2014 and 2015. In October 2009, the semi-arid regions of the Krishna River experienced unprecedented rain fall of 33-57 cm within 3-4 days (30<sup>th</sup> September to 3<sup>rd</sup> October) as compared to an average monthly rainfall of 7-13 cm (Figure 2)<sup>27</sup>. High rainfall in a short span of time lead to high water levels in the dams forcing abrupt release of water from reservoirs causing intense flooding in the lower regions. Cascading effect lead to the highest water levels in the Srisailem dam on 30<sup>th</sup> September, in Nagarjuna Sagar dam on 3<sup>rd</sup> October and in Prakasam Barrage on 6<sup>th</sup> October<sup>27</sup>. Water inflow of nearly 31,000 m<sup>3</sup>s<sup>-1</sup> was recorded at the Prakasam Barrage on 6<sup>th</sup> October 2009<sup>27</sup> against an annual average flow of 2,213 m<sup>3</sup>s<sup>-1</sup><sup>28</sup>. The high inflow surpassed all previous records of water flow including the great flood of 1903 which occurred before the dams were built<sup>27</sup>. The flood water breached the river banks at several places thereby inundating several low lying areas and populated regions (Figure 3a). With decrease in precipitation and regulation of water release from dams from 15<sup>th</sup> October 2009, water discharge returned to normal levels by the end of October 2009 (Figure 3b). Significant load of sediment and suspended organic matter were delivered to the oceans during the extreme precipitation and discharge periods. The impact of high discharge caused by the Godavari River to the coastal western BOB has been reported earlier<sup>29</sup>. The objective of the present study is to assess the shift in characteristic of SPM and organic matter delivered to the coastal BOB during severe flooding of the Krishna River.

The SPM was collected in the Krishna Estuary from a bridge (16.033°N; 80.873° E; Figure 1) about 60 km downstream of the Prakasam Barrage. The sampling was done on alternate days starting from 9<sup>th</sup> October 2009 till 27<sup>th</sup> October 2009 (Table 1). Sampling could not be carried out for the first week after the start of the flood as the area was inaccessible due to flooding. Surface water was collected in large clean plastic buckets and suspended matter allowed to settle for a day. The clear water was decanted, the remaining slurry transferred to acid cleaned plastic bottles and stored in a refrigerator. The slurry was filtered onto 0.4 µm polycarbonate filters, and while still wet removed from the filter using a plastic blade and subsequently freeze dried and powdered.

Total carbon and nitrogen and inorganic carbon (TIC) contents were measured by using Carlo-Erba NCS 2500 analyzer and UIC CO<sub>2</sub> 5014 Coulometer respectively. The analytical precision and accuracy based on replicate analysis and international reference material (MAG-1 and SGR-1) is within ±5%. The organic carbon (%) was calculated as the difference between total carbon and TIC. Another aliquot of the particulate matter was washed repeatedly with 1N HCl and distilled water for removing calcium carbonate before measuring δ<sup>13</sup>C<sub>org</sub>. The complete removal of carbonate from the

particulate matter was ensured by treating the sample with 1N HCl till complete absence of CO<sub>2</sub> effervescences.

An elemental analyzer coupled with Isotope Ratio Mass Spectrometer (EA-IRMS-Delta V, Finnigan, Germany) was used to measure  $\delta^{13}\text{C}_{\text{org}}$  in the particulate matter. The results are expressed relative to Pee Dee Belemnite (PDB) limestone<sup>30</sup> as  $\delta$  notation. High purity CO<sub>2</sub> was used as a working standard for  $\delta^{13}\text{C}_{\text{org}}$ . The CO<sub>2</sub> gas was calibrated with internal reference materials of Glutamic Acid, Alanine, marine sediment and International Atomic Energy Agency (IAEA) standards. Standard deviation of duplicate analysis and long term precision of the instrument is within  $\pm 0.2\%$  for carbon. The analytical results are presented in Table 1.

The organic carbon and nitrogen concentrations of particulate matter show distinct variations during and after the flood period. During the initial intense flood period both C and N contents are low (0.98% and 0.06%, Table 1), increase gradually and reach a maximum of 7.32% and 1.16% respectively during the receding phase of the flood. On the other hand C/N ratios are high (14-19) during the initial phase of the flood, and decrease gradually to reach a low of  $\sim 7$  during its ebb phase. The  $\delta^{13}\text{C}_{\text{org}}$  of particulate matter vary widely between  $-21.3\%$  and  $-27.1\%$  (Table 1). The  $\delta^{13}\text{C}_{\text{org}}$  is enriched ( $-21.3\%$ ) during the initial flood period and gets gradually depleted to  $-27\%$  at the ebb phase.

The large temporal variation in  $\delta^{13}\text{C}_{\text{org}}$  ( $-21.3\%$  to  $-27.1\%$ ) and C/N (Figure 4a) indicate changes in the provenance of organic matter (Table 1). The X-Y plot of C/N ratio versus  $\delta^{13}\text{C}_{\text{org}}$  can be used to characterize organic matter sources<sup>18</sup>. The initial flood period is characterized by high C/N ratios and enriched  $\delta^{13}\text{C}_{\text{org}}$  values which progressively trend towards low C/N ratios and depleted  $\delta^{13}\text{C}_{\text{org}}$  values. By the ebb phase of floods, the  $\delta^{13}\text{C}_{\text{org}}$  values and C/N ratios are close to  $-27\%$  and 7 respectively which is typical of C3 vegetation and fresh water phytoplankton<sup>13-15,18,19</sup>. The  $\delta^{13}\text{C}_{\text{org}}$  during flood period differ significantly nearly by  $\sim 8\%$  when compared to the Krishna River estuarine particulate matter ( $-29.7\%$ )<sup>31</sup> collected during summer monsoon period. This isotopic difference suggests a shift in the organic matter provenance during flood period to C4 rich vegetation from C3 rich vegetation and fresh water phytoplankton during non-flood period. Moreover in the X-Y plot between C/N and  $\delta^{13}\text{C}_{\text{org}}$  the intercept along  $\delta^{13}\text{C}_{\text{org}}$  axis at  $-27\%$  (Figure 4 a), close to Krishna River particulate matter, further supports the provenance shift observed in  $\delta^{13}\text{C}_{\text{org}}$  variation during the cycle of the present flood (Figure 4b).

In order to understand variations of carbon sources and quantify the relative contribution of each source, an isotope mixing model SIAR (Stable Isotope Analysis in R) an open source R package (<http://cran.r-project.org>) is used. This model has been used to explain carbon source

appropriation<sup>12,32</sup>. The carbon in the present samples may have multiple sources such as terrestrial carbon (soil carbon, C3 and C4 vegetation) and aquatic carbon (fresh water, estuary and marine). The end member carbon isotopic value of each source is required for model calculation. As the  $\delta^{13}\text{C}_{\text{org}}$  for the Krishna River Basin sedimentary organic matter was not available for mixing calculations, we have utilized the  $\delta^{13}\text{C}_{\text{org}}$  data available for the adjacent Godavari River Basin<sup>12</sup> which has a similar source area. The calculated proportions of carbon from different sources indicate that soil carbon, C3 and C4 vegetation together contribute highest carbon (50%; Figure 5a) to the Krishna River particulate matter during floods. While carbon derived from aquatic sources (fresh water 40%; estuary 20%; marine 10%) dominates during the receding phase of floods compared to terrestrial sources (C3 20%; C4 5%; soil 5%; Figure 5b). The terrestrial carbon from mixed sources during flood period is replaced with carbon from aquatic sources during receding phase of floods.

. The traditional major crops in the semi-arid region of Peninsular India are Jowar (*Sorghum*), corn (*Zea mays L.*) and millet (*Pennisetum americanum*) which are typical C4 plants<sup>33</sup>. These traditional crops have been replaced with rice, a C3 plant, near reservoirs. In the deltaic Krishna region which receives moderate rain fall and assured supply of water from reservoirs the cultivated crops are rice (*Oryza Sativa*), sugar cane (*Saccharum sp.*) and commercial crops like cotton, ground nut (*Arachis hypogaea*) and chilies (*Capsicum spp.*)<sup>34,35</sup>. Rice is a typical C3 type crop while sugarcane is a C4 type.

The  $\delta^{13}\text{C}_{\text{org}}$  (-21.4‰ to -23.5‰) of suspended matter in the flood waters suggest that terrestrial carbon derived from C3 and C4 type crops from the semi-arid region contributed significantly to the particulate matter in the Krishna River during flood period. The high C/N ratios (14-19; Table 1) suggest organic matter was degraded (Fig. 4). The  $\delta^{13}\text{C}_{\text{org}}$  as well as C/N ratio of the particulate organic matter in the receding flood waters suggests an alternate source for the organic matter is possible. The depleted  $\delta^{13}\text{C}_{\text{org}}$  (-25.5‰ to -27.1‰) suggest that the organic carbon is mainly from C3 vegetation (20% Figure 5b). During ebb phase of floods a reduction in C4 vegetation (18 to 5%) also supports dominance of C3 type organic matter. Very low C/N ratios (7-9; Table 1) suggest fresh leaf litter, agriculture residues and phytoplankton. An examination of the suspended particulate matter by microscope indicates that the organic matter is composed mainly of fragments of rice plants and foliage. The mixing calculations show that the organic carbon is derived from aquatic sources (fresh water 40% and estuarine 20%) during receding phase of floods.

During the 2009 monsoon (June-October) the particulate matter discharged by the Krishna River at Wadenapalli was ~2.54 million tonnes of which 2.30 million tonnes was discharged during

the month of October 2009<sup>26,27</sup>. Most of this particulate load (~94% of the total) was discharged by the Krishna River during the first ten days in October during intense flooding (Figure6)<sup>26,27</sup>. Our calculations show that the amount of total sediment and organic carbon discharged during the first half of October, during which the flooding event occurred, amount to 1.9 million tonnes and 0.02 million tonnes (Table 1) respectively.

The sediment discharge during the flood period is three foldsto that of total sediment discharged during 2000 to 2005 (0.63 million tonnes) to the western Bay of Bengal by the Krishna River (Figure6). Thus extreme precipitation and associated floods are important events wherein during a shortperiod of time large amounts of riverbed sediments and particulate organic matter are transferred to the coastal regions. The present day transfer of sediment and organic matter, therefore, depends on the area of flooding and release of waters from dams and reservoirs.

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## Figure captions

**Figure 1** Map showing the Krishna River and its tributaries. The location of the suspended particulate matter sampling is shown as a rectangle. Different shades of grey represent the annual average precipitation (mm) along the Krishna River basin for the period 1951-2003<sup>36,37</sup>. The depth contours are at 200 m interval.

**Figure2** Map showing high precipitation (mm, bold) in four days (30<sup>th</sup> September - 3<sup>rd</sup> October 2009) compared to normal monthly rain fall in the semi-arid Krishna River Basin<sup>27</sup>. The inset shows the Krishna River basin.

**Figure3 a** Satellite image (Modis Terra True Colour Image 1km) of 7<sup>th</sup> October 2009 showing the suspended sediments being discharged into the Bay of Bengal during the peak flood period.

**3 b** Satellite image (Modis Terra True Colour Image 250 m) of 24<sup>th</sup> October 2009 showing noticeable reduction of suspended sediment discharge during the receding phase of flood.

**Figure4a** X-Y plot of C/N ratios versus  $\delta^{13}\text{C}_{\text{org}}$  (‰) of the Krishna River particulate matter collected during October 2009. Notice a drastic change in the terrigenous organic matter source during the peak and receding phase of the floods. The  $\delta^{13}\text{C}_{\text{org}}$  (‰) values for C3 and C4 type plants are from the literature<sup>18</sup>.

**Figure 4 b** Differences in the terrestrial carbon load discharged during flood and receding phase of the October 2009 flood.

**Figure 5** Source material proportional contributions from terrestrial C3 (TC3) and C4 (TC4) plants, soil, freshwater (FP), estuarine (EP) and marine phytoplankton (MP) to the particulate matter during a) flood period and b) receding flood period. Boxes indicate credibility intervals of 95 and 75% contribution from each source.

**Figure6** Annual sediment load carried by the Krishna River at Wadenapalli<sup>26</sup>. The arrow represents the total sediment load during the flood period is based on particulate matter collected in this study.

## Table caption

**Table 1** Details of suspended particulate matter collected during great October 2009 flood along with elemental and carbon isotope data. Total suspended load (million tonnes) and organic carbon load (tonnes) during flood period is also provided.

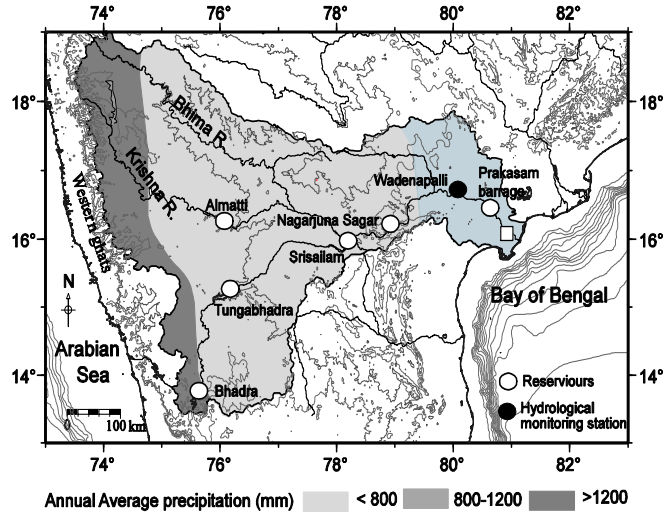


Fig. 1 Map showing the Krishna River and its tributaries. The location of the suspended particulate matter sampling is shown as a rectangle. Different shades of grey represent the annual average precipitation (mm) along the Krishna River Basin for the period 1951-2003<sup>42,43</sup>. The depth contours are at 200 m interval.

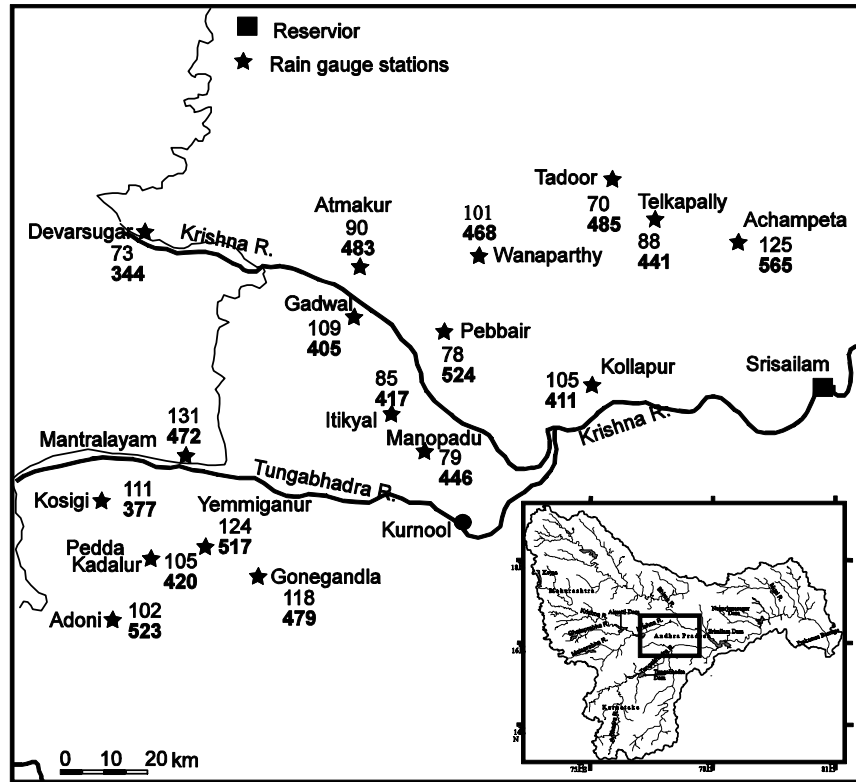
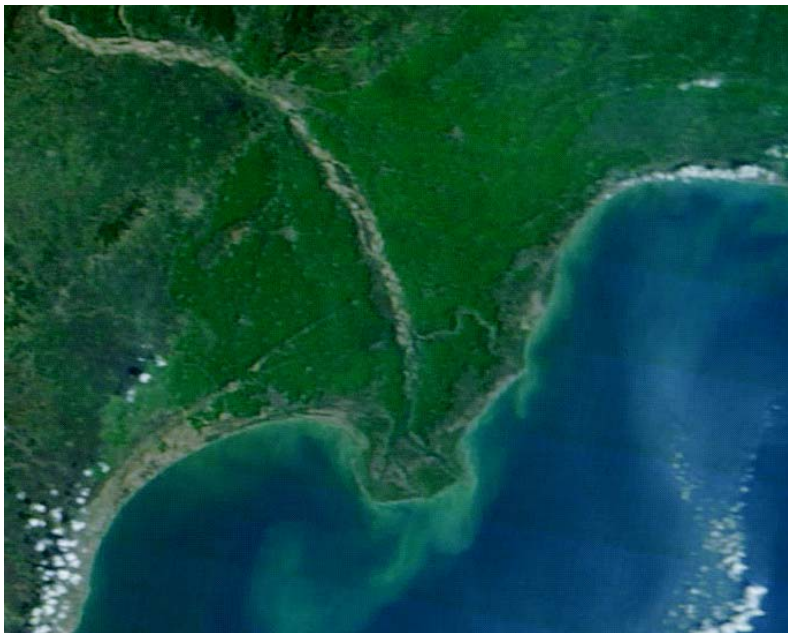


Fig. 2 Map showing high precipitation (mm, bold) in four days (30<sup>th</sup> September - 3<sup>rd</sup> October 2009) compared to normal rain fall (mm, normal) in the semi-arid Krishna River basin<sup>27</sup> (Data sources: Dept. of Economics and Statistics, Govt. of Andhra Pradesh). Insert shows the Krishna River basin.



**Figure 3 a** Satellite image (Modis Terra True Colour Image 1 km) of 7<sup>th</sup> October 2009 showing the suspended sediment being discharged in to the Bay of Bengal during the peak flood period



**Figure 3 b** Satellite image (Modis Terra True Colour Image 250 m) of 24<sup>th</sup> October 2009 showing noticeable reduction of suspended sediment discharge during the receding phase fo flood.

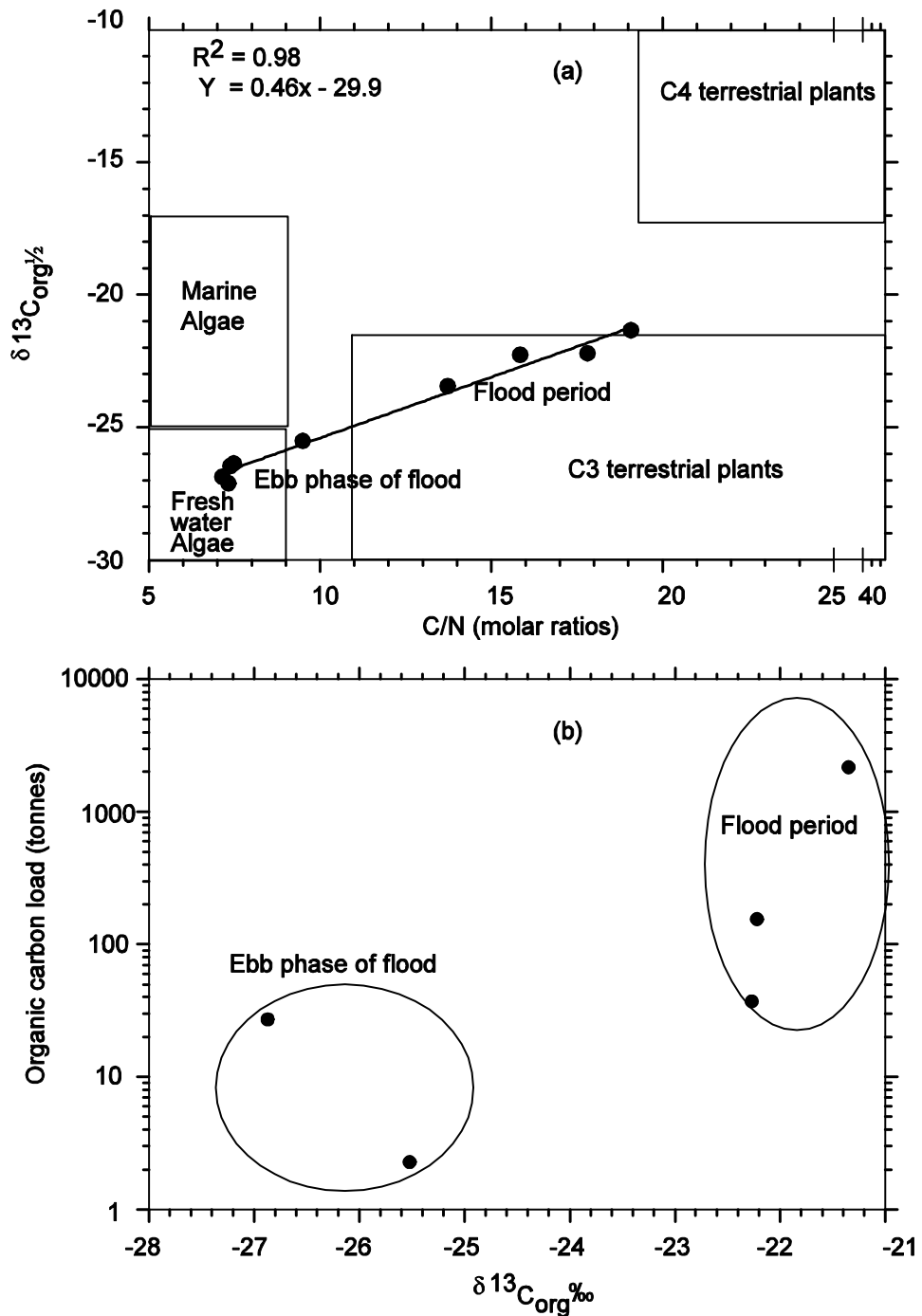


Figure 4 a) X-Y plot of C/N ratios versus  $\delta^{13}C_{org}$  (‰) of the Krishna River particulate matter collected during October 2009. Notice a drastic change in the terrestrial organic matter sources during the peak and receding phase of the floods. The  $\delta^{13}C_{org}$  (‰) values for C3 and C4 type plants are from the literature<sup>18</sup>.

b) Differences in the terrestrial carbon load during flood and receding phase of the October 2009 flood.

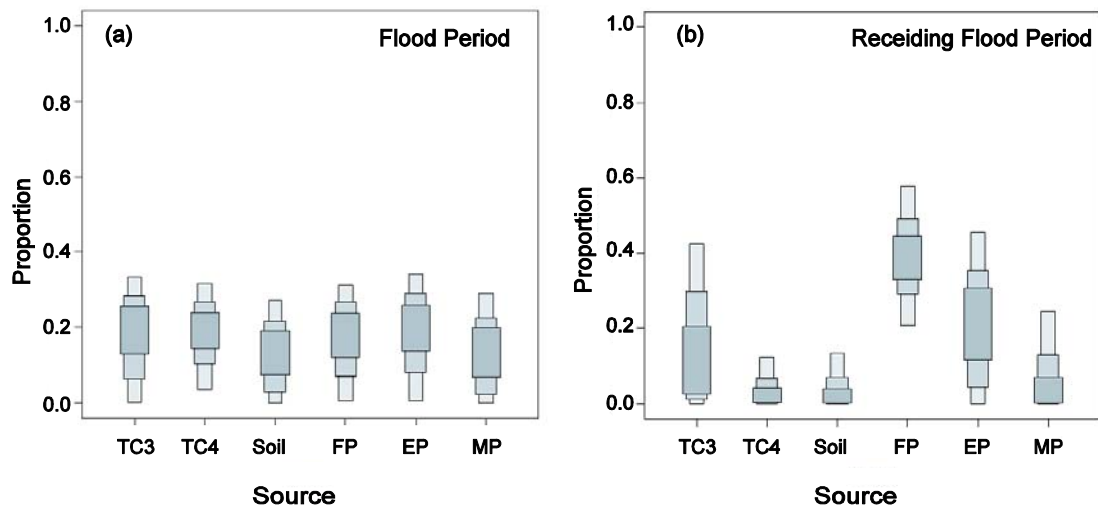


Figure 5 Source material proportional contributions from terrestrial C3 (TC3) and C4 (TC4) plants, soil, freshwater (FP), estuarine (EP) and marine phytoplankton (MP) to the particulate matter during a) flood period and b) receding flood period. Boxes indicate credibility internals of 97 and 75% for contribution from each source.

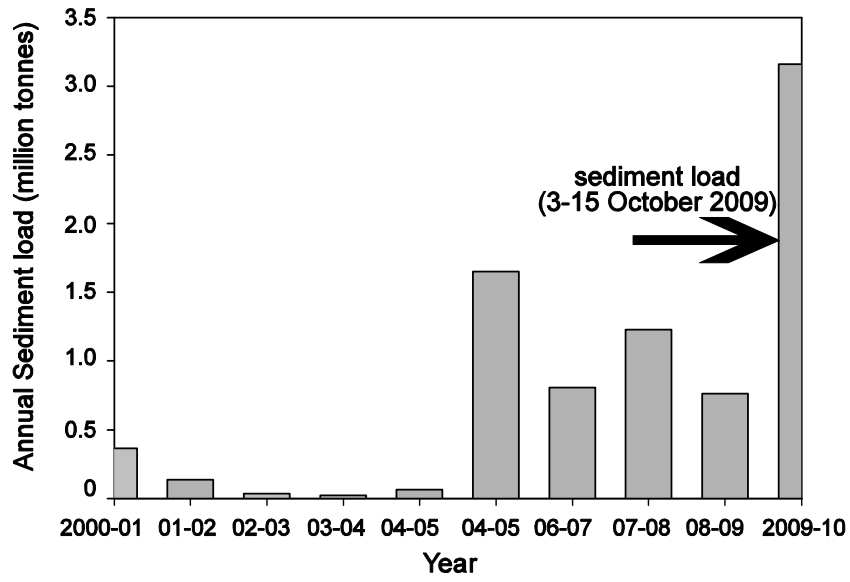


Figure 6 Annual sediment load carried by the Krishna River at Wadenapalli<sup>26</sup>. The arrow represents the total sediment load during the flood based on the particulate matter collected in this study.



Table 1 Details of total suspended particulate matter (SPM) collected during the great October 2009 flood along with elemental and carbon isotope data. Total suspended load (million tonnes) and organic carbon load (tonnes) during flood period is also provided

Sample ID	Date of collection	Lat. (N)	Long. (E)	SPM wt. (mg/l)	Nitrogen (wt.%)	Organic carbon (wt.%)	C/N (molar ratios)	$\delta^{13}\text{C}_{\text{org}}\text{‰}$ vs PDB	Total suspended load (million tonnes)	Organic carbon load (tonnes)
SSKR-1	9.10.2009	16.033°	80.873°	178	0.06	0.98	19.085	-21.35	0.221	2166
SSKR-2	11.10.2009	16.033°	80.873°	81	0.06	0.91	17.815	-22.22	0.017	155
SSKR-3	13.10.2009	16.033°	80.873°	64	0.08	1.08	15.840	-22.27	0.0034	37
SSKR-4	15.10.2009	16.033°	80.873°	22	0.10	1.17	13.733	-23.46	--	--
SSKR-5	17.10.2009	16.033°	80.873°	19	0.28	2.27	9.485	-25.52	0.0001	2.27
SSKR-6	19.10.2009	16.033°	80.873°	8	0.85	5.32	7.323	-27.11	--	--
SSKR-8	23.10.2009	16.033°	80.873°	15	0.89	5.43	7.138	-26.87	0.0005	27.15
SSKR-9	25.10.2009	16.033°	80.873°	8	0.69	4.41	7.478	-26.36	--	--
SSKR-10	27.10.2009	16.033°	80.873°	9	1.16	7.32	7.383	-26.46	--	--