Sediment geochemistry of the Krishna river system: Implications to Weathering pattern and elemental mobility

A Thesis

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by

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Certificate

This is to certify that this dissertation entitled **Sediments geochemistry of the Krishna river : Implications to Weathering pattern and elemental mobility sediments** towards the partial fullment of the BSMS Dual Degree Programme at the Indian Institute of Science Education and Research, Pune represents study/work carried out by **Vaishnavi Vitthal Kardile**, (Reg. No. : 20171124) at IISER Pune under the supervision of **Dr.Gyana Ranjan Tripathy**, Department of Earth and Climate Sciences, IISER Pune during academic year 2021-2022.

Tripathy

Dr Gyana Ranjan Tripathy

Declaration

I hereby declare that the matter embodied in the report entitled **Sediments geochemistry of the Krishna river : Implications to Weathering pattern and elemental mobility sediments** are the results of the work carried out by me at the Earth and Climate Science Department, Indian Institute of Science Education and Research, Pune, under the supervision of Dr Gyana Ranjan Tripathy and the same has not been submitted elsewhere for any other degree

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Content

Abstract

Weathering of continental rocks is a key component in the global biogeochemical and climatic cycles. This land surface processes are found to be disproportionally higher (compared to their areal extent) in the tropical river basins, mainly due to their conducive climate (runoff and temperature). In particular, the rivers from the Peninsular India receive high rainfall mainly during south-west monsoon periods and also, predominantly flow through terrains dominated by silicate rocks. In this thesis work, the major oxide concentrations of the bed sediments from the Krishna mainstream and its major tributaries to infer chemical mobility of elements and sediment provenances for the basin. These samples, with good spatial-resolution covering samples from both Deccan traps and Archean Granitic terrains, have already been collected during high flow stages (August, 2015) of the river system and currently, archived at IISER, Pune. These data for the sediments from the Deccan trap regions fall between end-member compositions of Basalts and smectite. The concentrations of mobile elements show that the chemical weathering play a dominant role in influencing the sediment chemistry of these samples. In contrast, the sediment from the Archean terrain locations fall closer to the granitic composition and possibly retain the source signature. At the outflow, the Fe, Mg and P concentrations fall closer to the granitic end-member compositions than the basaltic compositions. This indicates that the sediment production in the basin is mainly restricted in the granitic terrains and in the lower reaches. The upper reaches i.e. north-western part of the basin(with high basin slope) composed of basaltic rocks (with faster dissolution kinetics) seem to play minimal role in the physical erosion in the basin. Outcomes from this study indicates that the lithology play a key role in the basin in regulating the sediment budget of the Krishna river basin.

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1. Introduction

Weathering of continental rocks is one of the key component of the global biogeochemical and climatic cycles (Gaillardet et al., 1999). Specifically, the chemical erosion of silicate minerals act as a major sink for atmospheric CO_2, which in turn helps in maintaining the thermostat of our planet. These erosion intensities are regulated by several factors, which includes runoff, temperature, lithology, vegetation, elevation, geomorphic properties (basin slope) and intensity of physical erosion (West et al., 2005). Available chemical weathering rate estimates show large spatial variability at a global scale, with higher rates being observed for the tropical river basins. The high erosion rates in the tropics are possibly linked to their conducive climate (rainfall and temperature) which promotes efficient water-rock interaction (Samanta et al., 2019). Traditionally, dissolved major ion chemistry of rivers are used to estimate the silicate weathering rates and related CO_2 consumption rates. These rate calculations involve mass balance calculation involving river water chemistry and chemistry of their possible solute sources. This approach, however, is prone to large uncertainties due to lack proper information about chemical release ratios during rock dissolution and lack of time-series chemical data for rivers with highly varying runoff variations at a seasonal scale. Moon et al. (2014) have showed that erosion rates estimated based on less number of samples ($n < 40$) can be associated with large errors and may not reflect the true chemical annual fluxes from river basins to the global ocean. Also, the annual water discharge of rivers shows large inter-annual changes due to spatial variability in rainfall in basins. These inter-annual runoff fluctuations further complicate the usage of water chemistry in constraining the erosion rates and access their importance in long-term carbon budget.

In contrast to water chemistry, chemistry of sediments (in comparison to their source rock) can serve as a time-averaged erosion rate of river basins. The release of mobile elements during chemical weathering leads to a depletion in their concentrations with respect to their source rock and this difference can be used to quantify the chemical erosion rate and chemical mobility of elements. Additional to chemical erosion, the chemical composition of river sediments also holds clues for sediment provenances and sediment budget of the basin. Studies on chemical weathering and erosion based on riverine particulate loads are less common (McLennan, 1993; Gaillardet et al., 1995; Das and Krishnaswami, 2007; Singh, 2010) compared to those based on the dissolved load approach. Lupker et al. (2012) have investigated the sediment geochemistry of the Ganga river basin to show dominancy of chemical erosion in the flood plains than that in the headwaters. This observation was crucial to identify the locus of weathering in large river system. This detail, however, was complicated to infer based on water chemistry due to multiple aquatic processes occurring in the floodplains, such as saline-alkaline soil dissolution, calcite precipitation and transport-limited weathering. Similarly, the chemical and isotopic studies of river sediments from the Ganga (Singh et al., 2008) and Brahmaputra (Singh and France-Lanord, 2002) basins were successful in quantifying the relative sediment contributions from different litho-units and to identify the factors regulating these sediment processes in the Himalaya. In contrast to the Himalayan rivers, there exists limited sediment geochemistry study from the Peninsular Indian rivers. The study of river sediments from the Deccan flowing rivers (Das and Krishnaswami, 2007) was useful in quantifying the chemical mobility of major and trace elements in these terrains and related chemical fluxes to the Bay of Bengal.

In this thesis work, major ion chemistry of bed sediments from one of the large tropical rivers (Krishna river) from the Peninsular India have been investigated. The rivers from the Peninsular India receive high rainfall mainly during south-west monsoon period and also, predominantly flow through terrains dominated by silicate rocks. Considering role of silicate weathering in global CO_2 cycle, the Peninsular Indian rivers serve as a natural laboratory to study the impact of two important factors, lithology and climate, on the weathering intensity. whose chemical weathering act as a major sink for atmospheric CO_2 over geological timescale. The Krishna river mainly flows through two silicate dominating terrains (Deccan Trap basalts and Archean Granite-Gneisses) with different weathering kinetics. This thesis attempts to compare the sediment chemistry data of the river with literature-available data for sources rocks to compute the erosion rates and mobility of elements during weathering.

1.1. Objectives of the study

The major objectives of this study are as follows:

(i) Chemical characterization of bed sediments of the Krishna mainstream and its major tributaries

(ii) To quantify the relative sediment contribution from the Deccan basalts and Peninsular Archean rocks at the Krishna outflow, and factors regulating this sediment budget.

2. Krishna River Basin

The Krishna is one of the largest river systems in the Peninsular India. It has a total length of ~ 1,400 km and drainage area of ~ 258,948 km^2 (Fig. 1). It rises in the Mahadev range of the Western Ghats at an altitude of 1,337 m near Mahabaleshwar in Maharashtra State, about 64 km from the Arabian Sea. It flows for a distance of 305 km in Maharashtra, 483 km in

Karnataka and 612 km in Andhra Pradesh before finally out falling into the Bay of Bengal. Thirteen major tributaries join the Krishna River along its course, out of which six are right bank tributaries and seven are left bank tributaries. Among the major tributaries, the Ghatprabha, the Malprabha and the Tungabhadra are the principal right bank tributaries which together account

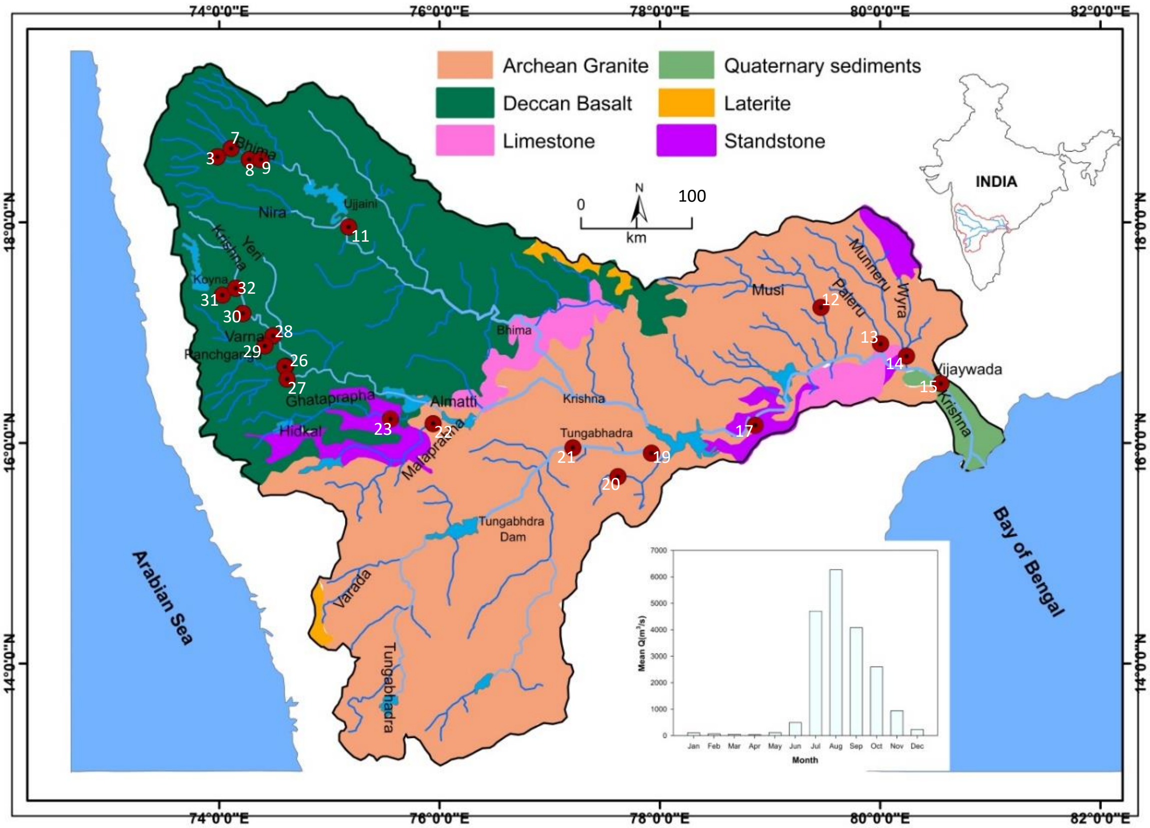

Figure 1: Location map of the sediment samples collected from the Krishna river system for this study(Number indicates sample number,e.g. 1: KR-1).

for 35.45% of the total catchment area, whereas the Bhima and the Musi are the principal left bank tributaries which together account for 35.62% of the total catchment area. The catchment area, length and elevation of source of the tributaries are given in Table 1. The drainage network of KRB is developed on a wide spectrum of geological formations of peninsular India (Table 1) ranging in age from the Precambrian to recent, which include the Deccan traps (Upper Cretaceous to Paleogene), granitoids and metasediments (Achaean to Proterozoic), sedimentaries (Mesoproterozoic to Neoproterozoic) and fluvial, fluvio-marine, Aeolian and coastal sediments (Quaternary) (Source: Geological Survey of India). A major portion of the basin is developed on the Precambrian Dharwar Craton (or the Karnataka Craton), while north to northwestern portion of the basin is solely underlain by the Deccan Traps. The Deccan Traps covers an area of about 500,000 km^2 of peninsular India, mostly in Maharashtra State and adjoining regions in Gujarat, Madhya Pradesh, Andhra Pradesh and Karnataka. The upstream sub-basin of the Krishna basin, such as Koyna, Panchganga, Dhoodhganga, and Bhima are predominantly covered (i.e., more than 80% of the basin area) by basalts (Table 1). Further, roughly 60% of the basin area of Ghataprabha is also dominated by basalt lithology. The dominant lithology of the Krishna is comprised of the rock suites of the Dharwar Craton (~400,000 km^2). Similar to the rest of the cratons of the Indian Shield, Dharwar Craton is also dominated by the Archean tonalite-trondhjemite gneiss (TTG), which is also known as Peninsular Gneiss. The soil types do also exhibit considerable variability across the basin, mainly due to the spatial variability in the geology and climate in KRB. The important soil types found in the basin are black soils, red soils, lateritic soils, alluvium, mixed soils and saline and alkaline soils (MoWR, 2014).

Table 1: Water Discharge, drainage area and major lithology of major tributaries of the Krishna river. These data are compiled from available literature (Jain et al., 2007)

Tributaries	Discharge 10^6 m^3/yr	Area (km^2)	Major lithology (areal coverage)
Koyna	3964	4,890	Basalt (100%)
Panchganga		2,575	Basalt (100%)
Doodhganga		2,350	Basalt (98%), Bhima Group (2%)
Ghataprabha	5380	8,829	Basalt (59%), Kaladgi Group (36%), TTG (2%), Bhima Group (1%), Laterite (1%)

Malaprabha	1980	11,549	TTG (38%), Greywacke with volcanics and chemogenic precipitates (25%), Kaladgi Group (19%), Basalt (6%), Granite (6%), Metavolcanics with metasediments and granitoid gneiss (3%), Granitoid and gneiss (3%)
Bhima	12690	70,614	Basalt (88%), Bhima Group (5%), Granite (4%), Potassic granodiorite to granite (2%), Laterite (1%)
Tungabhadra	14700	71,417	TTG (30%), Greywacke with volcanics and chemogenic precipitates (22%), Granite (18%), Potassic granodiorite to granite (14%), Metavolcanics with metasediments and granitoid gneiss (4%), Shallow marine shelf metasediments/volcanic sequence (4%), Granitoid and gneiss (3%), Laterite (2%), High grade schists and ultramafites (1%), Vempalle Formation with basic sills (1%)
Musi	1410	11,212	Potassic granodiorite to granite (87%), Basalt (7%), Granite (4%), Laterite (1%)
Paleru	483	3,263	Potassic granodiorite to granite (98%), Kurnool Group (2%)
Munneru	1980	10,409	Potassic granodiorite to granite (53%), Migmatite Complex (26%), Pakhal Supergroup (13%), Khondalite (2%), Gondwana Supergroup (2%), Metavolcanics with metasediments and granitoid gneiss (2%), Charnockite (1%), Gabbro-Anorthosite (1%)

3. Sampling and Analysis

Twenty-three bed sediment samples from the Krishna river basins were collected during 2015. These archived samples from the river mainstream and major tributaries of the Krishna river are used for this study. These samples were mostly collected from remote locations, in order to minimize the anthropogenic influences. The samples are collected from three locations separated by 200-300 m and mixed to form one aliquot. This approach was adopted to get a representative sample of the river bed. In the laboratory, the samples were powdered using agate mortar and pestles. The powdered samples were analyzed for their major oxide concentrations. Towards this, the powdered samples were ashed at 900° C for 4 hrs to estimate the Loss of ignition (LOI) of the samples. The ashed samples were fused to prepare beads for the XRF analyses. For this, sediment and flux (Lithium tetraborate 66%/Lithium metaborate 34 %) were taken in specify ratio (0.55 g: 9.35g) and few (8-10 drops) drops of 99 % of Lithium Bromide Anhydrous was added to make bead. The bead was prepared in a platinum crucible at a temperature of 1100°C. These beads were measured for their oxide concentrations of major elements (Na, K, Fe, Mn, and Si, Ca, Mg, Al, Ti, and P) using the XRF facility available at IISER Pune. These measurements were carried out using a standard-calibration approach. The accuracy of measurements was checked by analyzing the USGS standards BCR-2 and BHVO-2 (Table 2). The accuracy for measurement for BCR-2 is within ~ ± 3 % & BHVO-2 is ~ ± 4% (Fig. 2).

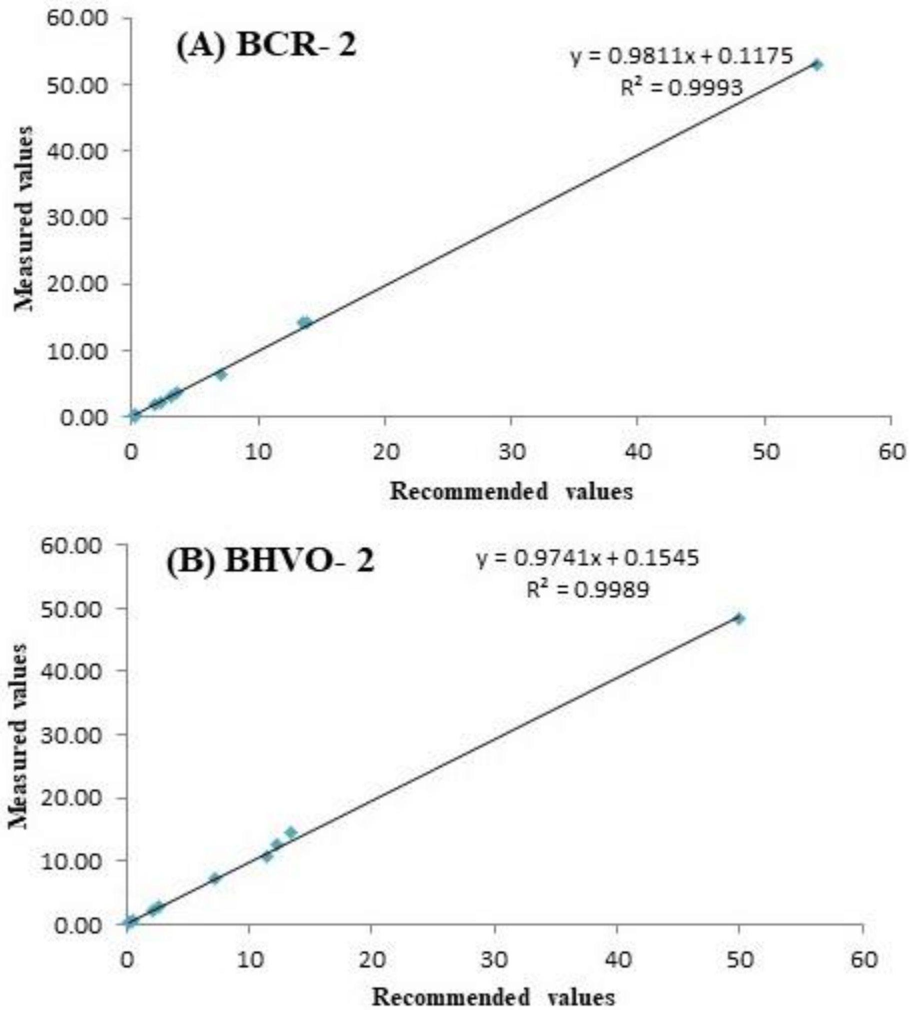

Figure 2: Comparison of measured and reported elemental concentrations for two reference USGS standards (BCR-2 and BHVO-2). The straight line here depicts the 1;1 line.

Table 2: Comparison of chemical data for two reference USGS standards (BCR-2 and BHVO-2)

	BCR-2			BHVO-2		
	Reported	**Measured**	**Error (%)**	**Reported**	**Measured**	**Error (%)**
Na_2O (%)	3.16 ± 0.11	3.04 ± 0.02	3.83	2.22 ± 0.08	2.051 ± 0.015	8.27
MgO (%)	3.59 ± 0.05	3.62±0.01	0.81	7.23 ± 0.12	7.263 ± 0.006	0.45
Al_2O_3 (%)	13.5 ± 0.2	14.35 ± 0.14	6.33	13.5 ± 0.2	14.442 ± 0.046	6.52
SiO_2 (%)	54.1 ± 0.8	52.93 ± 0.08	2.17	49.9 ± 0.6	48.490 ± 0.066	2.91
P_2O_5 (%)	0.35 ± 0.02	0.35 ± 0.00	1.33	0.27 ± 0.02	0.266 ± 0.001	1.69
SO_3 (%)	_	0.17±0.00	_	_	0.111 ± 0.000	_
K_2O (%)	1.79 ± 0.05	1.74 ± 0.01	2.92	0.52 ± 0.01	0.506 ± 0.002	2.87
CaO (%)	7.12 ± 0.11	6.54 ± 0.04	8.09	11.4 ± 0.2	10.694 ± 0.008	6.61
TiO_2 (%)	2.26 ± 0.05	2.29 ± 0.01	1.36	2.73 ± 0.04	2.752 ± 0.001	0.78
Mn_2O_3 (%)	0.221 ± 0.008	0.21±0.01	4.52	0.185 ± 0.006	0.185 ± 0.034	_
Fe_2O_3 (%)	13.8 ± 0.2	14.10±0.03	2.18	12.3±0.2	12.562 ± 0.002	2.08

Table 3: Major oxide concentrations for bed sediments for the Krishna mainstream and its major tributaries

Sample Name	River name	Location	Sum (%)	SiO2 (%)	Al2O3 (%)	Fe2O3 (%)	Na2O (%)	K2O (%)	CaO (%)	MgO (%)	TiO2 (%)	P2O5 (%)	Mn2O3 (%)	LOI
Krishna mainstream														
KR 15 - 32	Krishna R.	Umbraj, Maharashtra	97.144	33.588	11.036	17.422	0.911	0.372	9.247	3.938	4.758	0.212	0.244	15
KR 15 - 30	Krishna R. (After confl with Koyna)	Wathar, Maharashtra	100.581	34.083	12.133	19.4	1.932	0.449	5.146	3.757	5.58	0.194	0.26	17
KR 15 - 28	Krishna R. (Before confl with Warana)	Sangali, Maharashtra	97.459	35.751	13.363	23.329	1.421	0.255	10.111	3.741	8.52	0.118	0.332	6
KR 15 - 25	Krishna R. (before confl with Panchganga)	Narsobawadi, Maharashtra	96.871	34.032	12.242	20.644	1.012	0.268	7.383	3.669	6.746	0.13	0.278	10
KR 15 - 13	Krishna (after confl with Musi)	Muktyala, Telangana	98.335	76.611	7.882	0.922	1.401	3.387	2.514	0.237	0.109	0.025	0.059	5
KR 15 - 17	Krishna (after confl with Tungbhadra R.)	Srisailam, Andhra Pradesh	91.29	65.538	7.013	10.054	0.386	2.687	2.944	1.749	0.302	0.05	0.353	3
KR 15 - 15	Krishna (after the bridge)	Vijayawada, Andhra Pradesh	99.223	79.244	8.765	1.337	1.519	3.232	2.254	0.362	0.182	0.038	0.061	2

Sample Name	River name	Location	Sum (%)	SiO2 (%)	Al2O3 (%)	Fe2O3 (%)	Na2O (%)	K2O (%)	CaO (%)	MgO (%)	TiO2 (%)	P2O5 (%)	Mn2O3 (%)	LOI
Bhima mainstream														
KR 15 - 07	Bhima (After confl. With Indrayani)	Koregaon, Bhima Bridge	98.484	42.038	12.61	12.066	0.964	0.619	6.279	2.981	2.139	0.181	0.174	18
KR 15 - 09	Bhima (After confl with Mula)	Pargaon (Shirur Satara Road)	98.457	45.179	13.121	13.815	1.951	0.662	9.941	4.908	2.093	0.222	0.24	6
KR 15 - 11	Bhima (after confl with Nira)	Pandharpur, Maharashtra	87.296	30.38	8.86	9.267	0.993	0.34	22.685	3.978	2.007	0.122	0.336	8
KR 15 - 03	Indrayani River	Alandi, Pune, Maharashtra	97.812	40.945	12.169	16.008	1.39	0.718	9.376	4.293	1.747	0.48	0.233	10
KR 15 - 08	Mula (Before confl with Bhima)	Rahu, Maharashtra (Rahu Pimpalgaon Road)	96.511	43.136	12.705	12.231	1.798	0.546	11.073	4.674	1.661	0.175	0.228	8
Krishna tributaries														
KR 15 - 31	Koyna R.	Nisare, Maharashtra	98.477	35.469	14.048	18.202	0.781	0.373	4.138	3.05	4.499	0.198	0.29	17
KR 15 - 29	Warana R.	Dudhgaon, Maharashtra	98.046	41.448	16.699	23.564	0.904	0.364	3.949	3.013	7.088	0.207	0.329	12
KR 15 - 26	Panchaganga R.	Narsobawadi, Maharashtra	97.884	39.674	18.073	24.837	0.711	0.385	2.872	2.306	7.819	0.247	0.396	15
KR 15 - 27	Doodhganga R.	Danwad, Maharashtra	100.601	41.243	14.591	25.084	1.057	0.358	4.633	2.909	9.603	0.204	0.364	12

KR 15 - 23	Ghataprabha R.	Bagalkote, Karnataka (from a reservoir)	96.043	40.314	12.87	24.787	0.049	0.693	5.097	0.704	1.013	0.074	0.134	10
KR 15 - 22	Malaprabha R.	Near Hungund, Karnataka	98.133	53.734	11.352	9.974	0.785	1.164	4.891	2.732	0.997	0.088	0.109	12
KR 15 - 21	Tungabhadra R.	Mantralayam, Telangana	97.593	83.371	7.155	0.749	1.565	2.022	1.071	0.27	0.122	0.026	0.062	1
KR 15 - 20	Handri R. (Tributary of Tungbhadra)	Handri, Telangana (from the reservoir)	97.661	75.55	10.835	2.238	1.638	4.733	0	0.241	0.135	0.044	0.061	2
KR 15 - 19	Tungabhadra R.	Kurnool, Telangana	97.241	79.264	7.25	1.664	1.36	1.779	1.724	0.53	0.295	0.045	0.06	3
KR 15 - 12	Musi River (Very low water flow)	Suryapet, Telangana	97.532	74.862	9.906	1.123	1.778	3.794	1.224	0.344	0.176	0.063	0.06	4
KR 15 - 14	Munneru River	Kesara (near Nandigrama), Telangana	98.654	65.329	9.378	5.438	1.066	1.069	3.208	1.628	1.003	0.084	0.091	10

Table 4: Comparison of average chemical compositions of the mainstream sediments (Table 3) with possible sources (mentioned below).The numbers in the parenthesis reflect the Al-normalized ratios.

	Archean Granite [a]	Deccan Basalt [b]	Cuddapah Granite [c]	Krishna mainstream [d]
wt%				
Si	33.74±0.66(4.71±0.43)	22.82±1.69(3.13±0.32)	39.78±2.15(8.44±1.40)	23.96±10.05(4.37±2.11)
Al	7.17±0.65(1.00)	7.30±0.50(1.00)	4.71±0.74(1.00±0.22)	5.48±1.30(1±0.34)
Fe	1.55±0.85(0.22±0.12)	10.10±1.50(1.38±0.23)	0.83±1.32(0.18±0.28)	9.30±6.48(1.7±1.25)
Mn	0.07±0.05(0.01±0.01)	0.15±0.02(0.02±0.003)	0.00±0.00(0.00±)	0.16±0.08(0.03±0.02)
Mg	0.23±0.08(0.03±0.01)	3.74±0.66(0.51±0.10)	0.30±0.41(0.06±0.09)	1.50±1.01(0.27±0.2)
Ca	0.90±0.37(0.13±0.05)	7.30±0.80(1.00±0.13)	0.11±0.10(0.02±0.02)	4.04±2.35(0.74±0.46)
Na	2.78±0.53(0.39±0.08)	1.85±0.30(0.25±0.04)	0.24±0.35(0.05±0.07)	0.91±0.37(0.17±0.08)
K	3.60±0.51(0.50±0.08)	0.39±0.26(0.05±0.04)	2.65±1.44(0.56±0.32)	1.26±1.24(0.23±0.23)
P	0.04±0.02(0.01±0.002)	0.10±0.04(0.01±0.006)	0.02±0.03(0.005±0.0074)	0.05±0.03(0.01±0.01)
Ti	0.17±0.06(0.02±0.01)	1.33±0.40(0.18±0.06)	0.05±0.05(0.01±0.01)	2.24±2.10(0.41±0.4)

[a] Avg of data compiled from Eby et al.,1990 ; Chadwick et al.,1984 ; Jayananda et al., 1995; Dey et al.,2003.

[b] Das et al.,2007

[c] Khan et al.,2019

[d] Present study

4. Results and Discussion

Major oxide abundances of the Krishna sediment samples are provided in the Table 3. Average of these concentrations are compared with possible sources in Table 4. The Krishna mainstream sediments are dominantly composed of Si (24 ± 10 %). This average Si concentration is consistent with that reported for the Deccan basalts (23 ± 1 %) and Archean Granites (33.7 ± 0.7 %). Among the tributaries, the Si concentration is found highest for the Tungabhadra river (~ 39 %), and lowest for the Bhima system (KR15-11; Table 3). The average Al concentration of the mainstream sediments (5.5 ± 1.3 %) is found marginally lower than that reported for both the major lithologies (~7 %). The Fe concentration of the mainstream samples vary significantly from 0.6 to 16 %, comparable to that reported for Deccan basalts (~10 %) and granites (~1.5 %). Average Na concentrations in these sediments (~0.9 %) is lower by about two times than its source rocks. The Ti concentrations in the mainstream sample (~2.2 %) is systematically higher than those reported for the basalts (1.3%) and granitic (0.2 %) source rocks. The P concentrations are found closer to the granitic source, than the Deccan traps. Most of the elements (Fe, Ti, Mn and P) show strong correlations with Al (Table 5). In particular, Al is strongly correlated to Fe ($r = 0.825$; $p=0.00001$) and Ti ($r = 0.75$; $p=0.002$) in the Krishna sediments. This is in consistence with presence of weathering resistant minerals such as ilmenite in the Deccan traps (Das and Krishnaswami, 2007). We also see negative correlation for Na ($r = -0.18$; $p=0.41$) and K ($r = -0.58$;$p=0.003$) with Al.

Most of the elements show strong spatial variations. The relative standard deviation for the sedimentary concentrations for the Krishna mainstream samples are found highest for K (~98%), and lowest for Al (~24 %). These variations are linked to lithogical variation in the basin, which is mainly comprised of basalts in the upper reaches i.e north-western part of the basin and granitic rocks in the lower reaches. Consistently, Fig. 5 depicts higher Fe/Al ratios in the sediments from the upper reaches i.e north-western part of the basin than the

Table 5 : Co-relation coefficient between chemical constituents of sediments from Krishna river and its major tributaries.

-	Si	Al	Fe	Na	K	Ca	Mg	Mn	p	Ti
Si		-0.687	-0.856	0.288	0.857	-0.653	-0.838	-0.773	-0.65	-0.686
Al			0.825	-0.18	-0.583	0.0946	0.497	0.606	0.605	0.75
Fe				-0.419	-0.775	0.276	0.598	0.787	0.576	0.833
Na					0.289	-0.00295	0.0827	-0.315	0.0274	-0.144
K						-0.559	-0.775	-0.664	-0.589	-0.646
Ca							0.724	0.472	0.36	0.178
Mg								0.687	0.714	0.513
Mn									0.539	0.769
P										0.44
Ti										

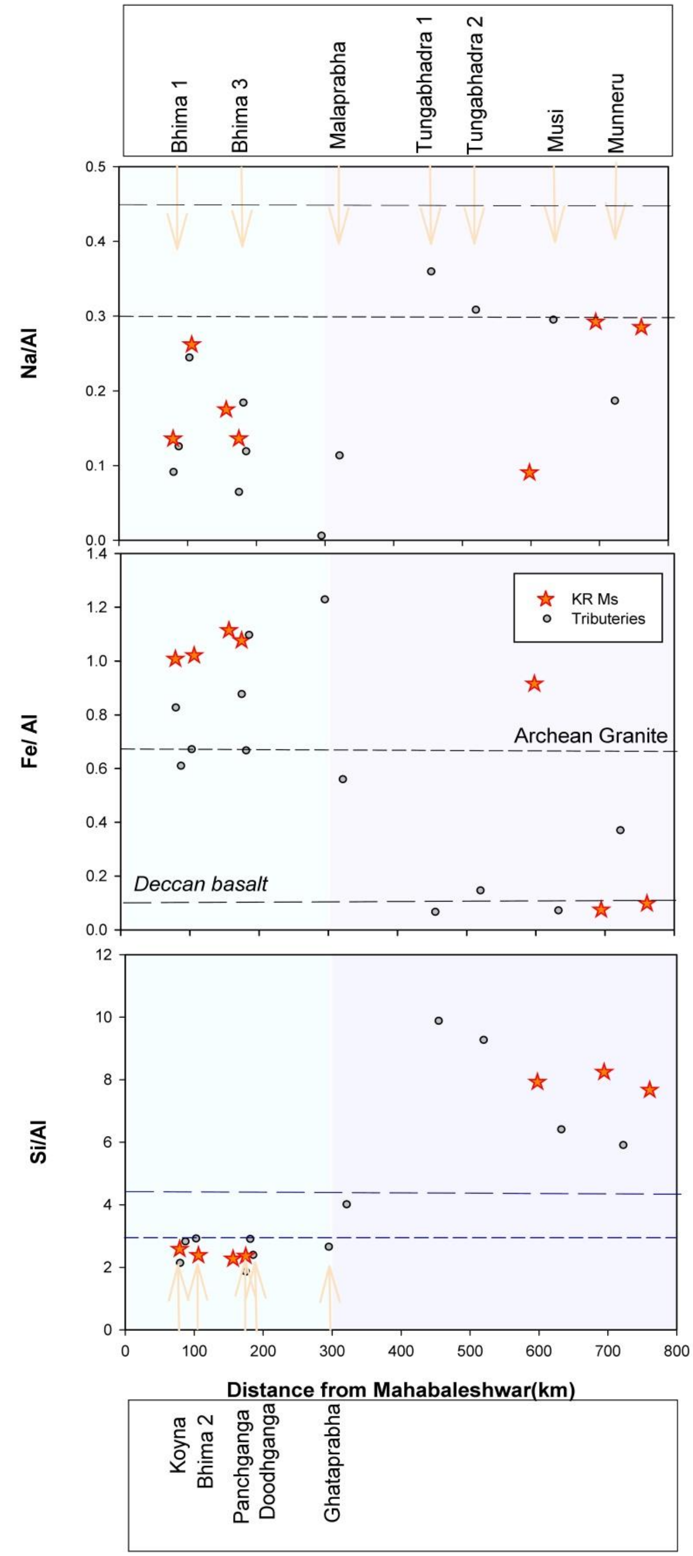

Figure 3: Spatial variation in Al- normalized ratios of Si, Fe and Na ratios in the Krishna sediments (KR Ms : Krishna river main stream).

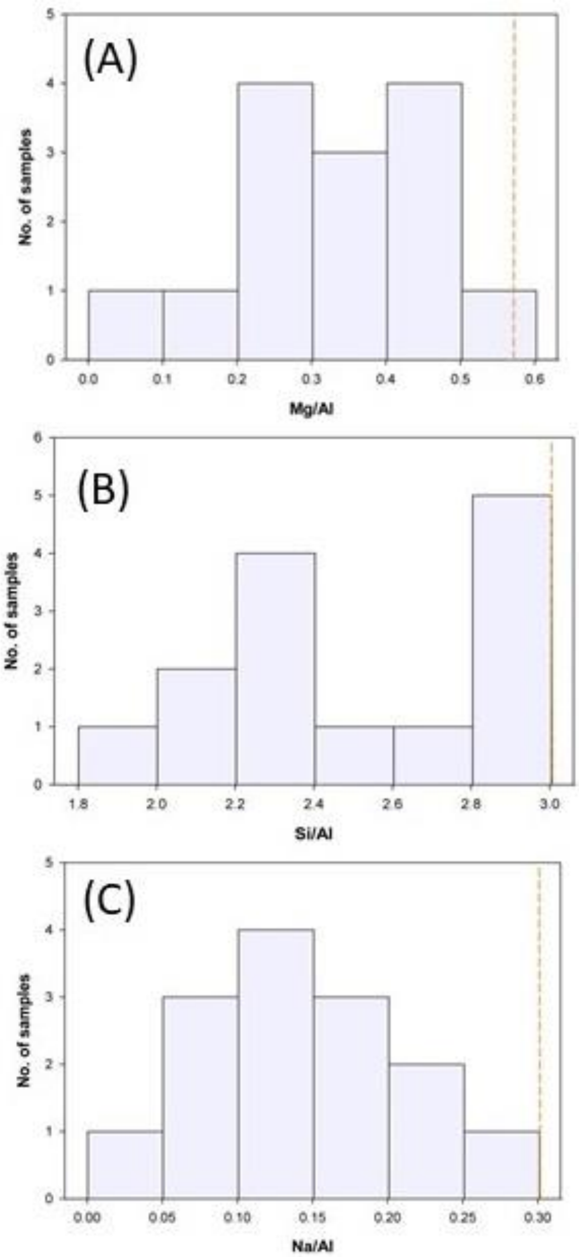

Figure 4: Frequency distribution of Al-normalized ratios of Mg, Si and Na. The dotted line reflects average ratios reported for the Deccan basalts.

lower part of the basins. Lower Si/Al ratios in the upper reaches i.e north-western part of the basin than that in the lower reaches points to dominancy of basalt rock (than granites) in the upper reaches i.e north-western part of the basin. In contrast to these observations, the frequency distribution of Na/Al, Si/Al and Mg/Al ratios (Fig. 4) are found to be systematically lower than that reported for Deccan Trap basalts. Here, the ratios are normalized with respect to aluminum to correct for effects of mineralogical changes/dilution. This difference in Fig. 4 can be attributed either to (i) chemical mobilization of these elements during chemical weathering processes or, (ii) dominant supply of sediments from the Archean granites. These possibilities are evaluated in the following discussion.

Chemistry of sediments can be used to access the intensity of chemical weathering in basins. A chemical weathering of a rock-type is expected to release mobile elements to the dissolved load, which in turn should deplete the elemental concentrations in the sediments. For typical basaltic rocks, the susceptibility of minerals to chemical weathering follows the order of olivine > plagioclase ≈ pyroxene > Fe-Ti oxide (Nesbitt and Wilson, 1992) although some exceptions related to particular textural characteristics or the weathering environment have been reported. As weathering progresses from to intermediate and advanced stages, clays such as kaolinite is typical stable end-products. Therefore, such type of chemical weathering is sometimes referred to as kaolinitisation. During the early stages of rock weathering, the mobile elements (Na, K, Ca, and Mg) get removed, whereas immobile elements (Al, Si, and Fe) are predominantly retained in sediments. Therefore, quantification of weathering intensity during these stages typically assumes conservation of Al and measures the loss of the mobile elements (Ca, Na, K, Mg). Based on this principle, the chemical index of alteration (CIA) have been used frequently to infer chemical erosion pattern of river basins (Nesbitt and Young, 1982; Singh et al., 2008). The CIA value can be computed using the following equation:

$$CIA = 100 \times \frac{Al_2O_3}{(Al_2O_3 + CaO* + Na_2O + K_2O)} \qquad (1)$$

Where, CaO* stand for the carbonate-corrected CaO concentration of the sediments. In absence of carbonate data, the CaO* estimation is not possible during this study. For this, we have used a modified CIA* value for accessing the intensity of chemical erosion in the basin.

$$CIA = 100 \times \frac{Al_2O_3}{(Al_2O_3+Na_2O+K_2O)} \qquad (2)$$

The CIA* values for samples is given in Table 6. The bed sediments samples from the Deccan trap region ranges between ~ 76 and 93 with an average of 84 ± 5 (Table 6). The CIA* value for unweathered Deccan basalt have been reported to be ~ 75. The samples from the Archean granites have CIA* values, ranging from 58 to 81 with an average of 64 ± 8 (Table 6). These values overlap with the average CIA* value for Archean granite (~55), pointing minimal impact of chemical weathering on the sediments from the Archean granite lithology.

Table 6: modified chemical index of alteration, CIA* values for the Krishna sediments.

Deccan trap region		**Peninsular granite region**	
(CIA*=~ 75)		(CIA*=~55)	
Sample Name	CIA*		
KR 15 - 03	79.89	Sample Name	CIA*
KR 15 - 07	84.83	KR 15 - 12	58.49
KR 15 - 08	78.17	KR 15 - 13	56.90
KR 15 - 09	76.97	KR 15 - 14	76.31
KR 15 - 11	81.57	KR 15 - 15	59.38
KR 15 - 23	93.94	KR 15 - 17	66.43
KR 15 - 25	86.23	KR 15 - 19	63.53
KR 15 - 26	91.93	KR 15 - 20	58.09
KR 15 - 27	87.28	KR 15 - 21	60.03
KR 15 - 28	83.64	KR 15 - 22	81.65
KR 15 - 29	89.88		
KR 15 - 30	76.80		
KR 15 - 31	89.27		
KR 15 - 32	85.30		
Average	84.7	Average	64.5
STDEV	5.3	STDEV	8.3

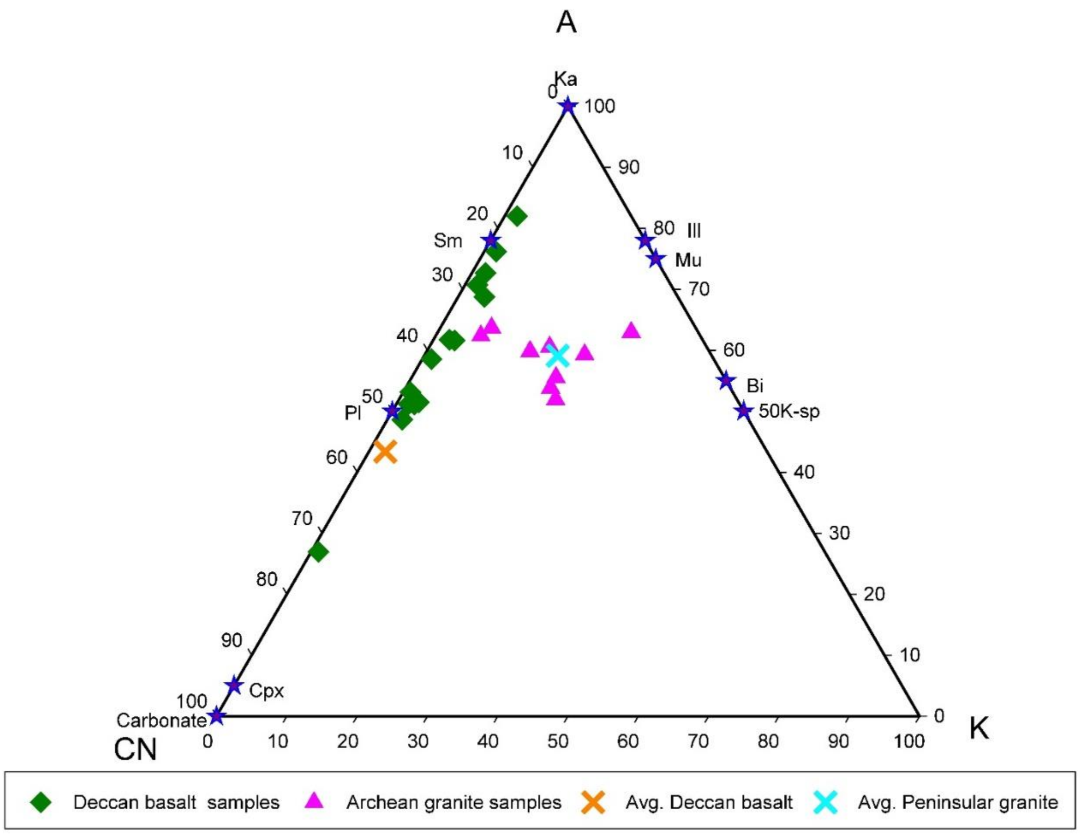

Figure 5: A-CN-K (Al_2O_3-CaO+Na_2O-K_2O) diagram for the Krishna sediments and its possible sources.

Figure 5 depicts the A-CN-K (Al_2O_3-CaO+Na_2O-K_2O) diagram for sediments from the Krishna river system. The data distribution in this plot can be linked to chemical weathering and sediment provenances. The sediment samples from the Deccan trap regions fall along the A-CN line, and also, between the compositions expected for Deccan basalts and smectite. This clearly depicts that these samples have gone through chemical weathering. In contrast, the samples from the Archean granitic terrains fall mostly around the end-member composition of the granitic rocks and/or along the Deccan-Archean granite mixing trend. These data mostly show that these samples are less altered compared to those from Deccan trap regions. Consistent with this observation, the Fe concentration of the sediments from the Krishna outflow is found significantly lower than that observed in the Deccan trap regions. The basaltic rocks are mostly mafic in nature and hence, rich in Fe and Mg. the low Fe content at the outflow indicates that the sediments produced in the basin are mostly from the granitic terrains. This observation also draws support from the average P concentration, which in closer to the Archean granitic (than Basaltic) composition. This confirms that the sediment from the Krishna supplied to the Bay of Bengal are mostly produced in the lower reached with granitic lithology. The upper reaches i.e north-western part of the basin is mainly composed of basaltic rocks. These rocks are mainly composed of minerals with faster dissolution kinetics and hence, may contribute disproportionally higher to dissolved phases and not to the particulate phases. This indicates that the sediment budget of this tropical basin is mainly regulated by lithology and not by basin slope or, any other climatic parameters.

5. Conclusion

Major oxide concentrations of (bed) sediments from the Krishna mainstream and its major tributaries were analyzed. These concentrations show wide spatial variations, attributable to significant lithological variation within the basin. The mobile elements, specifically Na, are found significantly lower than its source rocks, indicating significant release of these elements to the dissolved phase. The CIA* values of these samples vary significantly (56-94). Although most of the CIA* vales match well with those reported for the Deccan basalts (~75) and Archean granites (~55), few samples are characterized with high CIA* values indicating impact of chemical weathering of these sediments. The concentrations of immobile elements, such as Fe, Mg, and P, at the river outflow are found closer to the granitic (than basaltic) end-member composition. This observation points to dominant supply of sediments from the Archean granitic terrains than that from the Deccan basalts to the Krishna basin. The upper reaches i.e north-western part of the basin although is composed of basalts, these rocks play minimal role in the ultimate sediment flux from the river to the Bay of Bengal. This outcome is consistent with efficient dissolution kinetics of this rock-type and hence, indicates important role of lithology in regulating sediment budget of this tropical river.

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