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Sediment yield along the Andes: continental budget, regional variations, and comparisons with other basins from orogenic mountain belts

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ABSTRACT

We assess the sediment yield at 119 gauging stations distributed from Colombia to Patagonia, covering the different morphotectonic and morphoclimatic settings of the Andes. The most productive areas are the Meta River basin within the northern Andes and the Bolivian and northern Argentina-Chaco systems, which produce an average of 3345, 4909 and 2654 t km^2 y^{-1} of sediment, respectively. The rivers of the northern and central Andes (excluding the Pacific watersheds of Peru, northern Chile, and central Argentina) have a weighted mean sediment yield of 2045 t km^{-2} y^{-1} and produce 2.25 GTy^{-1} of total sediment. A major constraint estimating the Andean continental budget of sediment yield lies in the lack of gauging data for the Peruvian region. Using the available gauge stations, the regional sediment yield appears underestimated. Assuming a higher value of sediment yield for the Peruvian Andes, the total budget for the whole central Andes could range between 2.57 GT y^{-1} and 3.44 GT y^{-1}. A minimum of ~ 0.55 GT y^{-1} and a probable maximum of ~ 1.74 GT y^{-1} of sediment are deposited in the intramontane and surrounding proximal sedimentary basins. The magnitude of sediment yield in the Andes is comparable to other rivers draining orogenic belts around the world.

1. Introduction

Knowledge of river basins sediment yield at a continental scale provides useful information for (i) developing quantitative models of landscape evolution, (ii) studying geochemical and sediment mass balance, (iii) estimating the intensity of continental and regional erosion, and (iv) assessing the volume of solids contributed from continents to the Ocean and the trapping of sediments at the continental scale (Pinet and Souriau, 1988; Summerfield and Hulton, 1994; Harrison, 2000; Hovius, 2000; among many others). Sediment yields for South American rivers have been documented as part of global databases of sediment load into the coastal ocean. Three of the largest river systems draining the Andes (the Amazon, Paraná, and Orinoco) have attracted the most attention (Milliman and Syvitski, 1992; Ludwig and Probst, 1998; Syvitski and Milliman, 2007; Milliman and Farnsworth, 2011; among others). But recently a few small-and medium-sized catchments along the northern Andes (e.g., Magdalena), on the Pacific margin (e.g., San Juan, Patía, Chira, and BioBio), and in the Patagonian region (e.g., Negro, Colorado, and Chubut) also have been added to global databases (Syvitski and Milliman, 2007; Milliman and Farnsworth, 2011). However, these databases do not represent a continental picture of sediment yield near Andean foothills. In addition, data for some Andean catchments are still missing. One attempt to predict erosion rates along the whole Andes by applying a latitudinal gradient of erosion index (Montgomery et al., 2001) fails to predict realistic values when compared to sediment yields obtained from measurements in fluvial systems. Thus, the role of Andean rivers on the global denudation system remains only partially understood.

At the regional scale, sediment yields for the Andean rivers have been collected over the last decades for various regions and catchments of different sizes. Most available studies have attempted to explain regional patterns of sediment yield in terms of the combined effect of local topography, soil properties, climate, vegetation cover, catchment morphology, and land use (Guyot et al., 1994, 1999; Restrepo and Kjerfve, 2000; Latrubesse et al., 2005; Aalto et al., 2006; Restrepo et al., 2006; Laraque et al., 2009; Kettner et al., 2010; Pepin et al., 2013).

While all mentioned datasets and results contain relevant numbers of sediment yield, none has evaluated the variations in sediment yield at a macroscale (i.e., covering the entire Andes). Furthermore, data for a significant number of Andean catchments are still missing in the international literature, notably for rivers draining the northeastern Orinoco and Amazon basins, the central Andes flowing through the Chaco region, and for central Argentina. Thus, our knowledge on the regional variation of sediment yield and its relationship with spatial scale and other environmental factors within the Andes is still limited. We address this knowledge gap by presenting and discussing new sediment yield data and by estimating the continental budget of sediment yield

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Table 1
Drainage basin, measured water and sediment discharges, and calculated sediment yields for the Andean rivers.

Andean region, major receiving basin and river	Area ($\times 10^3$ km^2)	Water discharge (m^3 s^{-1})	Sediment load (Mt y^{-1})	Sediment yield (t km^{-2} y^{-1})	Andean region, major receiving basin and river	Area ($\times 10^3$ km^2)	Water discharge (m^3 s^{-1})	Sediment load (Mt y^{-1})	Sediment yield (t km^{-2} y^{-1})
Northern Andes					Madre de Dios[10]	124.2	5210.0	71.0	570
Colombia					Ucayali[10]	198.38	11260.0	205.0	570
Caribbean basin					*Pacific basin*				
Suaza[45]	1.01	44.4	0.6	562	Chira[3]	20.00	158.5	20.0	1000
Páez[45]	4.76	180.7	2.9	607	Segment-Bolivia				
Cabrera[45]	2.71	69.8	1.9	682	*Amazon basin*				
Sumapaz[45]	2.43	41.2	0.5	206	Caine[11,12]	9.20	59.0	126.0	13700
Bogotá[45]	5.41	38.1	1.3	244	La Paz[11,12]	6.50	99.0	119.0	18310
Coello[45]	1.04	41.2	1.6	1575	Unduavi[11,12]	0.27	12.0	2.0	7420
Recio[45]	0.64	19.0	0.2	249	Tamampaya[11,12]	0.95	52.0	2.4	2520
Gualí[45]	0.46	22.2	0.2	415	Tamapaya[11,12]	1.99	67.0	7.8	4110
Guarino[45]	0.84	31.7	0.5	536	Huayllani[11,12]	0.02	0.1	0.1	4060
La Miel[45]	2.36	244.2	2.7	1126	Achumani[11,12]	0.04	0.2	0.2	5300
Negro[45]	4.58	136.4	8.0	1742	Luribay[11,12]	0.81	10.0	6.4	7910
Cocorna[45]	0.79	57.1	0.6	747	Porvenir[11,12]	0.24	3.0	0.8	3310
Samana[45]	1.71	180.7	0.9	543	Cot[11,12]	5.60	84.0	40.6	7240
Nare[45]	5.56	396.4	2.6	465	Santa Isabel[11,12]	0.20	15.0	0.7	3550
Carare[45]	4.90	263.2	16.8	3415	Spe[11,12]	0.32	27.0	3.5	10940
Opón[45]	1.75	88.8	3.4	1912	Ico[11,12]	2.30	130.0	11.4	4960
Suárez[45]	9.78	301.2	3.4	349	Piray[11,12]	1.42	11.0	2.9	2040
Fonce[45]	2.08	85.6	0.6	274	Espejos[11,12]	0.20	3.0	0.4	2070
Sogamoso[45]	21.21	434.4	11.2	529	Chayanta[11,12]	11.20	70.0	14.1	1260
Cauca[45]	66.75	2384.6	49.1	735	Grande[11,12]	23.70	130.0	154.3	6510
Atrato[6]	12.10	1620.4	11.3	933	Grande[11,12]	31.20	230.0	206.9	6630
Chigorodó[6]	0.10	14.6	0.2	1088	Mizque[11,12]	10.80	47.0	14.1	1310
León[6]	0.70	63.4	0.8	1000	Azero[11,12]	4.36	32.0	2.2	510
Carepa[6]	0.15	5.1	0.3	2050	Parapeti[11,12]	7.50	79.0	19.4	2590
Currulao[6]	0.23	9.8	0.2	1027	Coroico[11,12]	4.70	260.0	7.1	1500
Pacific basin					Alto Beni[11,12]	29.90	840.0	115.0	3800
San Juan[6]	1.60	261.0	2.6	1570	Beni[11,12]	67.50	2170.0	219.0	3200
Patía[7]	8.90	225.1	15.4	1714	Piray[11,12]	2.88	12.0	2.3	799
Mira[8]	9.53	243.5	9.7	1018	Grande-Abapo[11,12]	59.80	290.0	125.0	2100
Amazon basin					Segment-Chaco: Paraná basin				
Caquetá (Angosturas) [&]	5.67	640.1	732	1289	Pilcomayo[13]	96.00	204.0	141.0	1469
Caquetá (Andaqui) [&]	3.61	408.3	382	1057	Cachimayo[14,]	1.61	17.8	2.9	1801
Orteguaza[&]	1.57	161.0	238	1508	San Juan del Oro[*]	19.70	17.3	3.9	198
Guayas[&]	1.46	210.0	191	1308	Cambiaya[*]	43.90	58.0	22.0	501
Guamues[&]	0.638	27.4	004	63	Pilaya[*]	89.90	90.0	41.6	463
Putumayo[&]	2.9	498.4	168	580	Bermejo[15,*]	25.00	356.0	120.0	4800
Orinoco basin					San Francisco[13,*]	25.80	356.0	20.4	791
Guape[&]	0.517	71.6	145	2803	Iruya[15,*]	2.12	24.0	17.7	8349
Guejar[&]	0.873	30.1	049	560	Valle Grande[15,*]	16.06	16.0	3.8	237
Guyuriba[&]	2.85	155.5	1131	3958	Pilcomayo-Talula[15,*]	6.49	19.6	10.8	1664
Negro[&]	1.31	27.0	118	896	Pilcomayo-Villa[*] Quemada[*]	13.5	49.9	24.5	1822
Blanco[&]	0.810	46.3	120	1478	Bermejo[*]	2.26	22.9	4.9	2168
Negro[&]	2.48	93.8	445	1793	Bermejo[*]	4.85	89.5	15.7	3237
Somondoco[&]	0.531	18.2	093	1753	Grande de Tarija[*]	10.46	48.0	14.0	1338
Lengupa (San Agustin) [&]	1.64	130.0	942	5739	Candelaria[*]	0.37	8.4	1.4	3784
Lengupa (Paez)[&]	0.774	52.1	503	6498	Juramento[16,*]	31.90	29.0	34.0	1066
Upía (Reventonera)[&]	0.911	77.9	357	3914	Salí[16,*]	4.70	15.0	4.9	1043
Upía (Guaicaramo) [&]	7.94	432.2	2773	3492	Dulce[*]	15.00	98.0	23.7	1580
Cravo Sur[&]	1.10	78.6	257	2339	Pescado[15,*]	1.7	50.6	24	14117
Catatumbo[&]	1.37	38.4	040	289	Segment-Argentina				
Margua[&]	2.60	91.5	051	197	Atuel[*]	3.80	35.2	1.2	323
Cobugón[&]	1.26	195.0	365	2884	Grande[*]	6.18	110.7	1.2	197
Ecuador					Tunuyan[*]	2.38	28.6	2.9	1237
Amazon basin					Tupungato[*]	1.80	23.6	1.0	553
Pastaza-Napo[9]	36.20	2210.0	42.4	1160	Diamante[*]	2.75	68.4	2.5	903
Napo[9]	12.4	1130.0	6.4	515	San Juan[*]	25.67	65.3	3.9	151
Coca[9]	5.2	350.0	6.0	1138	Aconcagua[3]	2.10	31.7	0.5	238
Peru					Colorado[*]	15.30	146.4	3.9	258
Amazon basin					Southern Andes				
Napo[10]	18.81	2230.0	21.0	770	BioBio[17]	24.00	1014.7	22.0	229
Napo[10]	100.50	6300.0	54.0	537	Neuquen[*]	30.20		8.0	264
Central Andes					Chubut[3]	40.00	41.2	0.6	15
Segment-Peru					Colorado[3]	22.00	130.0	6.9	314
Amazon basin					Gallegos[3]	5.10	31.7	0.1	20
Maranon[10]	104.80	4780.0	103.0	890	Negro[*]	89.00	1000.0	18.3	206
Huallaga[10]	53.12	2,820.0	42.0	710	Deseado[3]	14.00	4.8	0.5	36

Note: [4–16, *]Regional studies and reports of sediment transport: 4-Restrepo et al. (2006); 5-Kettner et al. (2010); 6-Restrepo and Kjerfve (2000); 7-Restrepo and Cantera (2011); 8-Restrepo et al. (2009); [&]IDEAM, Colombian Institute of Hydrological and Environmental Studies; 9-Laraque et al. (2009); 10-Guyot et al. (2007); 11-Guyot (1993); 12-Guyot et al. (1994); 13-Basile (2004); 14-Guyot et al. (1990); 15-Cafaro et al. (2010); 16-Spalletti and Brea (2002); 17-Link et al. (2002); [*] Sub-Secretary of Water Resources, Argentina.