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Introduction

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1.1 A BOOK ON LARGE RIVERS

Large rivers are important components of continental landforms. A number of them have been associated with the growth and development of human civilization in their fertile valleys. The structured water utilization in the Nile Valley is an excellent example. Several have been impounded, starting from the second quarter of the twentieth century. The Hoover Dam over the Colorado is one of the early huge engineering structures, the Three Gorges Dam over the Changjiang (Yangtze) the most recent one.

In spite of these rivers being physical marvels and resources utilized by a large number of people, our knowledge about their form, evolution or function remains limited. This is possibly due to logistical problems, as case studies in the fields of geomorphology, sedimentology or river ecology are generally on smaller rivers that are easier to investigate, model or manage. For example, direct measurements of sediment are not regularly available for a number of these big rivers, requiring indirect estimates of sediment load. Our knowledge of these rivers also varies. A lot more is known about the Mississippi or the Colorado than the Zambezi. The Nile has been measured for thousands of years but not the Congo. The Amazon is attracting a very large number of researchers from a wide range of institutions, countries, and specializations but such large-scale national or international endeavours are rare for other tropical rivers. Over the last four decades, a compilation of information on channel form, sediment, and mobility of the Lower Brahmaputra has built up, a dataset not available for its upper course. We have started to comprehend the interconnection between the flood pulse, sediment flux, and riverine ecology in these rivers. But the coverage is not uniform and for a number of major rivers our knowledge is inadequate for both generalization and planning. For example, at the current level of understanding, it is difficult to predict the effect of the expected climate changes on large rivers, a task that will undoubtedly become essential for the next generation of scholars.

This book is an attempt to bring together a number of papers on big rivers. It is not a complete coverage but provides an introduction to geomorphology and the management of rivers of large dimension. Certain rivers and topics have been hard to cover because of their complexity and location and a couple of the chapters originally planned did not arrive, but overall this is a unique volume not attempted before at this scale.

The book is designed in three sections. The first section is on the environmental requirements for creating and maintaining a large river. In that sense, the chapters included are valuable generalizations based on existing knowledge. The second section is a collection of case studies on big rivers flowing through a range of physical environments. The third section is on the measurement and management of large rivers and their basins. Almost all chapters have been rather demanding to write, but the end product is a bold pioneering volume that hopefully will generate enough interest and controversy to push the boundary of our knowledge related to large rivers. It may even contribute towards saving their channels and basins from both random and organized mismanagement.

Large Rivers: Geomorphology and Management, Edited by A. Gupta

1.2 WHAT IS A LARGE RIVER?

If we are to list the largest rivers in the world, all of us would probably list the same 15 or 20 rivers, but a proper definition is elusive. Potter, in his 1978 paper on the significance and origin of big rivers, listed four properties that could be considered for this purpose: size of the drainage basin, length of the river, volume of sediment transported, and water discharge. He used river length and drainage basin size to identify the 50 largest rivers of the world. All except one of these rivers were more than 10^3 km long and the smallest drainage basin was 10^5 km^2. These 50 streams collectively drain about 47% of the continental surface, excluding Greenland and Antarctica (Potter, 1978). Inman and Nordstrom (1971) listed rivers with drainage areas above 10^5 km^2, with the Amazon ranked as 1 and the Po as the last one to qualify at rank 58.

Quality data on the two other criteria of large rivers, discharge of water and especially discharge of sediment, are not always available. Meade (1996) listed the first 25 rivers for both water and average suspended sediment discharges to the coastal zone. It is difficult to determine the total sediment load of a large river and, as Meade has pointed out, bed load is especially difficult to measure. The two lists, however, do not coincide, as certain rivers such as the Zambezi or Lena carry a large water discharge but their sediment loads are low. Impoundments have reduced the sediment load of rivers such as the Mississippi-Missouri, and almost removed it for the Nile or the Colorado. Impoundments have also reduced the water discharge of a number of major rivers (Meade, 1996). The Huanghe now does not reach the sea for about half the year. A river that should be in the list because of its former glory may not qualify on current performance. Recently Hovius tabulated the morphometric, climatic, hydrologic, transport and denudation data for 97 river basins, all of which measured above 2.5×10^4 km^2 (Hovius, 1998). Miall raised the question of identifying big rivers of the past, and attempted to define the 'bigness' in rivers based on previous studies (Miall, 2006).

Qualitatively, therefore, a large river carries a very big discharge, is long, has a large drainage basin and, commonly, but not always, annually transports a large volume of sediment. Of these, a huge volume of water flowing down the channel is probably the commonest expectation of a large river in a natural state, but given the variations that occur among three other properties, a rigorous definition is impossible. Instead it is expedient to list the top twenty or so and base our discussion on their characteristics. Table 1.1, compiled from various sources, is a comparison of the top 24 rivers of the world, selected on basis of their discharge. The discharge figures are from Meade (1996). Other measurements have been derived from a range of sources that are listed below Table 1.1. These measurements, however, differ between sources, especially regarding the area of the basins which has been resolved by rounding off to 10^6 km^2. Even at this scale there are discrepancies. Given the scale, perhaps it is inevitable that different figures will be quoted by different authors. A relationship exists between river length and drainage basin areas (Leopold *et al*., 1964; Potter, 1978) but not between the other variables. Variations in basin geology, relief, and hydrology are responsible for the scatter.

The great length of these rivers allows them to flow across a range of environments. The Changjiang, Mekong, and Zambezi, for example, flow in and out of rock gorges into alluvial basins. Morphological and behavioural adjustments happen at each transition. The sequence of steep headwaters, a braided segment, a meandering channel through an alluvial floodplain, and a delta at the end as prescribed for rivers of a more manageable dimension may not hold. Other rivers may demonstrate significant hydrological variations along their courses. The Quaternary history may also be complicated with different kind of changes occurring at the mountainous headwaters, along the valley, and near the coast. In spite of their size, a number of big rivers have been anthropogenically modified out of their natural conditions.

1.3 THE BOOK AND ITS CONTENT

Certain characteristics and conclusions are repeated independently by different contributors throughout the book. Although the ages vary, large rivers could have been in existence for a long period. The Mississippi, for example, has a history going back to at least the Late Jurassic. The present course of a river, however, could be an assemblage of several subunits of different age and appearance. Formation and sustenance of big rivers are commonly associated with orogenic belts, the Upper Indus, for example, remains pinned in a suture zone for a considerable part of its course. Large rivers interestingly also occur in rift valleys and cratonic settings, and many transect more than one setting along their length. Neither the Congo nor the Danube arises from a high orogenic belt, and they traverse a range of structural environments that cause them to regionally adjust their forms and behaviour. Even in the wide alluvial valleys, crustal deformation and belts of transverse resistant lithology change the low gradient of rivers resulting repeatedly in channel form and behaviour changes. The most striking example is the structurally controlled Amazon flowing in an extremely wide valley

Table 1.1 Selected characteristics of 24 large rivers

River	Annual average water discharge ($10^9\,m^3$)	Length (km)	Drainage basin area ($10^6\,km^2$)	Current average annual suspended sediment discharge ($10^6\,t$)
1. Amazon	6300	6000[a]	5.9[a]	1000–1300
2. Congo	1250	*4370*	*3.75*	43
3. Orinoco	1200	770[a]	1.1[a]	150
4. Ganga-Brahmaputra	970	*B-2900* *G-2525*	*1.06* *(B-0.63)*	900–1200
5. Changjiang	900	*6300*	*1.9*	480
6. Yenisey	630	5940[b]	2.62[b]	5
7. Mississippi	530	*6000*	*3.22*	210
8. Lena	510	*4300*	*2.49*	11
9. Mekong	470	*4880*	*0.79*	*150–170*
10. Paraná-Uruguay	470	3965[c]	2.6[c]	100
11. St Lawrence	450	3100[d]	1.02[d]	3
12. Irrawaddy	430	2010[e]	0.41[e]	260
13. Ob	400	>5570[b]	2.77[b]	16
14. Amur	325	4060[b]	2.05[b]	52
15. MacKenzie	310	4200[d]	2.00[d]	100
16. Zhujiang	300	2197[g]	0.41	80
17. Salween	300	2820[e]	0.27[e]	about 100
18. Columbia	250	2200[d]	0.66[d]	8
19. Indus	240	*3000*	*0.97*	50
20. Magdalena	240	1540	0.26	220
21. Zambezi	220	*2575*	*1.32*	20
22. Danube	210	*2860*	*0.82*	40
23. Yukon	195	3200[d]	0.83[d]	60
24. Niger	190	4100[f]	2.27	40

These figures vary between sources although perhaps given the size such variations are proportionally negligible. Discharge and sediment figures unless otherwise mentioned are from Meade (1996). Figures in italics are from chapters in this book. Other sources are indicated by superscripts: [a] Warne *et al*. (2002); [b] Koronkevich (2002); [c] Orfeo and Stevaux (2002); [d] Wohl (2002); [e] Gupta (2005); [f] Allen (1970); [g] Z. Chen, personal communication. Drainage basin areas rounded off to $10^6\,km^2$ to avoid discrepancies between various sources. Note that the Nile is 6500 km long but does not qualify for this table as its water and sediment discharges are relatively low.

filled with alluvium. Structural controls may exist on a continental scale that determines the primary location of the river in a downwarped plate tectonic setting. Within such a setting, structural control on a smaller scale also forces the river to change its direction, gradient, shape, and behaviour sharply, contributing to a series of regional variations on a scale of tens and hundreds of kilometres. Tectonics, climate and eustasy may control a long river in combination, each of these factors being significant in different parts of its course.

Rivers of this dimension obviously require large precipitation over their basins, which is met both in the monsoonal tropics and regions seasonally drained by meltwater floods from winter ice and snow. A large river therefore could be dependent on its headwater mountains for sustenance of its discharge. The headwater mountains, and in certain cases mountains at the head of major tributaries, also are the usual sources for the supply of sediment that travels down the channel to the mouth with short transfer times and long storage periods, especially when the sediment is stored in the floodplain. Sediment therefore arrives in the trunk stream via a restricted number of paths. Storage and remobilization of floodplain sediment influence the distribution and sustenance of regional plant and animal species. Isolated basins and gorges have given rise to speciation and origin of endemic organizations contributing rivers with diverse flora and fauna along their courses. Large rivers tend to build megadeltas, although, irrespective of the age of the rivers, the current megadeltas were formed in the Holocene. These deltas have experienced changes due to both natural and anthropogenic causes, the latter accelerating delta growth following human settlements in river basins. Such anthropogenic changes influence rivers even at the scale of the Yangtze.

Many major rivers have undergone extremely large shifts in discharge due to climate change or meltwater floods at the end of the Pleistocene and in Early Holocene.

These late Quaternary megafloods have altered drainage evolution and channel geometry in a number of rivers and the planetary pattern of water and sediment contribution to the oceans. Sediment from this time may still exist in the channel or the floodplain of the river. A major river may exist at the same location for a long period of time, but its present form tends to reflect forcing caused by tectonics, climate shifts, and sea level changes subsequent to origin; and, over the last several millenniums, anthropogenic activities in the drainage basin and the channel.

It is possible that evidence of deposition by large rivers like the Brahmaputra has not been noticed in sedimentary rocks or has been misinterpreted due to the huge scale. The reconstruction of rivers at this scale going back in geological time is therefore rather limited. An urgent need therefore exists to gather more and higher quality data on sedimentation by modern large rivers and to determine their preservation in older rocks.

The second section of the book (Chapters 8–21) is a collection of case studies on a number of rivers: Amazon, Mississippi, Colorado, Lena, Danube, Nile, Congo, Zambezi, Indus, Ganga, Brahmaputra, Mekong, and Changjiang. Several of these rivers have again been discussed elsewhere regarding specific aspects such as management, but these are important rivers and such repetition reflects reality. Although the book has been designed as a holistic unit, individual chapters can be read independently. An attempt was made to cover a wide range of geological and climatological environments, and although it has not been possible to include all the rivers originally planned, there is enough here to provide a very reasonable cross-section of the major river basins of the world. Two major points follow from these studies. First, a number of common characteristics, as summarized above and discussed in detail in the first section of the book (Chapters 2–7), show up in the case studies; and second, certain specific properties, such as structural control, high erosion rates or anthropogenic modification, may be significant enough for an individual large river to demand further discussions.

The third section of the book (Chapters 22–30) is on utilization, techniques, and management, although it has been expedient to base such discussions on individual rivers to some extent. The Nile has been used to connect a long history of hydraulic civilization with the physical characteristics of the river. Utilizing a major river as a resource by impoundment or other structural changes affects even huge rivers and several of the current biggest negative environmental impacts arise out of attempts to control or manage rivers. The scale of large rivers requires innovative tools for their study or modelling and techniques such as use of satellite imagery, channel geometry analysis, and mapping disturbances in the channel have been discussed. Even with satellite imagery it is extremely difficult for an individual to be familiar in detail with more than one long river which inhibits research. River management is a demanding task, and particularly so at this scale. The management policy and techniques not only have to take into consideration the physical and biological backgrounds concerning the entire catchment, channel, and floodplain but also, as rivers are intimately associated with people, the prevalent economic, social and political backgrounds. The technique of integrated water resources management (IWRM) is frequently proposed. As large rivers tend to flow in international basins, the political demand on management may override other expectations. As managing many of these rivers requires capacity-building in their basins, management could be very difficult.

Primarily, we need to know about large rivers and their basins covering all these aspects. This book is only a beginning and it is focused on the physical environment of rivers. It is absolutely crucial that subsequent volumes are produced to extend our knowledge of rivers at this scale, so that their sustainable management becomes feasible even in the future with climate change and sea level rise.

REFERENCES

Allen, J.R.L. (1970) Sediments of the modern Niger Delta: a summary and review. In: *Deltaic Sedimentation: Modern and Ancient* (J.P. Morgan, Ed.), Society of Economic Paleontologists and Mineralogists Special Publication 15, Tulsa, 138–151.

Gupta, A. (2005) Rivers of Southeast Asia. In: *The Physical Geography of Southeast Asia* (A. Gupta, Ed.), Oxford University Press, Oxford, 65–79.

Hovius, N. (1998) Controls of sediment supply by large river. In: *Relative Role of Eustasy, Climate, and Tectonism in Continental Rocks* (K.W. Shanley and P.J. McCabe, Eds), Society for Sedimentary Petrology Special Publication 59, Tulsa, 3–16.

Inman, D.L. and Nordstrom, C.E. (1971) On the tectonic and morphologic classification of coasts. *Journal of Geology*, 79, 1–21.

Koronkevich, N. (2002) Rivers, lakes, inland seas, and wetlands. In: *The Physical Geography of Northern Eurasia* (M. Shahgedanova, Ed.), Oxford University Press, Oxford, 122–148.

Leopold, L.B., Wolman, M.G. and Miller, J.P. (1964) *Fluvial Processes in Geomorphology*, W.H. Freeman, San Francisco.

Meade. R.H. (1996) River-sediment inputs to major deltas. In: *Sea-level Rise and Coastal Subsidence: Causes, Consequences, and Strategies* (J.D. Milliman and B.U. Haq, Eds), Kluwer, Dordrecht, 63–85.

Miall, A.D. (2006) How do we identify big rivers? And how big is big? *Sedimentary Geology*, 186, 39–50.

Orfeo, O. and Stevaux, J. (2002) Hydraulic and morphological characteristics of middle and upper reaches of the Paraná River (Argentina and Brazil). *Geomorphology*, 44, 309–322.

Potter. P.E. (1978) Significance and origin of big rivers. *Journal of Geology*, 86, 13–33.

Warne, A.G., Meade, R.H., White, W.A., Guevara, E.H., Gibeaut, J., Smyth, R.C., Aslan, A. and Tremblay, T. (2002) Regional controls on geomorphology, hydrology, and ecosystem integrity in the Orinoco Delta, Venezuela. *Geomorphology*, 44, 273–307.

Wohl, E.E. (2002) Rivers. In: *The Physical Geography of North America* (A.R. Orme, Ed.), Oxford University Press, Oxford, 199–216.