Sediment in Rivers – Origin and Challenges

Three Gorges Project

Photo: China Yangtze Three Gorges Project Development Corporation

Soil erosion is a natural process accelerated by human activities. Each year, erosion of surface soil from river basins amounts to 60 billion tons, resulting in 24 billion tons of sediment flux to the oceans in the world and almost 25 billion tons of soil lost from agricultural land. From a global point of view, this currently represents a redistribution of soil resources by about 7 per cent each decade with multiple consequences. Much of this sediment moves into the river system, posing many problems for river management and control. By assimilating nutrients and contaminants, sediment has serious implications both in rivers and coastal waters.

Erosion

Geologic erosion varies in different places on the earth's surface because of differences in character of the rock and of the climatic and vegetative conditions. The control over geologic erosion is often difficult to achieve because the natural conditions that have prevailed over centuries cannot be changed significantly to effect any great reductions in erosion. Under certain local conditions, however, improvements can be made to reduce erosion.

Accelerated erosion is brought about by human activity. It is not uncommon that erosion rates have increased by more than 100 times that of the geological erosion. Agricultural activities, urbanisation, road and highway construction, mining operations, and altering runoff conditions and river control works are those which induce accelerated erosion.

Soil erosion and sediment yield

Erosion and sediment redistribution processes are the primary drivers of landscape development and play an important role in soil development. Soil erosion is integrally linked to land degradation, and excessive soil loss resulting from poor land management has important implications for food production and security and thus for the sustainable use of the global soil resource. Soil erosion is difficult to quantify and is site-specific. It is characterised by high spatial variability and must therefore be documented over very small areas. As a result, it is difficult to produce the erosion rate of a large area, let alone of a country and even global generalisations.

It must be emphasised that erosion rate and sediment yield are two different things. The sediment yield from a river basin reflects only that part of the sediment eroded from within the basin that reaches the basin outlet.

The present global rate of soil erosion has been estimated at 10.2 ton per hectare per year, with rates of soil loss having increased by circa 1.5 ton per hectare per year (i.e. by around 17.2 %) during the 20th century, and would in the 2090s increase by almost a further 14 %, with about 65 % of this increase being the result of climate change and increased erosivity, and about 35 % the result of population growth and changes in land use. Although both land use and impact of climate change caused increased erosion rates in most areas of the globe, reductions were predicted for North America and Europe as a result of land use changes and for North America due to climate change, resulting in a net reduction on both these continents.

Figure 1 shows sediment yield in the world. It indicates that the largest area of serious soil erosion is in Asia, and the most seriously effected countries are China, India and Pakistan.

Landslides and debris flows

In mountainous regions, landslides, debris flows and slope collapses may be the major sources of sediment production and the most serious disasters among all water-related ones. In Japan, the annual average loss of life from landslide hazards is 170. In the US landslides cause an estimated USD 2 billion in damage and 25-50 deaths each year. The situation is much worse in developing countries and remote mountainous regions due to lack of financial resources and inadequate disaster management. Debris flow events are common in mountainous areas worldwide. In southwest China debris flow gullies are widely distributed and they induce damages and disasters yearly. For mitigating the disasters control works have been built in many gullies.

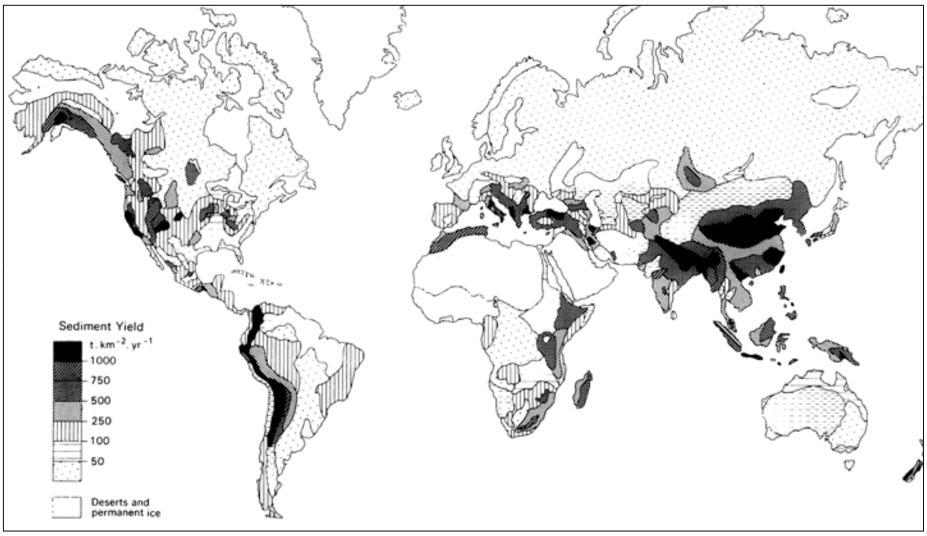

Figure 1. Global map of distribution of sediment yield Source: "Erosion and Sediment Yield: Global and Regional Perspectives" IAHS Publication No.236,1996.

Changes in sediment load

Many of world's rivers can be expected to show evidence of changing sediment loads in response to recent land-use change. The net effect of these changes on the global land-ocean sediment flux suggests that the 'natural' or 'pre-human' flux has been almost doubled by anthropogenic impacts. But almost 50 % of the gross flux has been trapped in reservoirs. However, when other causes of reduced sediment loads are considered, it seems that the net land-ocean flux may now be less than the 'pre-human' or 'natural' flux. Leading experts stress that it is important that the sensitivity of the sediment loads of rivers to recent environmental change is recognised both in terms of the potential significance of these changes to the functioning of the Earth system, for example via geochemical cycling; of local and regional impacts and problems, such as the recession of delta shorelines due to the reduced sediment supply; and of the destruction of coral reefs due to increased sediment inputs to coastal seas.

River pollution and water quality

River sediment is not only the major water pollutant by weight and volume but also serves as a catalyst, carrier and storage agent for other forms of pollution. Usually, the greater the sediment concentration, the poorer the water quality. Sediment alone degrades water especially for urban supply, recreation, industrial consumption and cooling, hydroelectric facilities, and aquatic life. In addition, chemicals and wastes are assimilated onto and into sediment particles. Ion exchange occurs between solutes and sediments. Runoff water often contains many chemical constituents including heavy metals, organometallic species, polycyclic aromatic hydrocarbons (PAHs), fossil fuels, lubricating and transmission oils, grease, and anti-corrosion and anti-freeze agents. These chemical pollutants may affect the water chemistry of rivers and lakes and be deleterious to biological and aquatic ecosystems. In recent years, the rapid development of industry and agriculture has resulted in increased pollution of heavy metals which are a significant environmental hazard for invertebrates, fish, and humans. A significant amount of heavy metals is discharged into rivers resulting in sub-lethal effects or deaths in local fish populations.

The sediment in rivers and lakes play a significant role in determining water quality. Suspended sediment adsorbs pollutants from the water, thus lowering the concentration of pollutants in the water. However, pollutants may also be released when the sediment is disturbed. Benthic sediments also provide habitats and a food source for benthic fauna. Pollutants may be directly or indirectly toxic to the aquatic flora and fauna. Effect of pollutants may also be detected on land due to the effects of bioaccumulation and bio-concentration in the food web.

Reservoir sedimentation

It is difficult to find a river left without human interference. Figure 2 shows the total storage capacity of reservoirs and the index RI of several large rivers. By using reservoir index (RI) rivers can be classified as natural (RI is less than 10 %), semi-natural (RI is between 10-50 %), semi-controlled (RI is between 50-100 %) and controlled (RI is larger than 100 %). RI is the ratio of the total storage capacity of river reservoirs to the mean annual runoff of the river. The Colorado, the Nile, the Yellow, and the Mississippi rivers have become the controlled rivers, while the Yangtze and the Pearl rivers are semi-natural rivers.

The construction and operation of reservoirs can bring many benefits to the society, such as flood control, water supply, power generation, irrigation, navigation, recreation, and environmental benefits. Meantime, side effects of reservoirs may appear. As soon as a reservoir starts storing water, part or most of the sediment processes in the river is interrupted. Most of the incoming sediments are trapped in the reservoir, forming a delta, and the backwater affects a long distance upstream. Reservoir sedimentation can reduce the reservoir's capacity and thus its benefit. Relatively clear water released

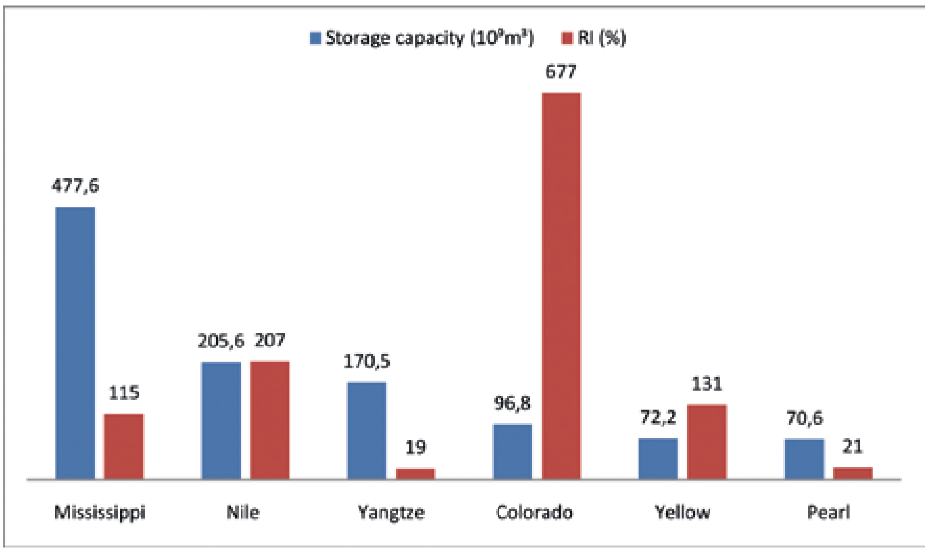

Figure 2. Total storage capacity of reservoirs and RI of selected large rivers. Source: Wang, 2007.

Photos: Yellow River Conservancy Commission, China and IRTCES

Left photo: Sediment flushing at Xiaolangdi, project, Yellow River. Right photo: Landslide.

from a reservoir can cause downstream river bed degradation. If no action is taken to remediate the sedimentation problems, a reservoir may lose its original design functions, and may pose a safety concern.

In 2003 there were totally 49,697 large dams in the world. 25,800 in China, followed by the US (8,724), the ex-USSR, Japan and India. The figures were estimated by the International Commission on Large Dams (ICOLD). A large dam is defined by ICOLD as one measuring 15 m or more from the foundation to crest or with reservoir storage capacity greater than 1 million m^3. In 2008, China has a total of 86,353 dams with storage capacity of 692.4 billion m^3.

It is estimated that the annual loss rate of reservoir storage capacity due to reservoir sedimentation is 0.5-1.0 %, corresponding to an annual loss of reservoir storage capacity of some 45 billion m^3 (estimated by the rate of 0.75 %), a great loss.

To cope with sedimentation problems and develop sustainable reservoir operation and management strategies, engineers and researchers have developed many innovative methods, such as drawdown flushing and empty flushing, venting turbidity currents, dredging, etc. In China, based on the experience of managing reservoir sedimentation, one of them is an operation scheme called "discharging the turbid water and impounding the clear water" to slow down the sedimentation processes and ensure the long-term functioning of the reservoir. This operation scheme has been applied for the Three Gorges Project (TGP) on the Yangtze River, the largest hydro-project in the world, commissioned in 2009 with the mean annual suspended sediment concentration at the dam site of 1.22 kg/m^3.

Future action

Along with the recognition of the importance of sediment-related issues the society has paid increasing attention to erosion and sedimentation problems. Many tasks remain to be tackled in the first half of the 21^{th} century. Some of them can be briefly described as follows.

Strengthening research: There is still a need to clarify many unclear phenomena and to establish new regularities, so that future work of erosion and sedimentation management will be based on a more scientific and sound ground.

Comprehensive and integrated planning: For erosion and sedimentation management planning there is a clear need for more coordinated and integrated approach to manage land-water interaction and for tailor-made policy at catchment level, including the interaction with the coastal waters.

Strengthening policy-making: Policies are the bases of sustainable development of the society. At present policies at three levels (International, regional and national) are in need. International policies supervised by UN agencies are of utmost important.

Legislation is important for erosion control, river management, and environment protection, etc. Although there are many laws and regulations in the field of water, it seems that enforcing laws may be more difficult than legislation. Establishing law enforcement teams is one of the measures to be adopted.

Strengthening management: The concept of "harmony between mankind and nature" has become more popular in dealing with their relationship. Thus, sediment management has replaced control of rivers. Management should be the basic concept of river planning and design.

International cooperation: International cooperation includes many aspects of works on erosion and sedimentation, particularly in the management aspect.

The challenge of modern river management is no longer one of engineering – how to control the river – but one of management – how to allocate water between competing uses while still maintaining ecosystem services.

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Further reading

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