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# Suspended sediment yields of rivers in Turkey

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**Abstract** The aim of this paper is to quantify the spatial distribution of suspended sediment yields of rivers in Turkey, and to quantify the suspended sediment flux to the sea, to lakes and reservoirs, and out of the country. Sediment yields in Turkey vary in accordance with the erosion potential of the river basins and values range from 12 to 609 t $km^{-2}$ $year^{-1}$. The total mass of suspended sediment flowing to the sea, lakes, reservoirs, and out of the country is 175 000 000 t $year^{-1}$. The sediment yields of selected basins are compared with average values for the world.

## INTRODUCTION

Man has faced problems caused by erosion, transportation and deposition of sediment ever since the civilisations that developed in the fertile valleys of the Nile, Tigris, Euphrates, Indus and the Yellow River. As early as 4000 BC people dug canals, built storage dams, diverted water and constructed flood protection works. With the development of rivers for multi-purpose use, such as irrigation, power generation, flood control, navigation, water supply for industry and drinking, and recreation, man has interfered with the equilibrium of alluvial streams and created several problems.

Erosion of soil from river basins involves the processes of detachment of soil from the soil surface and its transport by runoff and wind. Some sediment is also eroded from the bed and banks of small and large channels. Part of the sediment eroded by the action of rainfall and surface flow is deposited in the lower parts of the basin, in streams and on flood plains, and the remainder is transported to the sea unless it is deposited in reservoirs. The study of erosion and sediment yield from river basins is important for many reasons. Deposition of sediment in a reservoir reduces its capacity, thereby adversely affecting water supply for irrigation, domestic and industrial use and for power generation. Depletion of reservoir capacity is a serious problem, since after some years reservoirs may become ineffective in holding large quantities of water. When sediment eroded from river basins is deposited on stream beds and banks it can cause braiding of river reaches, inundation of the flood plain during floods and reduction of clearance below bridges. The removal of fertile topsoil from a river basin will also adversely affect the agricultural production.

## MATERIAL AND METHODS

Systematic data collection on the sediment transport characteristics of surface waters in Turkey, compatible with International Standards was initiated by the General Directorate

of Electric Power Research Survey and Development Administration (EIE) in 1962 within the framework of the hydrometric observations at the basic station network in Turkey.

Suspended sediment sampling is undertaken by the depth-integrated method using USDH-48 and USD-49 sampling equipment. The sediment concentrations of the samples are determined in the EIE laboratory, mostly by filtration, and analysis of the grain size composition of these samples is performed to determine the sand, silt and clay content.

Suspended sediment concentrations are expressed as parts per million by dry weight of the sample. Suspended sediment samples are usually collected at monthly intervals and are used to develop sediment rating curves for each streamgauging station site, where values of sediment discharge (t $day^{-1}$) are plotted against the river discharge at the time of sampling. For each of the 95 streamgauging stations operating in 1990, the annual suspended sediment load is computed using available daily discharge data and the sediment rating curve. The main river basins of Turkey are shown on the map presented in Fig. 1.

## Calculation of sub-basin sediment yields

Average annual values of suspended sediment yield from successive downstream sub-basins have been calculated using the method presented in Fig. 2. If the suspended load decreases downstream the sediment yield for the intervening sub-basin has not been calculated (Lajczak & Jansson, 1993).

## RESULTS

Mean annual suspended sediment yields for the basins are presented in Table 1. From Table 1 it can be seen that the highest sediment yield is 609 t $km^{-2}$ $year^{-1}$.

## Suspended sediment inflow to the sea, to lakes and reservoirs, and out of the country

The gauging stations near river mouths have been used to calculate the mean annual suspended sediment inflow to the sea, to lakes and reservoirs, and out of the country. Transport to the sea by rivers without sediment gauging stations has been tentatively estimated using analogous neighbouring gauged rivers, taking account of their drainage areas.

Table 2 presents the mean annual suspended sediment flux to the sea from the river basins of Turkey. The Kizilirmak River is the main source of suspended sediment flux to the sea. The contribution by this river reaches 19 533 275 t $year^{-1}$, i.e. 25.5% of the total input to the sea. The Sakarya River discharges 11 953 516 t $year^{-1}$, i.e. about 15.6% of the total input to the sea.

Table 3 presents the mean annual suspended sediment input to lakes and reservoirs, and the transport out of the country. The Euphrates River transports 54 987 544 t $year^{-1}$, i.e. 56.4% of the total input to lakes, reservoirs, and transport out of the country. The

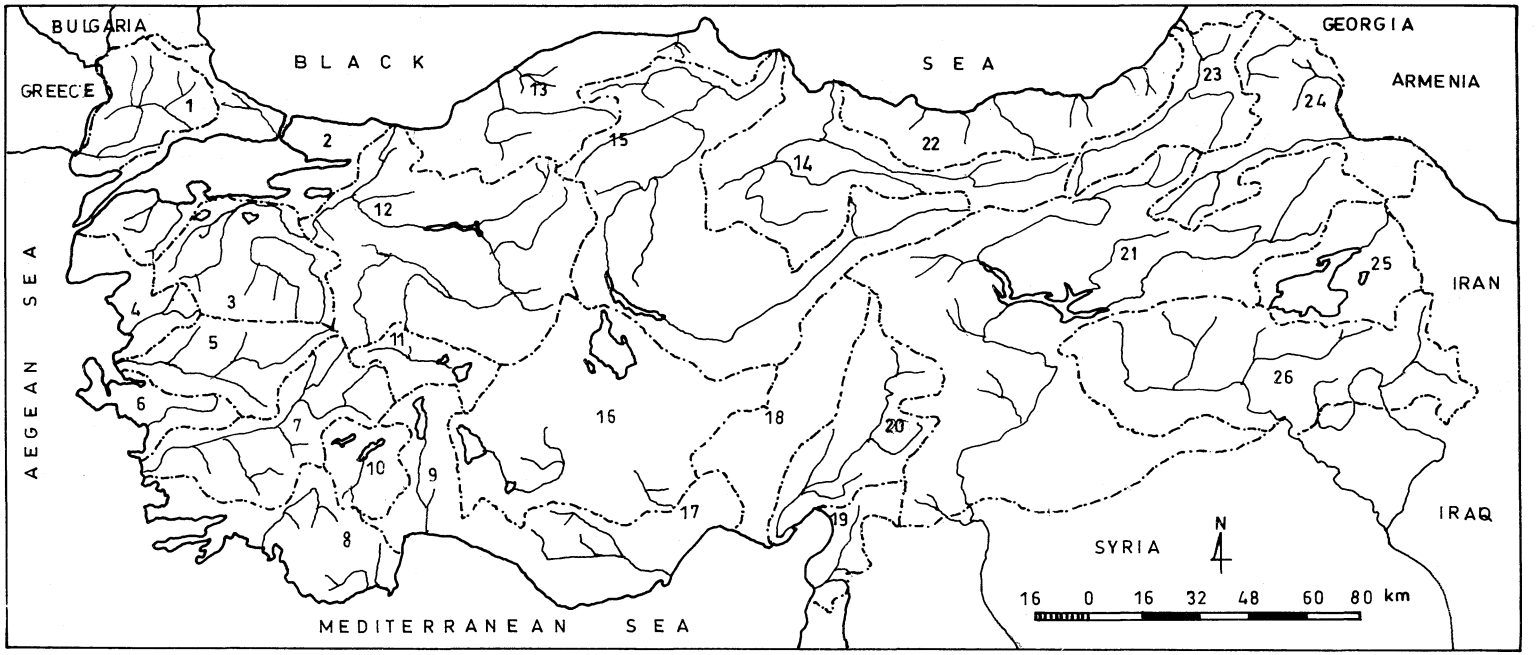


**Fig. 1** Map of the river basins of Turkey.

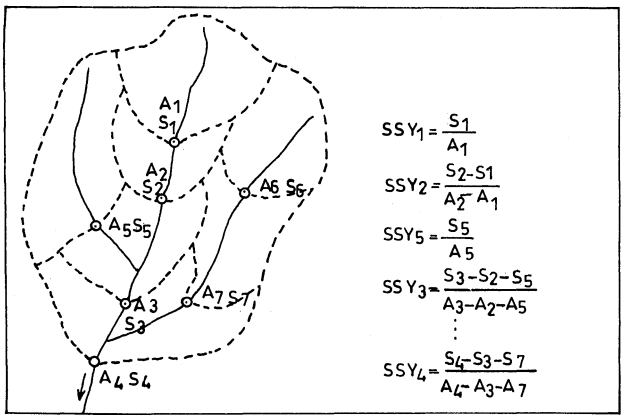


**Fig. 2** The method of calculating suspended sediment yield from successive downstream sub-basins. $A$ = drainage area (km$^2$); $S$ = suspended sediment load (t year$^{-1}$); and $SSY$ = suspended sediment yield (t km$^{-2}$ year$^{-1}$).

**Table 1** Suspended sediment yields of river basins in Turkey.

| Basin number and name | Period | Average annual precipitation (mm) | Average suspended sediment yield (t km$^{-2}$ year$^{-1}$) |
|---|---|---|---|
| 26 Dicle (Tigris) | 1966-1990 | 814 | 609.0 |
| 21 Firat (Euphrates) | 1963-1990 | 582 | 466.2 |
| 23 Coruh | 1967-1990 | 540 | 396.0 |
| 14 Yesilirmak | 1967-1990 | 556 | 279.7 |
| 20 Ceyhan | 1966-1991 | 758 | 247.0 |
| 15 Kizilirmak | 1967-1990 | 459 | 235.9 |
| 8 Western Mediterranean | 1969-1990 | 865 | 235.2 |
| 13 Western Black Sea | 1963-1990 | 803 | 219.9 |
| 17 Eastern Mediterranean | 1966-1990 | 669 | 187.5 |
| 12 Sakarya | 1963-1991 | 534 | 182.3 |
| 24 Aras | 1969-1990 | 462 | 173.1 |
| 18 Seyhan | 1966-1990 | 629 | 149.1 |
| 3 Susurluk | 1964-1990 | 730 | 141.9 |
| 9 Antalya | 1969-1990 | 910 | 128.3 |
| 22 Eastern Black Sea | 1969-1990 | 1291 | 98.8 |
| 6 K. Menderes | 1973-1990 | 740 | 94.0 |
| 5 Gediz | 1967-1990 | 639 | 84.6 |
| 7 B. Menderes | 1967-1990 | 656 | 63.0 |
| 4 North Aegean | 1979-1990 | 730 | 35.0 |
| 1 Meric-Ergene | 1971-1990 | 640 | 34.0 |
| 25 Van Lake | 1979-1988 | 507 | 32.0 |
| 2 Marmara | 1973-1990 | 766 | 25.0 |
| 16 Konya closed basin | 1983-1990 | 437 | 23.0 |
| 19 Asi | 1975-1990 | 837 | 15.0 |
| 10 Burdur lakes area | 1979-1990 | 436 | 12.0 |

**Table 2** Mean annual suspended sediment flux to the sea from river basins in Turkey.

| Basin number and name | Data source: | | Suspended sediment flux: | |
|---|---|---|---|---|
| | Measured ($km^2$) | Estimated ($km^2$) | (t $year^{-1}$) | (%) |
| 1 Meric-Ergene | 10 298 | 3 681 | 461 222 | 0.6 |
| 2 Marmara | 1 194 | 17 218 | 460 300 | 0.6 |
| 3 Susurluk | 4 370 | 4 003 | 1 070 576 | 1.4 |
| 4 North Aegean | 1 576 | 8 427 | 350 105 | 0.5 |
| 5 Gediz | 9 615 | 8 117 | 1 263 598 | 1.6 |
| 6 K. Menderes | 3 277 | 3 628 | 649 070 | 0.8 |
| 7 B. Menderes | 20 250 | 1 116 | 784 583 | 1.0 |
| 8 Western Mediterranean | 6 939 | 11 440 | 4 322 653 | 5.6 |
| 9 Antalya | 5 031 | 7 012 | 1 541 689 | 2.0 |
| 12 Sakarya | 12 219 | 44 189 | 11 953 516 | 15.6 |
| 13 Western Black Sea | 14 632 | 12 927 | 6 059 619 | 7.9 |
| 14 Yesilirmak | 33 504 | 2 388 | 6 229 588 | 8.1 |
| 15 Kizilirmak | 50 039 | 27 440 | 19 533 275 | 25.5 |
| 17 Eastern Mediterranean | 12 310 | 9 738 | 4 133 415 | 5.4 |
| 18 Seyhan | 14 015 | 6 365 | 3 079 302 | 4.0 |
| 20 Ceyhan | 19 095 | 2 340 | 5 294 445 | 6.9 |
| 22 Eastern Black Sea | 5 692 | 18 383 | 2 341 234 | 3.1 |
| 23 Coruh | 16 353 | 1 718 | 7 164 036 | 9.4 |
| Total | 240 409[a] | 190 130[a] | 76 692 226 | 100.0 |

[a] Parts of river basins outside the boundaries of Turkey are not included.

**Table 3** Mean annual suspended sediment inflow to lakes and reservoirs, and transport out of the country.

| Basin number and name | Data source: | | Suspended sediment inflow: | |
|---|---|---|---|---|
| | Measured ($km^2$) | Estimated ($km^2$) | (t $year^{-1}$) | (%) |
| 10 Burdur, lakes area | 1 276 | 5 098 | 624 452 | 0.6 |
| 11 Akarcay | - | 7 605 | 1 809 990 | 1.9 |
| 16 Konya closed basin | 281 | 53 850 | 1 245 013 | 1.3 |
| 21 Firat (Euphrates) | 81 869 | 44 490 | 54 987 544 | 56.4 |
| 24 Aras | 13 320 | 13 472 | 4 637 343 | 4.8 |
| 25 Van lake | 1 544 | 19 405 | 670 368 | 0.7 |
| 26 Dicle (Tigris) | 45 360 | 11 874 | 33 465 271 | 34.3 |
| Total | 143 650[a] | 155 794[a] | 97 439 981 | 100.0 |

[a] Parts of the river basins outside the boundaries of Turkey are not included.

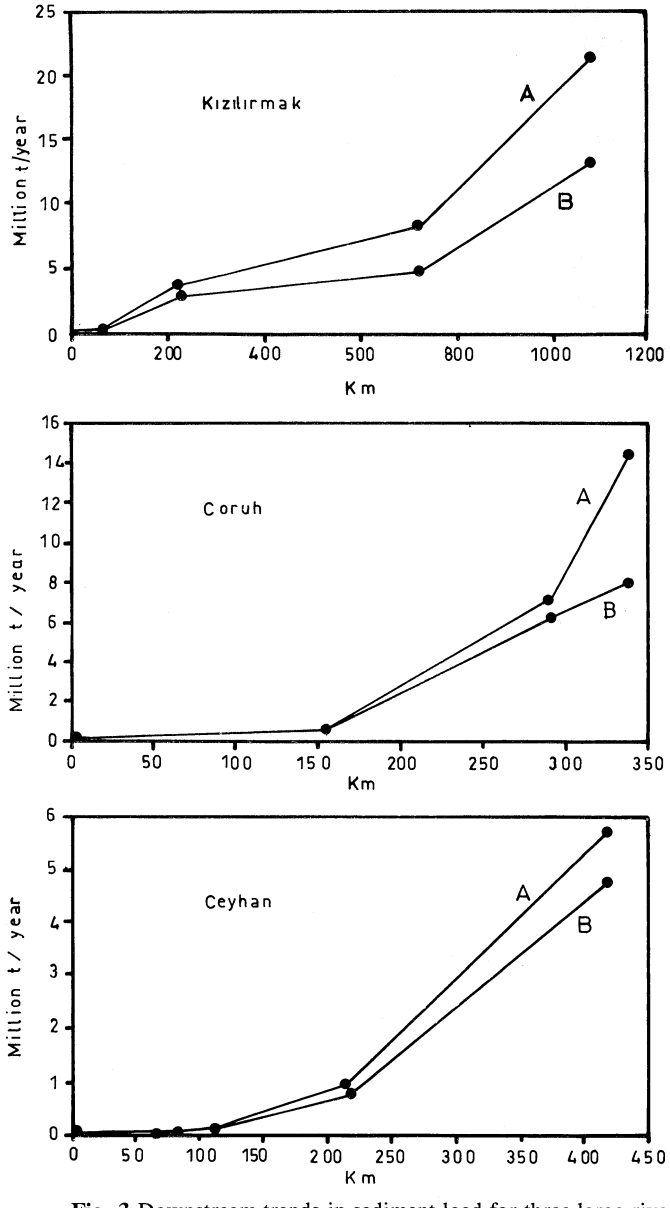


**Fig. 3** Downstream trends in sediment load for three large rivers draining to the sea, Curve A represents the hypothetical cumulative sediment inflow to the main river, curve B represents the actual sediment load in the main river calculated from measurements.

Tigris River transports 33 465 271 t year$^{-1}$, i.e. 34.3% of the total input to lakes, reservoirs, and transport out of Turkey.

When compared with the data included in other publications, e.g. Holeman (1968), the values given presented above for Turkey must be seen as high, except in comparison to the Asian Continent. It is estimated that the Earth's surface is being eroded at an

average rate of 3 cm per thousand years and hence it may take about 28 million years for the Earth's surface to be reduced to sea level (Garde, 1991).

## Suspended sediment deposition along large rivers

Rates of suspended sediment deposition within the individual basins can be calculated for large rivers which have more than two tributaries as indicated in Fig. 3. The sediment load measured in the main river is represented as curve B, whereas curve A represents the suspended matter transport in a hypothetical situation without sedimentation (based on tributary loads). The difference between the two curves shows the deposition rate, which also includes material deposited in reservoirs. Sediment is deposited in river channels, on the flood plain and in reservoirs. There are, for example, about 34 large and small reservoirs on the Kizilirmak River and its tributaries, and eight and seven large and small reservoirs on the Ceyhan and Coruh Rivers and their tributaries respectively. In consequence, fluvial sediment transport is reduced by deposition in a large number of reservoirs.

Calculation methods are of great importance in influencing the magnitude and accuracy of calculated loads. For instance, in Turkey, where suspended sediment samples are usually collected at monthly intervals, concentration values representative of the maximum values occurring during flood events are generally missing from the record (Ozturk & Kodal, 1988). This affects the representativeness of the data and the magnitude of the estimated loads, especially in small mountainous rivers with very rapid variations in water discharge and turbidity.

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