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Sediments to Water Quality and Vulnerability of Water Resources

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SEDIMENT, WATER QUALITY AND VULNERABLTY OF WATER RESOURCES

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Flow reaches wadis and channels by a variety of routes. These include overland flow from nearby catchment, seepage from the ground water and direct precipitation on the surface. Water flow is usually associated with flows of materials in solid and dissolved forms, i.e. sediment and solute, from catchment basins, surface and banks of wadi. Transfer of such materials may create a lot of problems to the receiving water bodies as well as catchment basin. In order to optimize utilization of water resources, it is essential to understand the basic physical processes that govern catchment basins and wadis behavior and their responses to natural and human changes.

This chapter will highlight the sediment and solute processes and the conservation measures for reducing their effect on the receiving water bodies.

6.1 SEDIMENT

6.1.1 SOURCES OF SEDIMENT

Sediments originate mostly from two sources. These are catchment basins source and wadi and channel sources. The amount of sediment derived from the catchment basin is influenced by storm and baisn characteristics. Catchment basin characteristics include the geometry of the basin, soil type, vegetation and ground cover and flow resistance. Storm characteristics include rainfall intensity, areal distribution and loss rates (Shen 1979).

Sheet flow erosion is considered the most important source of sediment. It occurs when the rate at which water is being applied to a surface exceeds the rate of infiltration. Runoff usually flows only a short distance as sheet flow before it concentrates into small channels or rills. Another source of sediment in catchment

(ii) Suspension, i.e. supported by the surrounding water during its entire motion.

Sediment transported by saltation or surface creep are called bed load, while those transported in suspension are called suspended load. Although bed load and suspended load are usually considered separately, there is no clear line of separation between them. The total sediment load is the summation of the two components.

6.1.3 SEDIMENT TRANSPORT RATE

6.1.3.1 Catchment basin erosion

One of the principal sources of stream born sediment is sheet erosion by surface runoff from precipitation on catchment basin. Sheet erosion is defined as the removal of surface soil by overland flow that does not allow the formation of channels of sufficient depth. Gullying and stream channel erosion also furnishes part of the stream load in a catchment basin. Therefore it is important to predict the amount of soil erosion occurring naturally in order to provide conservation practices or corrective measures.

Numerous mathematical models are available in literature to predict soil erosion. Most of these models require extensive data and complicated calculations. Pacheco-Ceballos(1993) developed simple analytical solution to predict watershed erosion in the following form;

$$q_{SE} = \frac{0.60}{\tan\theta} \cdot q \cdot S \cdot C \cdot P$$

in which q_{SE} is the watershed erosion rate per unit width, q is the flow discharge per unit width, $\tan\theta$ is the soil angle of repose, S is the slope, C is the cropping and management factor and P is the erosion control practices factor. Both C and P are empirical factors. Expanded tables for C and P values were presented by Wischmeier and Smith (1978) which represent most cropping-management schemes and control practices in use in the United States. Roose (1977) developed values for the cropping and practice in use in West Africa, these values are given in Table 1 and 2 for C and P values respectively.

according to their applicabilities into bed-load, suspended load and bed-material load formulas.

Large numbers of formulas are available in literature for sediment load computation in channels. Among these formulas are; DuBoys, Meyer-Peter-Muller and Einstein-Brown for bed load computations; Einstein, Bagnold and Lane-Kalinske for suspended sediment load; Colby, Englund-Hansen and Ackers-White for bed material load.

Sediment transport is complicated by enormous uncertainties that are generally not incorporated in formulas, such as erratic hydrological phenomena, geological hetrogenities and constraints. Therefore, it is very difficult, if not impossible, to recommend one equation for universal application. The user is required to look into the theoretical and empirical foundation on which each equation was developed. Basic assumptions and physical limitations must be clearly understood. Test and calibration are highly desirable, Chang(1988). Out of the various formulas, the following are an example of bed load, suspended load and bed material load formula.

(i) Meyer-Peter-Muller bed load formula

Meyer-Peter and Muller (1948) developed an empirical equation for bed-load discharge, q_b. in weight per unit time and channel width in the following form;

$$0.25 q_b^{2/3} \left(\frac{\gamma_s - \gamma}{\gamma_s} \right)^{2/3} \left(\frac{\gamma}{g} \right)^{1/3} = \left(\frac{k}{k'} \right) \tau_0 - 0.047 d_m (\gamma_s - \gamma)$$

in which γ_s is the sediment unit weight, γ is water unit weight, τ_0 is the bed shear stress, d_m is the effective diameter of the sediment mixture, g is the gravitational acceleration, k anf k' are the reciprocals of Manning's coefficient and value of (k/k') varies between 0.5 and 1. In the absence of bed forms, i.e. total roughness is caused by grain roughhness, (k/k') is 1 and for strong bed forms is 0.5.

(ii) Suspended sediment load

Suspended sediment load can be obtained by integrating the product of the velocity and sediment concentration over the depth of flow as follow;

production from cathment basins involves prevention of erosion or deceleration of sediment movements. Catchment basin soil erosion can be controlled by agronomical or mechanical protection methods. The role of agronomical method is to keep the land covered and to disturb it as little as possible utilizing conservation tillage practices. The role of the mechanical protection works is to reduce the runoff velocity, preventing the advancement of the eroded soil to the main channel system, encourage water to infiltrate into the soil and to dispose the surplus water safely. These are usually permanent structures of earth, masonry or both which designed and constructed to reduce the effective length of the slope of the land. Mechanical protection methods include interception, diversion and gully control structures.

Terraces interception structures seems to be a good practices in arid regions where agronomical practices are difficult if not impossible in extreme arid regions. Terraces are artificial earth embankment or combined channels and embankments constructed across sloping land at fixed vertical intervals down the slope. Terraces convert sloping land into a series of flat or nearly flat steps usually called bench terraces. Design of such structures depends on soil type, depth, climate and slope of the land.

Table 3. Coefficients value for Ackers-White bed-material load formula

Coefficient	$1<d_g \leq 60$	$d_g > 60$
C	$\log C=2.86 \log d_g - (\log d_g)^2 - 3.53$	0.025
n	$1-0.56 \log d_g$	0.0
A	$0.23/(d_g)^{0.5} + 0.14$	0.17
m	$9.66/d_g + 1.34$	1.50

6.2 WATER QUALITY

Precipitation or rainfall water contains a range of ions in solution as well as particulate matter washed out of the atmosphere. The sea is the major source of many salts found dissolved in rain water such as chloride, sodium, sulfate, magnesium, calcium and potassium ions. While land use, including urbanization and industrialization is the source of pollution found in rainwater due to the wide rang of chemicals discharged to atmosphere. For example, in Saudi Arabia rainwater

Field and laboratory studies indicated that the factors that affect runoff pollution are those that affect the chemicals persistence in the active runoff zone at the soil surface (Wallach and Shabatai 1993). Fertilizers and pesticides are adsorbed to the soil particles and associated with the sediment load. Nitrogen forms, however, are readily soluble and in areas where nitrogenous fertilizers are extensively used, high nitrate concentration has been found in underlying ground water (Barnes et al 1981). Soil tillage or irrigation shortly after chemical application may reduce the concentration on the active runoff zone.

In urbanized catchment areas, deposit build up at the surface is affected by a large number of relevant factors. The key factors are; dust fallout, human activities, traffic, wind and erosion from unpaved areas (Deletic et al 1997). These settled materials may include inorganic sediment, chemical cleansers and detergents, pesticides, fertilizers, animal fecal matter, garden clippings, oil and lead residues from motor fuels. During rainy season, these settled materials washed from the surface resulting in an initial flush of highly contaminated water. After prolonged rain, storm water quality enhanced resulting in relatively pollution free water. The pollution load associated with storm runoff can be significantly higher than that from secondary domestic sewage affluent (Cordery 1977). It can therefore cause degradation of surface and ground water bodies, and can also cause serious problems in drainage systems and traditional treatment facilities.

6.2.2 Water Quality Monitoring

It is necessary to take account of the intended uses of water (surface or ground water) when designing monitoring program. The quality of water used for irrigation is quite different from that used for recreational or drinking purposes.

Conductivity is widely used for water quality monitoring as it linked to the concentration of mineral salts in solution and easily related to the total dissolved solids. The acid or alkaline nature of the water is indicated by the pH value. Nutrient indicators such as phosphates and nitrates are also important in that they give some indication of the likelihood of entroplication of water bodies. Major ions such as sodium, potassium, calcium, magnesium, chloride, sulfate, carbonate and

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bicarbonate are important in that they form the chemical composition of runoff water. In addition to the above toxic substances is another quality indicator in some areas.

The above quality indicators must be checked against acceptable international standard for the intended water uses.

In Saudi Arabia, runoff water quality tests indicated that the total dissolved solids, calcium, magnesium and sodium ions increased by 15 to 20 times that of rainfall water. While chloride and sulfate were increased by 10 times of that of rainfall water with no changes in nitrate concentration (Handy et al 1986)

6.3 VULNERABLTY OF WATER RESOURCES

To be completed by Dr. Jean Khouri

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predominantly calcium bicarbonate and sulfate with pH greater than 6 and low nitrate values, i.e. 15 mg/l or less (Handy et al 1986).

In addition to the above, overland flow wash off debris accumulated in dry times and dissolved large amounts of mineral salts and organic. Thus dissolved solids determine the chemical properties of water such as hardness, acidity and conductivity, which in turn affect the physical properties of water.

6.2.1 Factors Affecting Water Quality

Surface water quality from a specific catchment area is dependent on geology, land use, topography and frequency and quantity of runoff.

The solubility of the rock forming minerals in the catchment area and wadi bed and the weathering regime under which it occur affect considerably the amount of dissolved solute. In large drainage basins with varied geological outcrops considerable spatial variation in solute load may exist. For example, limestone soils result in clear hard water, while impervious rocks such as granite results in turbid soft water.

The relation between solutes concentration and runoff discharge is commonly inverse. At low discharge values, water is derived from surface and ground water seepage. In such situation water spend a greater length of time in intimate contact with rock-forming minerals and thereby attains higher solute concentrations. While during high discharge periods, the intimate contact time is less and solute is diluted resulting in an overall low solute concentration.

Topography is another factor affecting solute concentration. For flat steep slope lands, solute concentration will be less than that of moderate slope of the same geological outcrop. In steep lands, water will have less contact time with the soil resulting in less solute concentration.

In agricultural lands, water quality is extremely variable as it influenced by soils, vegetation and cultural practices. In fact, fertile, highly productive and well-nourished soil is the major source of nutrient found in surface and subsurface water.

$$q_s = \int C_{sz} U_z dz$$

in which q_s is the suspended sediment discharge in weight per unit width, C_{sz} and U_z are the sediment concentration and velocity distribution formulas respectively. Measured concentration and velocity distribution relationships may be used or well known expressions such as Prandtl-von Karman velocity distribution and Rouse suspended sediment distribution equations may be used.

(iii) Ackers-White bed-material load formula

Ackers and White (1973) related the bed material load concentration, C_{bm} , by weight to the mobility number, F_g, in the following form;

$$C_{bm} = \frac{Q_{bm}}{Q} = C\left(\frac{\gamma_s}{\gamma}\right)\frac{d}{R}\left(\frac{U}{U_*}\right)^n\left(\frac{F_g}{A} - 1\right)^m$$

in which d is the sediment grain diameter, R is the hydraulic radius, U is the cross section mean velocity, U_* is the shear velocity, Q_{bm} is the bed material discharge for the cross section, Q is the flow discharge and n, C, A and m are coefficients depend on the dimensionless grain diameter, d_g, as shown in Table 3. The mobility number and the dimensionless grain diameter are defined as follow;

$$F_g = \frac{U_*^n}{gd\sqrt{\left(\frac{\gamma_s}{\gamma} - 1\right)}}\left(\frac{U}{\sqrt{32}\log\left(\frac{10R}{d}\right)}\right)^{1-n}$$

and

$$d_g = d\left(\frac{g\left(\frac{\gamma_s}{\gamma} - 1\right)}{v^2}\right)^{1/3}$$

in which v is the kinematic viscosity for water.

6.1.4 SEDIMENT CONTROL

The reduction of erosion on catchment basin land is the first step in correcting most of the sediment problems (ASCE. 1977). Controlling of sediment

Table 1 Cropping-management factor, C, for West Africa

Vegetal cover	Annual average value
Bare soil	1.0
Cotton	0.5 to 0.7
Peanuts	0.4 to 0.8
Crop cover of slow development or late planting first year	0.3 to 0.8
First year cassava and yam	0.2 to 0.8
Palm tree, coffee, cocoa with crop cover	0.1 to 0.3
Over-grazed savannah or prairie	0.1
Savannah, prairie in good condition	0.01
Forest or dense shrub, high mulch crop	0.001

Table 2. Erosion control practices factor, F, for West Africa.

Control practices	P factor
2-3 years of temporary grassland	0.50 to 0.10
Antierosive buffer strips from 2 to 4 meters width	0.30 to 0.10
Tied-ridging	0.20 to 0.10
Reinforced ridges of earth or low dry stone walls	0.1
Straw mulch	0.01

6.1.3.2 Channel erosion

There is two common classification of sediment loads in a stream. The first divides the load into bed load and suspended load, the second separates the load into wash load and bed-material load. Bed load is defined as that part of the load moving on or near the bed by rolling, saltation or sliding while Suspended load moves in suspension.

Wash load refers to the finest portion of sediment, generally silt and clay, that is washed through the channel, with an insignificant amount of it found in the bed. Bed-material load consists of particles that are generally found in the bed material. The discharge of wash load depends primarily on the rate of supply; it is generally not correlated with the flow characteristics while bed-material load is usually correlated with water discharge.

Sediment transport formulas are classified according to the development approach such as shear stress approach, power approach or parametric approach, or

basin is gully erosion. Gullies result from that one portion of a channel reaching base level much more rapidly than the channel upstream of the gully. Predominant processes that have been recognized in gully development include mass wasting of gully scarps and surface runoff transport of the resulting materials. Landslides provide a third sediment source. Alteration of the existing catchment basin landscape will increase sediment yield. Activities lead to landscape alteration are agricultural tillage, grazing, timbering, mining, urbanization,....etc. These landscape alterations include changing slope gradients, removal of vegetation, disturbing the surface soil and realigning hydrologic systems.

Channel sediments sources became extremely important on large wadis where the other sources are relatively negligible when compared to the total sediment load. There are numerous processes and activities that affect sediment from channel sources. These include, bank erosion, channel changes, hydraulic structures, channelization, gravel mining, ...etc.

In addition to the above, several types of natural disasters may cause huge increase in the supply of sediments in catchment basins and channel systems. These natural disasters include floods, earthquake and drought.

6.1.2 MOVEMENT OF SEDIMENT

Water flowing over a bed of sediment exerts forces on the grains. The motion of a particle is under the interaction of two opposing forces, the applied force and the resisting force. The former is caused by the hydrodynamics of the flow; the later in associated with the submerged weight. The particle will be moved or entrained if the applied forces overcome the resistance. At the critical condition for entertainment, that is, threshold of movement, the applied forces are just balanced by the resisting force. In reality, there is no truly critical condition for initiation of motion for which motion begins suddenly as the condition is reached.

Sediment particles are transported by the flow in one or a combination of the following ways:

(i) Surface creep, i.e. sliding or rolling along the bed;

(ii) Saltation, i.e. jumping into the flow and then resting on the bed; and