WATER QUALITY AND THE ENVIRONMENT

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1. Introduction

1.1 Water uses and human impact on water quality

With the advent of industrialisation and increasing populations, the rangc of requirements for water have increased together with greater demands for higher quality water. Other time, water requirements have emerged for drinking and personal hygiene, fisheries, agriculture (irrigation and livestock supply), navigation for transport of goods, industrial production, cooling in Fossil fuel (and later also in nuclear) power plants, hydropower generation, and recreational activities such as bathing or fishing. Fortunately, the largest demands for water quantity, such as for agricultural irrigation and industrial cooling, require the least in terms ofwater quality (i.e., critical concentrations may only be set for one or two variablcs). Drinking water supplies and specialized industrial manufacturers exert the most sophisticated demands on water quality but their quantitative needs are relatively moderate. In parallel with these uses water has been considered, since ancient times, the most suitable medium to clean, disperse, transport and dispose of wastes (domestic and industrial wastes, mine drainage waters, irrigation retums etc.).

Each water use, including abstraction of water and discharge of wastes, leads to specific, and generally rather predictable, impacts on the quality of the aquatic environment. In addition to these intentional water uses, there are several human activities which have indirect and undesirable, if not devastating, effects on the aquatic environment Examples are uncontrolled land use for urbanisation or deforestation, accidental (or unauthorised) release of chemical substances, discharge of untreated wastes or leaching of noxious liquids from solid waste deposits.

Similarly, the uncontrolled and excessive usc of fcrtilisers and pesticides has long-term effects on ground and surface water resources.

Structural interventions in the natural hydrological cycle through canalisation or damming of rivers, diversion of water within or among drainage basins, and the over-pumping of aquifers are usually undertaken with a beneficial objective in mind. Experience has shown. however, that the resulting long-term envíronmental degradatíon often outweíghs these benefits.

Pollution and water quatity degradation interfere with vital and Icgitimate water uses at any scale, i.e., local, regional or international (Meybeck et.al., 1989). Water quality criteria, standards. and the related legislation are used as the main administrative means to manage water quality in order to achieve user requirements. The most common national requirement is for drinking water of suitable quality, and many countries base their own standards on the World Health Organization (W'HO) guidclines for drinking watcr quality (WHO, 1984a,b). In some instanccs, natural water quality is inadequate for certain purposes, whereas other water bodies may still be perfectly usable for some activities even after their natural conditions have been altered by pollution.

Although the major proportion of all water quality degradation worldwide is due to anthropogenic influences, there are natural events, and environmental catastrophes, which can lead, locally, to severe deterioration of the aquatic environment. Hurricanes, mud flows, torrential rainfalls, glacial outbursts and unseasonal lake overturns are just a few examples. Some natural events are; however; aggravated by man's activities, such as soil erosion associated with heavy rainfall in deforested regions. Restoration of the natural water quality of tem takes many years, depending on the geographical scale and intensity of the event. The eruption of Mount Saint Helens, USA in 1980, and the subsequent mud flows, are still having a profound effect on downstream water quality (D. Rickert, US Geological Survey, pers. comm.).

1.2 Pollutant sources and pathways

In general, pollutants can be released into the environment as gases, dissolved substances or in the particulate form. Ultimately pollutants reach the aquatic environment through a variety of pathways, including the atmosphere and the soil.

Pollution may result from point sources or diffuse source (non-point sources). There is no clear – cut distinction between the two, because a diffuse source on a regional or even local scale may result from a large number of individual point sources, such as automobile exhausts. An important difference between a point and a diffuse source is that a point source may be collected, treated or controlled (diffuse sources consisting of many point sources may also be controlled provided all point sources can be identified). The major point sources of pollution to freshwaters originate from the collection and discharge of domestic wastewaters, industrial wastes or certain agricultural activities, such as animal husbandry. Most other agricultural activities, súch as pesticide spraying or fertiliser application, are considered as diffuse sources. The atmospheric fall - out of pollutants also leads to diffuse pollution of the aquatic environment.

The atmosphere is proving to be one of the most pervasive sources of pollutants to the global environment. Significant concentrations of certain contaminants are even being observed in Arctic and Antarctic snow and ice, with high levels of bioaccumulation magnifed through the food chain to mammals and native man.

Sources of anthropogenic materials to the atmosphere include:

- combustion of fossil fuels for energy generation,
- combustion of fossil fuels in automobiles, other forms of transport, heating in cold climates and industnial needs (e.g.. steel making),
- ore smelting, mainly sulphidcs,
- wind blown soils from arid and agricultural regions, and
- volatilisation from agriculture, waste disposal and previously polluted regions.

These sources, together, provide an array of inorganic and organic pollutants to the atmosphere which are then widely dispersed by weather systems and deposited on a global scale. For example, toxaphene and PCBs (polychlorinated biphenyls) have been described in remote lake sediments from lsle Royale, Lake Superior (Swaine, 1978) and in high Arctic ice (Gregor and Gummer, 1989) · In the former case, the source was postulated as the southern USA and Central America, whereas in the latter case, the source was believed to be Eastern Europe and the USSR. Deposition of pollutans from the atmosphere, either as solutes in rain or in particulate form, occurs evenly over a wide area; covering soils, forests and water surfaces, where they become entrained in both the hydrological and sedimentary (erosion, transport and deposition) cycles. This maybe terned secondary cycling, as distinct from the primary cycvle of emission in to atmosphere, transport and deposition. .

1.2.1 Point sources

By definition a point source is a pollution input that can be related to a single outlet. Untreated, or inadequately treated, sewage disposal is probably still the major point source of pollution to the world's waters. Other important point sources include mines and industrial efluents.

As point sources are localised, spatial profiles of the quality of the aquatic environment may be used to locate them. Some point sources are characterised by a relatively constant discharge of the polluting substances over time, such as domestic sewers, whereas others are occasional or fluctuating discharges, such as leaks and accidental spillages. A sewage treatment plant serving a fixed population delivers a continuous load of nutrients to a receiving water body. Therefore, an increase in river discharge causes greater dilution and a chacacteristic decrease in river concentration. This contrasts with atmospheric deposition and other diffuse sources where increased land run-off often causes increased pollutant concentrations in the receiving water system.

Non – atmospheric diffuse sources

Diffuse sources cannot be ascribed to a single point or a single human activity although, as pointed out above, they may be due to many individual point sources to a water body over a large area. Typical examples are:

- Agricultural run- off, including soil erosion from surface and sub-soil drainage. These processes transfer organic and inorganic soil particles, nutrients, pesticides and herbicides to adjacent water bodies.
- Urban run-off from city streets and surrounding areas (which is not channelled into a main drain or sewer). Likely contaminants include derivatives of fossil fuel combustion, bacteria, metals (particularly lead) and industrial organic pollutants, particularlyPCBs. Pesticides and herbicides may also be derived from urban gardening, landscaping, horticulture and their regular use on railways, airfields and roadsides. In the worst circumstances pollutants from a variety of diffuse sources may bc diverted into combined storm/sewer systems during storm-induced. high drainagc flow conditions,where theyb then contribute to major point sources.
- Waste disposal sites which include municipal and industrial solid waste disposal facilities; liquid waste disposal (particularly if groundwater is impacted); dredged sedimcnt disposal sitcs (both confined and open lake). Depending on the relative sizes of the disposal sites and receiving water bodies, these sources of pollution can bc considcrcd as cithcr difuse or point sources, as in thc case of groundwatcr pollution .

▪ Othcr diffuse sources including wastc from navigation, harbour and marina sediment pollution, and pollution from open lake resource exploitation, in particular oil and gas (e.g., Lakes Erie and Maracaibo). The time variability of pollutant release into the aquatic environment falls into four main categories. Sources can be considered as permanent or continuous (e.g., domestic wastes from a major city and many industrial wastes), pcriodic (e.g., seasonal variation associatcd with the influx of tourist populations, or food processing wastes), occasional (e.g., certain industrial waste releases), or accidental (e.g., tank failure, truck or train accidents, fires etc.). The ef£écts of these various types of pollutants on receiving water bodies are rather different The continuous discharge of municipal sewage, for example, may be quite acceptable to a river during high discharge periods when dilution is high and biodegradation is sufficient to cope with the pollution load. During low discharges, however, pollution levels and effects may excced acceptable levels in downstrcam river stretches.

1.3 Temporary and spatial variations of water quality

The temporal variation of the chemical quality of water bodies can be described by studying concentrations (also loads in the case of rivers) or by determining rates such as settling rates, biodegradation rates or transport rates. The spatial variation of water quality can be studied by means of profiles (longitudinal ones for rivers and vertical ones for lakes and reservoirs) or by preparing water quality maps, as is often done for groundwaters.

It is particularly important to define temporal variability. Five major types are considered here:

(i) Minute-to-minute to day-today variability resulting from water mixing, fluctuations in inputs etc., mostly linked to meteorological conditions and water body size (e.g., variations during river floods).
(ii) Diel variability (24 hour variations) limited to biological cycles, light/dark cycles etc. (e.g., 0_2, nutrients, pH), and to cycles in pollution inputs (e.g., domestic wastes).
(iii) Days-to-months variability mostly in connection with climatic factors (river regime, lake overtum etc.) and to pollution sources (e.g., industrial wastewaters, run - off from agricultural land).
(iv) The seasonal hydrological and biological cycles (mostly in connection with climatic factors).
(v) Year-to-year trends, mostly due to human influences.

2. Water quality

Water quality is closely linked to water use and to the state of economic development. In industrialized countries, faecal contamination of surface water caused serious health problems (typhoid and cholera) in large cities in the mid-1800s. At the turn of the century, cities in Europe and North America began building sewer networks to route domestic wastes further downstream of water intakes. Development of sewage networks and waste treatment facilities in urban areas has expanded enormously in the past two decades. However, the rapid growth of urban population, especially in Latin America and Asia, has outpaced the ability of governments to expand sewage and water infrastructure. While water-borne diseases have been virtually eliminated in the developed world, outbreaks of cholera and other gastro-enteric diseases still occur with alarming frequency in developing countries.

Since World War II and the dawm uf the 'chemical age', water quality has been heavily affected worldwide by industrial and agricultural chemicals. Eutrophication of surface waters from human and agricultural astes, and nitrification of groundwater from agricultural practices, has affected large parts of the world. Acidification of surface waters by air pollution is a recent phenomenon and threatens aquatic life in many areas. In developed countries, these general types of pollution have occurred sequentially with the result that most developed countries have successfully dealt with major surface water pollution. In contrast, newly industrialized countries such as China, India, Thailand, Brazil and Mexico, are now facing all these issues simultaneously.

3. Natural factors regulating water quality

If there was no human influence, water quality would be determined by the weathering of bedrock minerals, by atmospheric processes of evapotranspiration and the deposition dust and salt by wind, by the natural leaching of organic matter and nutrients from soils, and by hydrological factors that lead to run off.

Surface runoff is extremely variable. It is influenced by latitude, local differences in elevation (orography) and location on continents. In equatorial and monsoon regions, runoff exceeds 2000 mm/year or 63 litres km^{-2} s^{-1}. In regions where runoff is less than 25 mm/year, rivers are not perennial unless fed by wetter basins further upstream.

4. Hydrology

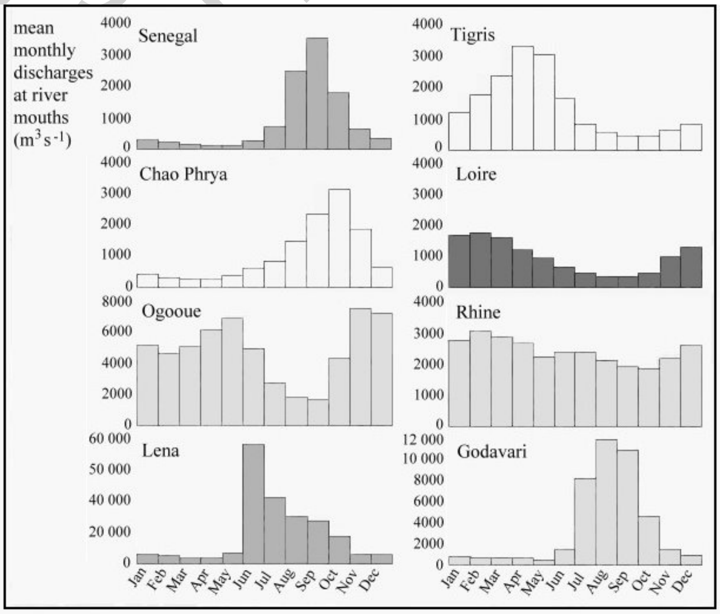

Figure 1: Selected hydrographs for average monthly discharges at river mouths

Discharge is the first factor that controls water chemistry, mainly through dilution. Discharge is also closely related to the transport of suspended sediment in rivers. Without continuous discharge measurement, fluxes (transport) of sediment and chemicals in rivers cannot be calculated. A plot of discharge through time is called a hydrograph (Figure 1). The shape of the hydrograph is linked to river size, river regime and the effects of lakes or groundwater.

Long-term monthly discharges characterize the regime of a river. Some examples are given in Figure 1

- tropical with maximum linked to rainfall pattern (Senegal);
- mountain snow melt and raïnfall (Tigris);
- late monsoon rainfall (Chao Phrya);
- oceanic type linked to
- evapotranspiration pattern (Loire);
- equatorial with two maxima linked to rainfall pattern (Ogooué);
- complex regime from glacier melt to;
- oceanic type (Rhine);
- lowland snow melt (Lena); and
- early monsoon type (Godavari).

5. Thermal characteristics

The rate of chemical and biological processes in surface waters, especially oxygen level, photosynthesis and algal production, are strongly influenced by temperature. Temperature is also an important variable for aquatic biota, particularly for fish. The thermal characteristics of lakes and reservoirs are a major factor in planning for effluent management and for withdrawal of water for industrial cooling purposes.

Temperature variation in surface water depends on local climate and on upstream influences such as snow and glacier melting, and occurrence of lakes. Siberian rivers, such as the Lena at its mouth, are frozen during eight months of the year while at the equator water temperature is nearly constant, 30 °C at sea level (Surabaya) and 23 °C at higher altitude (Thika). Seasonal variations are maximum at mid-latitudes where they can exceed 25 °C. Thermal pollution, wihich occurs tor example in the Meuse, rarely exceeds a few degrees and is usually masked by larger seasonal trends.

6. Suspended solids and water quality

Total Suspended Solids (TSS) is comprised of organic and mineral particles that are transported in the water column. TSS is closely linked to land erosion and to erosion of river channels. TSS can be extremely variable, ranging from less than 5 mg per litre to extremes of 30 000 mg per litre in some rivers. TSS is not only an important measure of erosion in river basins, it is also closely linked to the transport through river systems of nutrients (especially phosphorus), metal and a wide range of industrial and agricultural chemicals.

In most rivers TSS is primarily composed of small mineral particles. TSS is often referred to as “turbidity” and is frequently poorly measured. Higher TSS (more than 1000 mg per litre) may greatly affect water use by limiting light penetration and can limit reservoir life through sedimentation of suspended matter. TSS-levels and fluctuations influence aquatic life, from phytoplankton to fish. TSS, especially when the individual particles are small (less than 63 µm), carry many substances that are harmful or toxic. As a result, suspended particles are often the primary carrier of these pollutants to lakes and to coastal zones of oceans where they settle. In rivers, lakes and coastal zones these fine particles are a food source for filter feeders which are part of the food chain, leading to biomagnification of chemical pollutants in fish and, ultimately, in man. In deep lakes, however, deposition of fine particles effectively removes pollutants from the overlying water by burying them in the bottom sediments of the lake (see Figure2)In river basins where erosion is a serious problem suspended solids can blanket the river bed, thereby destroying fish habitat.

Sediment yield, expressed as tonnes km^2 year^{-1}, is calculated by dividing the total annual TSS load (tonnes) by the surface area of the watershed (km^2). Sediment yield is a key indicator of land erosion. Estimates of the average global annual sediment load to the world oceans varies from 15 to 30 billion tonnes.

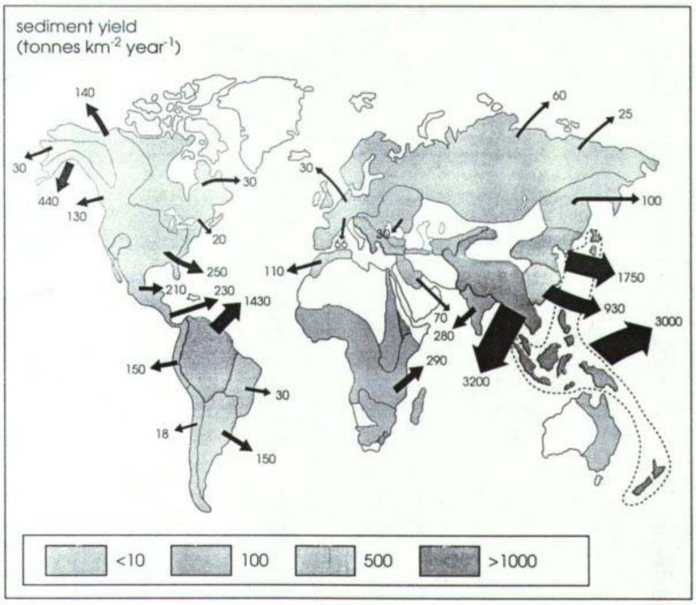

Figure 2: Global pattern of sediment yield, with river outputs of sediment to the oceans. Figures are in million tonnes

The large sediment loads to oceans in south-east Asia are two-thirds of the world's total sediment transport to oceans. This arises from the combination of active tectonics, heavy rainfall, substantial local relief with steep slopes, and erodible soils including the loess belt of northern China. The Huang He (Yellow) produces 1080 million tonnes of sediment annually; 480 for the Chang Jiang (Yangtze), 460 for the Ganges, and 710 for the Brahmaputra. Reservoir construction (Indus, and a future dam on the Chang Jiang) may affect these numbers in the future. In comparison; low

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