

Physiogenic and anthropogenic controls of global and regional ionic runoff

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ABSTRACT The average ionic runoff amounts to 4.3 or 3.6×10^9 t year⁻¹ and the average rate of the chemical denudation to 1.3 or 1.1 g s⁻¹km⁻². The estimated global anthropogenic ionic input of 0.7×10^9 t year⁻¹ in local cases leads to disturbance of the stability in hydrological systems, the effects of which may be compensated by building of structures and measures taken to influence processes.

Mécanismes de contrôle physiogéniques et anthropogéniques du flux ionique global et régional

RESUME En moyenne le flux ionique est 4.3 ou 3.6×10^9 t an⁻¹ et la partie d'érosion chimique est 1.3 ou 1.1 g s⁻¹km⁻². L'apport ionique anthropogène est estimée à 0.7×10^9 t an⁻¹. Par endroits il provoque des perturbations de la stabilité dans des systèmes hydrologiques, dont les réactions peuvent être compensées en prenant des mesures ou en construisant des ouvrages en vue de modifier les processus.

NOTATION

Symbol	Definition	Synonymous word	Measurement unit:	
			time- standardized	time-space- standardized
V (Q)	volume flow (\dot{V}) per time unit	discharge	$m^3 s^{-1}$ $km^3 year^{-1}$	
v (q)	volume flow (\dot{V}) per time unit per area unit	discharge modulus		$l s^{-1}km^{-2}$
M	mass flow (\dot{m}) per time unit	ionic, solid matter discharge	$kg s^{-1}$ $t year^{-1}$	
m	mass flow (\dot{m}) per time unit per area unit	rate of denudation		$g s^{-1}km^{-2}$ $t year^{-1}km^{-2}$
C	mass per volume unit ($mg l^{-1}$)	concentration		
c	concentration per time unit per area unit	intensity		$g l^{-1}s^{-1}km^{-2}$

Symbol	Definition	Synonymous word	Measurement unit:	
			time- standardized	time-space- standardized
Indices:	d - dissolved s - suspended t - total			
Abbreviations:	pt [*] - physiogenic (uncontrolled) type pt ^o - physiogenic (controlled) type tt - transition type (between pt and at) at - anthropogenic hydrochemical type +p - influenced by contribution from precipitation -p - not influenced by contributions from precipitation			

INTRODUCTION

The area- and time-dependent processes of mobilization, accumulation and modification of substances and energy within sedimentary environments operate within dynamic open systems. Chemical denudation, which involves the dissolution of soluble rocks and the ionic runoff of mobile solid components with a small ion potential, represents the greatest differentiation of matter in the lithosphere and the most intensive process of matter exchange between the lithosphere and the hydrosphere (Aurada, 1980). In the following treatment of ionic runoff and chemical denudation attention is focussed upon the ions Ca^{2+} , Mg^{2+} , Na^+ , K^+ , HCO_3^- , SO_4^{2-} , Cl^- and upon the total mineralization of terrestrial surface waters.

DATA SOURCES AND PROCESSING

Estimation of chemical denudation and ionic runoff requires data on the runoff, the average ionic composition and the total mineralization of drainage basin areas. Only areas of external drainage (excluding the Antarctic), which comprise $101.6 \times 10^6 \text{ km}^2$, were included in the calculations. Areas of internal drainage ($33.2 \times 10^6 \text{ km}^2$), such as that of Eurasia ($2.5 \times 10^6 \text{ km}^2$) have not been considered.

The global runoff balance of Baumgartner & Reichel (1975), which estimates total runoff (including the Antarctic) at $39.7 \pm 1.9 \times 10^3 \text{ km}^3 \text{ year}^{-1}$, has been used in the present calculations. The calculation of average ionic composition and of total mineralization is based on the investigation of Livingstone (1963), which still represents one of the most extensive studies of river water chemistry, and on more recent data from Beus *et al.* (1976). For comparison, data have been collected on the ionic composition of rain water from Wedepohl (1966), of ocean water from Goldberg (1957), Alekin (1970) and Horne (1972), and of continental runoff from Murray (1887), Clarke (1924), Conway (1942) and Livingstone (1963). The results of the present calculation are presented together with results from

several earlier studies in Table 1 and Fig.1.

IONIC RUNOFF AND CHEMICAL DENUDATION OF THE EARTH

The global ionic runoff for areas of external drainage amounts to $4.264 \times 10^9 \text{ t year}^{-1}$ or to $3.642 \times 10^9 \text{ t year}^{-1}$ if the average composition of Sugawara cited by Wedepohl (1966) is considered. A global rate of chemical denudation of 1.33 or 1.14 $\text{g s}^{-1}\text{km}^{-2}$ may be

TABLE 1 Comparison of recent calculations of m_q for areas of external drainage

Continents	Livingstone (1963) ($\text{g s}^{-1}\text{km}^{-2}$)	L'vovic (1974) ($\text{g s}^{-1}\text{km}^{-2}$)	Korzun (1974) ($\text{g s}^{-1}\text{km}^{-2}$)	Aurada (1980) ($\text{g s}^{-1}\text{km}^{-2}$)
Europe	1.53	0.79	1.20	1.85
Asia	1.86	0.65	1.04	1.71
Africa	1.13	0.38	0.96	0.54
North America	0.97	0.65	0.94	1.68
South America	0.89	1.03	1.03	1.66
Australia	0.12	0.62	0.92	1.41
Continents (+p)	1.21	0.64	1.00	1.33
Precipitation (after Sugawara, according to Wedepohl)				0.19
Continents (-p)	-	-	-	1.14

calculated from the estimates of ionic runoff. Based on estimates of mechanical and chemical denudation, the most probable value of total global denudation is $22.0 \times 10^9 \text{ t year}^{-1}$, where mechanical denudation

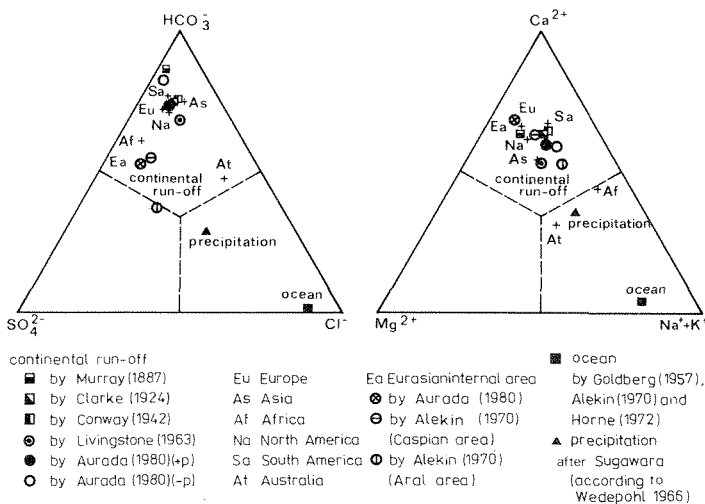


FIG.1 Average anion-cation-combination (mval %) of the runoff in continental areas with external drainage.

comprises $18.4 \times 10^9 \text{ t year}^{-1}$ (83.6%) and chemical denudation is $3.6 \times 10^9 \text{ t year}^{-1}$ (16.4%). In understanding global variations in the ionic composition of runoff, it can be assumed that the chemical content of sea water has remained constant since the Permian and probably since the early Phanerozoic (Fig.2).

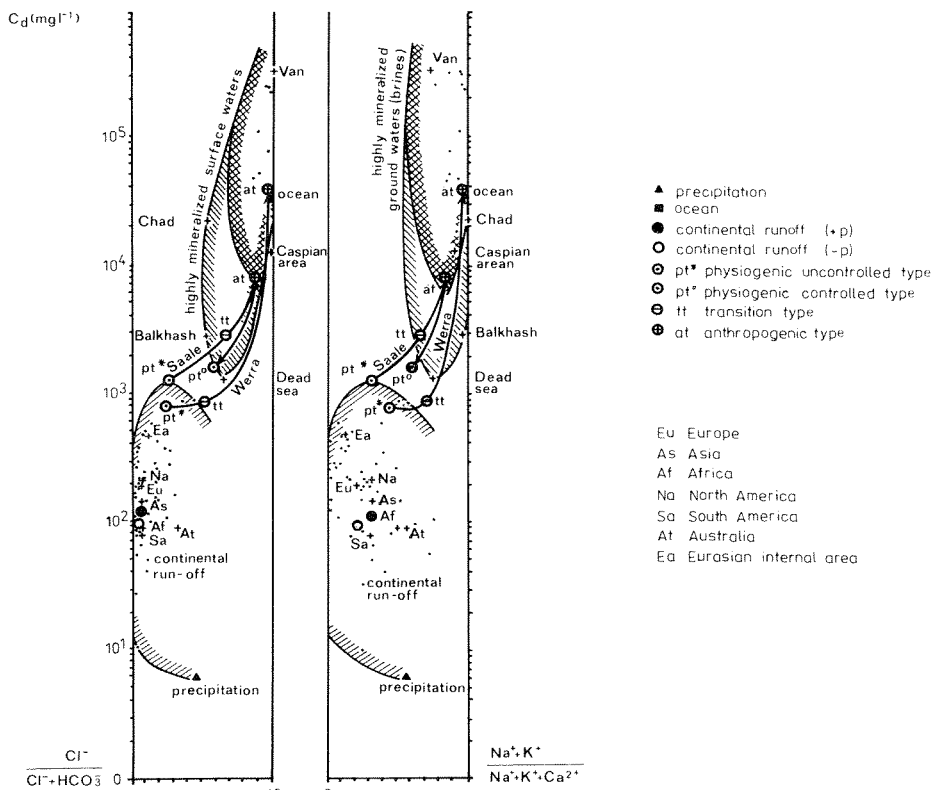


FIG.2 Representation of the control mechanisms of ionic runoff (developed from Gibbs, 1970).

CONTROLS OF IONIC RUNOFF AND CHEMICAL DENUDATION

Physiogenic controls

In areas where rocks undergoing chemical denudation form a weathering crust, variation in the chemical composition of surface waters is controlled by the meteorological factors of moisture input and loss, which results in a geographical zonation of ionic runoff and chemical denudation (Fig.3 and 4). This zonation is distorted by lithological, tectonic, geomorphological and climatological peculiarities. Furthermore, the chemical characteristics of runoff from drainage basins are influenced by ionic components derived from both autochthonous and allochthonous sources (Gregor, 1970).

The magnitude of solute uptake caused by infiltration of non-

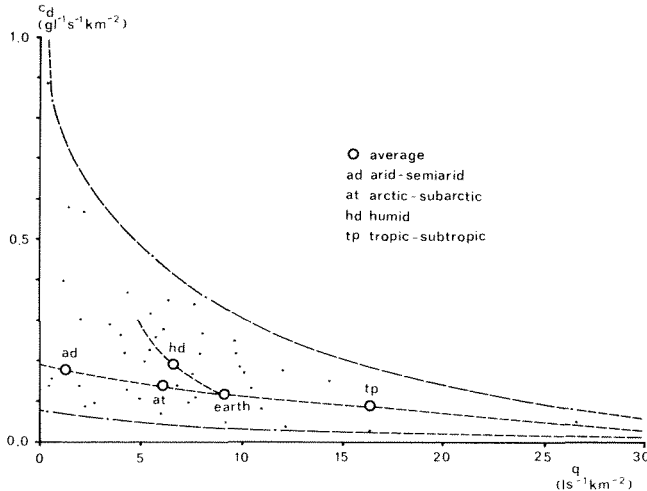


FIG.3 Representation of the ionic runoff intensity c_d .

saturated surface waters is conditioned by physiogenic, geochemical and geophysical factors. However, the rate of infiltration, the velocity of soil water movement and the residence time of individual runoff components in horizons of different solubility, which in turn are related to the degree of landscape dissection, will strongly influence hydrochemical characteristics. The decisive phase in the enrichment of meteoric waters, during the formation and concentration of runoff, may be calculated from the functional dependence of

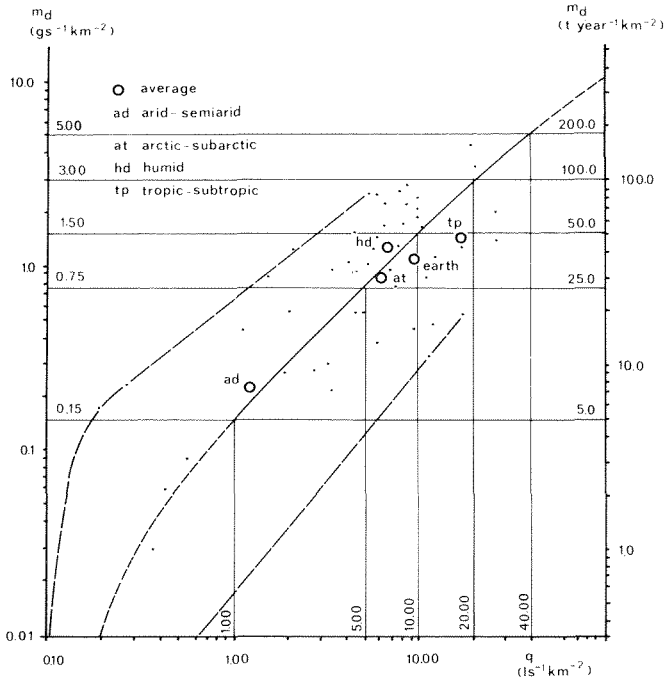


FIG.4 Representation of the chemical denudation rates m_d .

solute uptake (S_e) on the effective rainfall (P_e) or the direct runoff (R_d), expressed as

$$S_e = f(R_d) \quad (1)$$

or

$$S_e = a \times R_d^b, \quad (2)$$

in conjunction with a mean pulse-response-function (unit hydrograph, Fig.5) (Aurada, 1979).

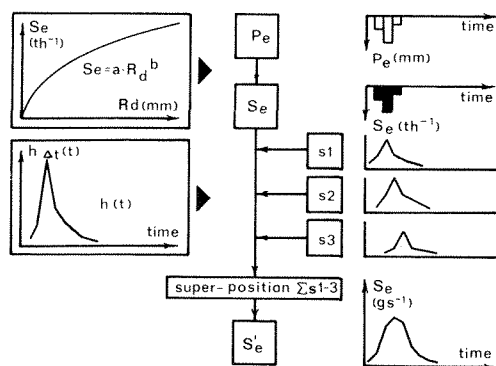


FIG.5 Scheme for the calculation of short-term solute uptake after runoff generated by precipitation.

Anthropogenic controls

The global input of the main ionic constituents from anthropogenic sources has been estimated as $0.714 \times 10^9 \text{ t year}^{-1}$ (Perelman, 1977), and is therefore nearly identical with the contribution from precipitation ($0.622 \times 10^9 \text{ t year}^{-1}$). The anthropogenic influence may cause considerable disturbance of the hydrological systems in small drainage basins (Aurada, 1982), and this is demonstrated by the examples of the Thuringian Wipper basin and the Thuringian-Hessian Werra basin (Fig.6). Inflow of salt-rich waste waters from the potash industry began in both rivers at the turn of the century. The mining reaches depths of 400-1100 m (Southern Harz district) or 400-900 m (Werra district) (Hoppe & Seidel, 1974).

From 1963 to 1972, the denudation rate in the Wipper basin (related to Cl^-) increased from 0.41 to $15.73 \text{ g s}^{-1} \text{ km}^{-2}$ and in the Werra basin from 0.66 to $53.94 \text{ g s}^{-1} \text{ km}^{-2}$. This effect finds its hydrochemical expression not only in the increasing total solute content, but also in the conversion of background $Ca-HCO_3$ or $Ca-SO_4$ water types (pt^+) into an anthropogenic $Na-Cl$ water type (at). The input of saliferous discharges causes the activation and acceleration of a natural process, which had remained largely unaltered over geological time, in the Wipper basin by 37.4 times and in the Werra basin by 80.7 times (see Fig.7 and the points pt^* and at in Fig.2).

In order to prevent or to reduce instabilities which may occur in heavily polluted hydrological systems there exist the following possibilities:

- (a) disposal of highly mineralized sewage through canals outside

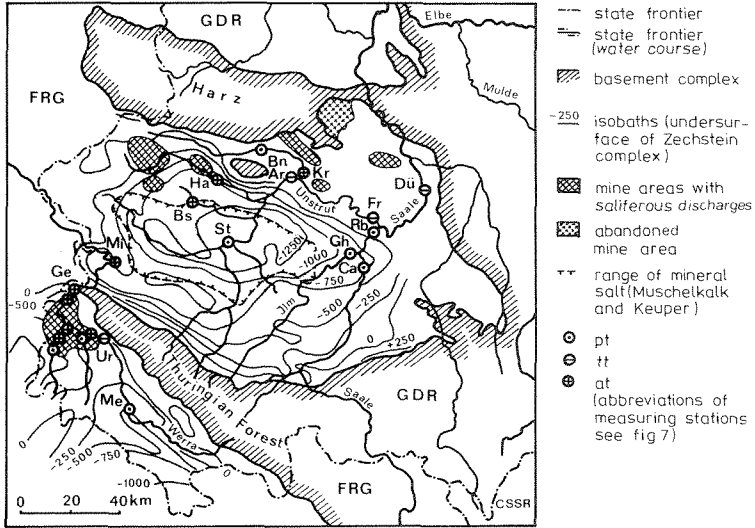


FIG.6 Depth of the basal contact of the Thuringian Zechstein (after Hoppe & Seidel, 1974) and location of the mining districts causing saliferous discharges.

of the river channel,

(b) occasional disposal of highly mineralized sewage into the ground, which has been done in the Werra basin from 1924 or 1925 to 1967,

(c) dilution of highly mineralized sewage by addition of the relatively slightly mineralized water from storage reservoirs, which was started as a trial in the Saale basin in 1943, and has been undertaken regularly since 1963 and underlies the process control system

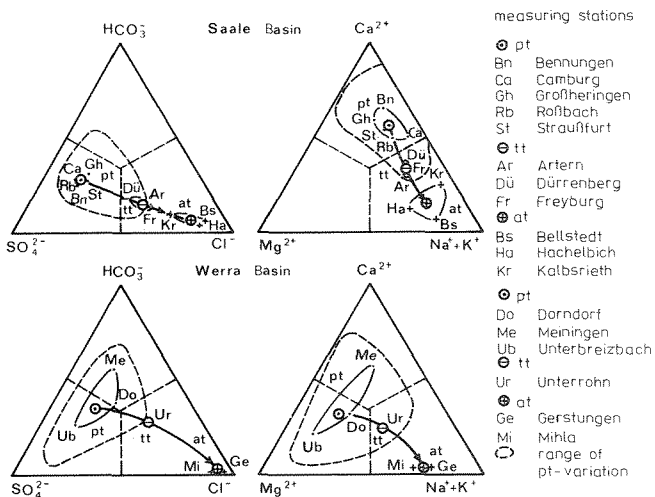


FIG.7 Average anion-cation-combination (mval%) of surface waters in the Saale basin (July 1971-March 1972) and in the Werra basin (July 1976-May 1977).

since 1976 (Aurada, 1979; Becker & Sosnowski, 1977) (see Fig.8 and the effects of the control in point pt⁰ in Fig.2).

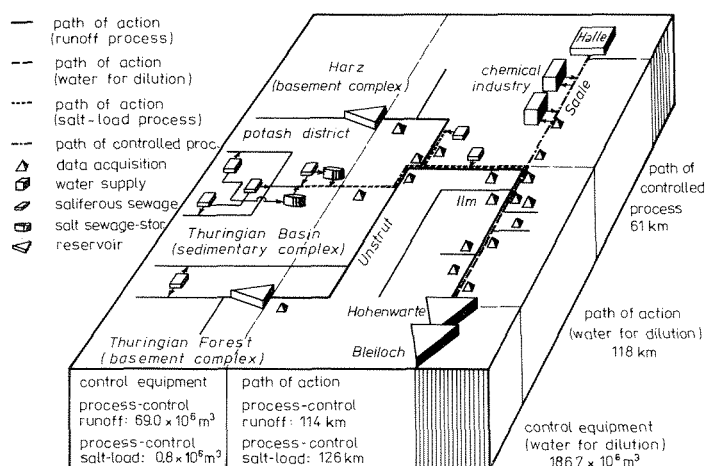


FIG.8 Model of runoff and ionic runoff (salt load) in the process control system in the Saale basin (GDR).

REFERENCES

- Alekin, O.A. (1970) *Osnovy Gidrochimii (Fundamentals of Water Chemistry)*. Leningrad.
- Aurada, K.D. (1979) Ergebnisse geowissenschaftlich angewandter Systemtheorie (Vorhersage und Steuerung lang- und kurzfristiger Prozessabläufe). *Petermanns Geogr. Mitt.* 123 (4), 217-224.
- Aurada, K.D. (1980) Steuerungsmechanismen des Ionenabflusses und der chemischen Denudation. *Acta Hydrochim. Hydrobiol.* 8 (6), 525-559.
- Aurada, K.D. (1982) Die Anwendung des systemtheoretischen Kalküls in der Geographie. *Petermanns Geogr. Mitt.* 126 (4), 241-249.
- Baumgartner, A. & Reichel, E. (1975) *The World Water Balance. Mean Annual Global, Continental and Maritime Precipitation. Evaporation and Run-off*. Amsterdam-Oxford-New York.
- Becker, A. & Sosnowski, P. (1977) Mathematical model system for continuous operational control of river flow and salt concentration in an industrialized river basin. In: *Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality* (Proc. Amsterdam Symp., October 1977), 191-198. IAHS Publ. no. 123.
- Beus, A.A., Grabovskaja, L.I. & Tichonova, N.V. (1976) *Geochemija Okruzajuscej Sredy (Geochemistry of the Environmental Milieu)*. Moscow.
- Clarke, F.W. (1924) The data of geochemistry, 5th edn. *USGS Bull.* 770.
- Conway, E.J. (1942) Mean geochemical data in relation to oceanic evolution. *Proc. Roy. Irish Acad. Sci.* B48 (8), 119-159.
- Gibbs, R.J. (1970) Mechanisms controlling world water chemistry.

- Science* 170, 1088-1090.
- Goldberg, E.D. (1957) Biogeochemistry of trace metals. In: *Ecology (vol. of Treatise on marine ecology and palaeoecology)* (ed. by J.W.Hedgpeth), 345-358. Geol. Soc. Am. Mem., 67.
- Gregor, C.B. (1970) Denudation of the continents. *Nature, Lond.* 228 (17), 273-275.
- Hoppe, W. & Seidel, G. (1974) *Geologie von Thüringen*. Gotha, Leipzig.
- Horne, R.A. (1972) *Morskaja Chimija (Struktura Vody i Chimii Gidrosfery)* (*Sea Chemistry: Structure of the Water and of the Hydrosphere*). Moscow.
- Korzun, V.I. (ed.) (1974) *Mirovoj Vodnyi Balans i Vodnye Resursy Zemli* (*World Water Balance and Water Resources of the Earth*). Leningrad.
- Livingstone, D.A. (1963) Chemical composition of rivers and lakes. Data of geochemistry, 6th edn. *USGS Prof. Pap. 440 G*, 1-64.
- L'vovic, N.I. (1974) *Mirovye Vodnye Resursy i ich Buduscee* (*World Water Resources and their Future*). Moscow.
- Murray, J. (1887) On the total annual rainfall on the land of the globe, and the relation of rainfall to the annual discharge of rivers. *Scottish Geogr. Mag.* 3, 65-77.
- Perelman, A.I. (1977) Zur Geochemie der Technogenese. *Z. angewandte Geol.* 23 (3), 111-115.
- Wedepohl, K.H. (1966) Die Geochemie der Gewässer. *Naturwiss.* 53 (14), 352-357.

