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Re-thinking erosion on Java

W. H. DIEMONT[1], A. C. SMIET[2] & NURDIN[2]

[1] Institute for Forestry and Nature Research (IBN-DLO), P.O. Box 9201, NL 6800 HB Arnhem, Netherlands
[2] School of Environmental Conservation Management, Balai Latihan Kehutanan, Ministry of Forestry, P.O. Box 109, Bogor 16001, Indonesia

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Abstract
Surface erosion from agricultural land, causing loss of agricultural productivity in uplands as well as off-site accelerated sedimentation, was already an issue on Java in the nineteenth century. The once denuded unproductive uplands known as 'dead land' (tanah mati) are now terraced or reafforested. But the productivity of food crops is still low and river sediment loads on Java are still among the highest in the world. It is discussed that (1) low inputs, not surface erosion, is the main cause of the low productivity of upland food crops and (2) high river sediment loads in Java are, besides surface erosion, caused by geological morpho-erosion, morpho-erosion from roads and the 'ngaguguntur' phenomenon in irrigated rice fields. Volcanic eruptions can also be a considerable source of sediments. A redirection of soil conservation policy, planning and research efforts is suggested.

Keywords: irrigated rice, land slides, river sediment load, soil conservation, watershed management

Introduction

With 108 million inhabitants and a population density of 840 people per square kilometre, the island of Java belongs to the most densely populated regions of the world. Large scale conversion of forest into cultivated land started in the middle of the last century and was instrumental in meeting the food requirements of the rapidly expanding population. When this process finally slowed down in the middle of this century, about 10 million ha of forest or some 80 % of its original area had been converted (Smiet, 1990). The link between accelerated surface erosion due to conversion and low agricultural productivity was already discussed by Holle (1866). Other authors at that time pointed, however, at the intensive cultivation practices without use of manure as the cause of low productivity (Sollewijn Gelpke, 1901). In the course of this century deforestation and expansion of agricultural land were increasingly seen as the cause of accelerated surface erosion and high river sediment loads. With few exceptions (Carson, 1989; World Bank, 1988) other erosion types and sediment sources were largely ignored. The present notion of the erosion problem on Java, reflected in government policies, seems also limited to surface erosion from rain-fed agricultural lands (Dames, 1955; Wiersum, 1980; Ambar, 1986; Repetto, 1986; Donner, 1987; Booth, 1988; Palte, 1989; Pearce et al., 1990), which is assumed to be a major cause of low agricultural productivity on rain-fed uplands in Java (Wiersum, 1980; Repetto, 1986). The annual costs of the productivity losses (on-site effects) by surface erosion in Java were even estimated at about 400 million USD. Costs from off-site effects such as increased sedimentation of reservoirs reducing the life expectation of these dams and estimated about 100 million USD, are also attributed to surface erosion (Magrath & Arens, 1989).

In the last 50 years many efforts have been made to tackle the problem of surface erosion in rain-fed crop areas in the uplands. The practice of terracing has been widely promoted, new crops and cropping systems have been introduced and generally the awareness of the erosion problem has been raised among farmers. Reforestation and regreening on both forest and private land have been encouraged. Results of these campaigns have been impressive and, although many exceptions occur, the overall impression is that surface erosion in upland agriculture is well under control. Nevertheless, river sediment loads remain high and sedimentation continues to be a problem.

In the last decennia various watershed management projects such as the FAO/UNDP Solo project, the USAID sponsored Citanduy project and the Netherlands DGIS sponsored Kali Konto project in cooperation with Indonesian governmental agencies, aimed at reducing surface erosion and at improving upland farm productivity. As well, these projects aimed to control off-site effects such as increased flood hazards in the lowlands and high sedimentation rates in water reservoirs. However, present information shows that aspects of soil conservation in these projects were different from original expectations. DHV (1990), for example, found that high river sediment loads were not matched by a high surface erosion, which had been expected as a result of deforestation and farming practices. Such findings point to other erosion types and sediment sources, besides surface erosion from farmland.

In this paper the information on surface erosion on Java is critically examined. It is discussed that surface erosion as a result of deforestation of uplands may be low, in particular on volcanic soils and is only partly responsible for high river sediment loads on Java. Other sources of erosion e.g. morpho-erosion which may cause high sediment loads are identified. As in many upland areas the surface erosion rates are probably not as high as previously assumed, also the causes of a low agricultural productivity in rainfed uplands are re-examined.

Erosion types and terminology

The process of natural soil erosion or denudation of the land is frequently accelerated by removal of ground cover, which often takes place after deforestation. Deforestation causes in general a decrease of the protection of the soil against the erosive force of raindrops as well as an increase of transport of detached soil particles by an increased run-off. Consequently, erosion rates from a surface area, measured in experimental 'Wischmeier' plots, increase. This type of erosion is surface erosion. But deforestation does not always result in an increase of surface erosion. For instance, surface erosion in bunded rice (sawah) cultivation is low. Rates of surface erosion measured under natural forest are less than 5 t ha^{-1} yr^{-1}, which is equivalent to a soil loss of about 0.5 mm, whereas on sloping agricultural land with a low yielding tapioca crop soil erosion in Wischmeier plots may be as high as 300 t ha^{-1} yr^{-1} or 30 mm soil loss. Surface erosion rates on agricultural land can be reasonably well assessed by Wischmeier plots and can be modelled by the well known Universal Soil Loss Equation.

Other types of water-induced erosion such as landslides, stream bank erosion, and road side erosion may be defined as 'morpho-erosion', e.g. active geologic or accelerated erosion depending on morphological conditions of the land (Meijerink, 1988). We assume that in Java most erosion under natural (forest) conditions is geology induced morpho-erosion. Landslides, for instance, are a common feature in the young volcanic mountain areas even under virgin tropical forest such as in the Gede-Pangrango mountain complex near Bogor. Morpho-erosion is, as surface erosion, often accelerated by human activities such as road construction, land clearing, and farming practices (see below). There can be no doubt that morpho-erosion in Java contributes to river sediment loads. The question of how large that contribution is, is presently not yet answerable.

Surface erosion

The need for adequate terracing in upland agriculture after deforestation was already recognized in the nineteenth century (Holle, 1866). In the same period forest management started and the need to manage natural forests for erosion control was recognized. However it lasted until the 1920s before natural forest management for watershed protection was effectuated, fuelled by the concern of lowland farmers and in particular the sugar industry that deforestation might cause a lack of irrigation water (Smiet, 1990). The colonial Forest Law of 1849 declared all forest, including teak plantations and natural forest, governmental property. This law was solely aimed at safeguarding a sustained supply of timber from teak plantation forests. It took another seventy years before the need for watershed protection by forest management and reforestation was acknowledged in the Forest Law of 1920. Since the 1920s forest management for watershed protection was actively pursued in combination with reforestation to improve watershed conditions. With some lapses as a result of political turmoil, this policy has been actively implemented until today (Smiet, 1990). Despite these efforts, the forested area decreased and the area of arable land increased between 1900 and 1950 (Figure 1). Reforestation of agricultural land (afforestation) was generally not practised, although it was considered the only sensible solution for marl and sedimentary areas with shallow soils (Dames, 1955). These soils cover a substantial part of Java (Table 1) and were previously known as 'tanah mati' (dead land). One of these areas, the Madjalengka region in West Java, was studied in the thirties by Dames (unpublished report). Photographs of the area at that time by Dames show a treeless landscape without terraces. Nowadays part of the forest land is reafforested and the arable land is terraced.

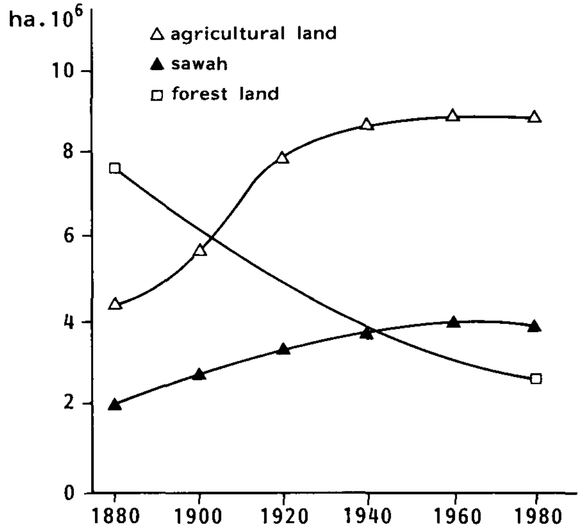

Fig. 1. Changes in land use in Java (compiled from van der Eng, 1988 and Smiet, 1990).

Table 1. Distribution of sedimentary soils and volcanic soils in 10^6 ha (and in %) in Java for various slope classes (calculated from data by Magrath & Arens, 1989).

	Slope (%) classes		
	0–8	8–30	>30
Alluvial	3.2 (25)	–	–
Acid sedimentary rocks	–	0.6 (4)	1.9 (15)
Marls/limestone	–	1.5 (12)	
Old volcanic soils	–	1.7 (13)	1.0 (8)
Young volcanic soils	–	0.3 (2)	1.7 (14)
Complex	–	–	0.8 (6)

It is likely that large-scale deforestation led to an increased surface erosion, as was presumed by analysing sediment loads of the Cilutung river, which increased from 0.9 mm ha^{-1} in 1912 to 1.9 mm ha^{-1} in 1937 and a further increase up to 5 mm ha^{-1} was recorded in 1975 (Ambar, 1986). However, besides surface erosion other factors than deforestation may have been involved such as landslides, road construction and increased stream bank erosion. Undoubtedly a positive correlation exist between deforestation and on-site soil loss in a watershed. But the relationship is probably unique as many factors such as soil type, topography, land management practices and farming system interfere. The latter factors affect the sediment delivery period needed to transport sediment from the upland to the river, which may take several decades (Trimble, 1981). Thus, it is not likely to find a general rela-

Table 2. Areas according to slope class in Java. The class >30% includes 200.000 ha volcanic cones; source: FAO Agroecological Date Base (cited in World Bank, 1988).

Slope class (%)	Area (10^3 ha)
0–8	4 604
8–30	4 817
>30	3 796
total	13 217

tionship for various watersheds as claimed by Ambar (1986).

It was previously suggested that 50 to 60 % of the deforested steep land with slopes over 8 % (Table 2) was seriously affected by erosion (recalculated from de Haan, 1952), but this estimate was not substantiated. The need for a comprehensive quantitative assessment of (surface) erosion for an overall erosion policy (Wiersum, 1980) was acknowledged by the Directorate General of Reforestation and Land Rehabilitation (RRL) in the Ministry of Forestry, which recently has accomplished a quantitative assessment, based on the Universal Soil Loss Equation (USLE), for the wole of Indonesia. Estimates based on this data set (Diemont unpublished) show that 5 % of all land with slopes over 8 % (Table 1) may be considered as 'critical' land. However, the estimate still lacks a definition on what is considered as 'critical' land. Thus there is still scope for improvement of definitions and methodology for the assessment of surface erosion on Java. At the request of RRL (Directorate General for Land Rehabilitation and Reforestation) critical watershed on Java have been studied by the School of Environmental Conservation Management in Bogor. USLE estimates for surface erosion in one of these watersheds, the Ciliwung watershed, yielded an annual surface erosion rate of 200 ton ha^{-1}, whereas the rate calculated by the Morgan model was 30 ton ha^{-1}. The latter estimate seemed more in agreement with measured river sediment loads (Mannaerts & Nurdin, 1988) and is therefore considered more realistic. Most of the difference between the results of the two models is caused by the fact that the Morgan model takes into account the infiltration rate of a soil, which may be extremely high in young volcanic soils. This is not new. Early studies on Java (Rutten, 1917; van Dijk & Ehrencron 1949) showed already that river sediment loads in volcanic areas were about 5 to 10 times lower than in sedimentary areas. While the impact of morpho-erosion cannot be distinguished from surface erosion in river sediment, morpho-erosion was excluded in studies using small experimental sub-watersheds (Gonggrijp, 1941) or using Wischmeier plots in experimental deforestated sub-watersheds (Bons, 1990, DHV, 1990; Rijsdijk et al., 1990). These studies show that even on steep slopes (>45 %) the surface erosion is very low in young, volcanic areas. Surface erosion on young, volcanic upland soils is probably low as a result of the high soil permeability i.e. a high water infiltration rate, which easily absorbs a shower intensity of 50 mm h^{-1}. But results are not univocal: soil loss on a volcanic soil near Bogor was rather substantial (Kurnia et al., 1984), which may be attributed to an older age of that soil.

The estimates on areas affected by surface erosion are still weak and, as a result of various methods applied and lack of definition, it is not possible to conclude that surface erosion has decreased in time. However, our rough estimate is that probably 75 % of all cultivated uplands (no statistics are available) in Java is terraced at present. Surface erosion on Java must also have decreased, because the rice cultivation on irrigated terraces has increased at the expense of rain-fed agricultural land (Figure 1).

Since the World War II additional confusion regarding rates of surface erosion has arisen by sedimentation problems in water reservoirs. Anticipated erosion rates in feasibility studies for various water reservoirs for supply of irrigation water and power generation have been incorrect. Feasibility studies for water reservoirs throughout Java (Wonogiri, Karangkates, Selorejo, Tokol) assumed a river sediment load equivalent to 0.25 mm ha^{-1} yr^{-1} denudation of the entire watershed (Bettes, 1987), although earlier studies (van Dijk & Ehrencron, 1949) showed that the denudation rate, even under natural forest, is equivalent to at least 0.5 and 4 mm ha^{-1} yr^{-1} for volcanic and sedimentary areas, respectively. Thus, sedimentation rates in these reservoir studies were grossly underestimated in feasibility studies. Therefore, the lower than anticipated life-times of reservoirs should not be attributed to an increase of surface erosion, but rather to unrealistic assumptions in the feasibility studies.

The conclusion from this section is that, although surface erosion has been serious in the past as a result of deforestation, it may presently be not as dramatic as generally assumed. In particular on terraced volcanic soils, surface erosion is low. The variability within volcanic soils with respect to surface erosion, which is probably related to age of the soil, should be studied in more detail.

Morpho-erosion

River sediment loads in Java as summarized by Ambar (1986) are sometimes very high, but it is generally far from clear where this sediment originates from. The Cilutung river in the Cimanuk watershed shows sediment loads equivalent to a soil loss of about 10 mm ha^{-1} yr^{-1}, in an area with predominantly sedimentary rocks and marls in West Java. River sediment loads in the Merawu river (Central Java) with sedimentary rocks were equivalent to about 35 mm ha^{-1} yr^{-1}, a world maximum till that date (Meijerink, 1977). Although surface erosion is high as compared to volcanic areas, morpho-erosion such as land slides may also be important. Frequent land slides were also observed in the sedimentary Cilanang catchment area (Meijerink, personal communication). However, also in volcanic areas rivers like the Cimuntur, a tributary of the Citanduy river in West Java, can have high sediment loads equivalent to 31 mm soil loss (Sub Balai RLKT Ciamis, personal communication).

In general surface erosion and morpho-erosion are both involved. Morpho-erosion not only includes landslides and incising rivers, but also roadside erosion and volcanic activity (lahars and ash rains) which affect sediment loads. A special source of morpho-erosion is found in valleys with irrigated rice areas, which may considerably contribute to sediment loads. It is called 'ngaguguntur' in Sundanese, which can be described as accelerated hillslope retreat (Trustrum, personal communication). Ngaguguntur is a term used by the population to denote all activities where running water in a manmade canal is used to remove and transport any surplus of soil. A temporary ditch, divided from a rivulet, may be dug to a new house plot in order to remove the surplus of soil derived from levelling the plot. This method is also used in road construction, in places where the natural slope has to be cut. No special care is taken to restore the former slope angle. As a result of such destabilization the slope collapses and the excess soil is tranported by water in the manmade canal. Farmers in Java also actively enlarge sawahs in valleys by excavating the toe of the valley in the rainy season (Figure 2). The surplus of soil is thrown in the irrigation canal which is always located in the most elevated part of the valley, e.g. near the valley side toe, in order to be able to irrigate the sawahs by gravity. In such cases all excavated soil is instantly delivered to the drainage system of the area, so the so-called sediment delivery ratio is 100%.

The impact of ngaguguntur has not yet been studied systematically, which seems somewhat surprising as ngaguguntur is integrated in Javanese farming practices. Since 23% or 1 million ha of the sawah area is located in upland areas with predominantly slopes of over 30%, the contribution of ngaguguntur to river sediment loads may be considerable. Some examples may give an idea of the possible impact of ngaguguntur on river sediment loads. In the Citanduy watershed the Cimuntur river has carved out a dendritic pattern of small valleys formed in deep volcanic soils. To widen the valley bottom for sawahs, all valley sides have been truncated up to the bazalt rock up to a depth of some 20 m. In many places the exposed rocks are

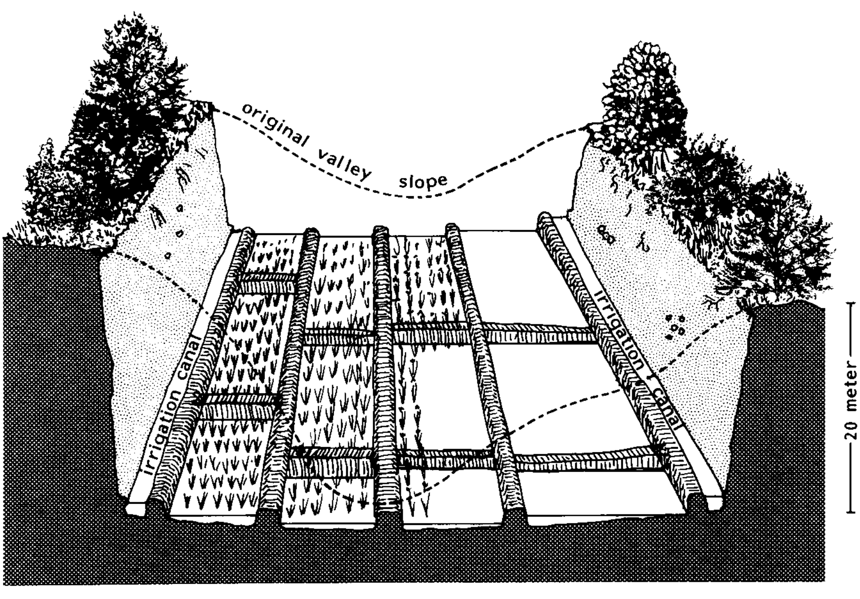

Fig. 2. Ngaguguntur or accelerated hillslope retreat.

even mined for road construction. Surface erosion in the upland of the Cimuntur is low (only 1.3 mm ha^{-1} yr^{-1} according to an experimental basin study in the Citanduy II project), but the river sediment load is equivalent to 31 mm ha^{-1} yr^{-1}! The same phenomenon can be seen in the Cimandiri watershed in an area with sedimentary rocks overlaid by some volcanic deposits near Gunung Walet (Sukabumi). In these areas the width of the valley was expanded at least a few times over.

Unpaved road networks, but also not well maintained paved roads, should also be considered as a serious source of sediment. Data from the US (Amimoto, 1978, as quoted in FAO, 1989) suggest that a road density of 20 m ha^{-1} may produce some 500 m^3 yr^{-1} of sediment. The paved road density in Java is about 20 m ha^{-1} (calculated from Anonymous, 1987, p. 423). The unpaved road density is probably at least similar. Thus, sediment production from roads cannot be a priori omitted. Preliminary results reported from the Kali Konto watershed in East Java consider sediment from road erosion as the major source of sediment (Rijsdijk et al., 1990).

The impact of volcanic eruptions on river sediment loads on Java is occasionally impressive. Historical accounts (Scidmore, 1899) report that the eruption of the Salak volcano in 1699 caused the silting up of the old harbour of Batavia (Jakarta) through sediment delivered by the Ciliwung river. A new harbor was therefore constructed in Tandjung Priok. The eruption of the well known Krakatau volcano in between Java and Sumatra was one of the most impressive ones recorded. About 18 km^3 of material was blown away. In the period after 1900 records show 6 eruptions with an export of material of more than 0.1 km^3 (Table 3). A total volume of 500 million m^3 in 90 years or an annual mean of about 5 million m^3 has had a profound local impact. The eruption of the Galungung produced about 6.9 million t volcanic debris and ash in 1982. This event doubled the sediment load in the Cimanuk river (EXSA International, 1989).

The conclusion of this section is that even in cultivated, volcanic areas with a low surface erosion the river sediment load can be high as a result of other sediment sources. In landscapes where ngaguguntur is widely practised, sediment loads may become extremely high. Also volcanic eruptions may occasionally increase sedi-

Table 3. Estimated volume of deposited material from volcanic eruptions on Java since 1900, modified after Kusumadinata (1979).

Location	Year	Volume (10^6 m^3)
Krakatau	1963	0.3
	1973	12.0
Bromo	1972	1.4
Kelud	1901	2.0
	1951	200.0
	1966	90.0
	1990	50.0
Merapi	1973	4.5
Galungung	1982	150.0
Total		510.2

ment loads. Substantial methodological refinement is necessary to adequately facilitate conclusions about erosion, let alone its components.

Upland productivity and surface erosion

A most pressing problem in the humid tropics is the assessment of agricultural production losses. All over the world many denuded landscapes are proof that erosion should be taken as a serious problem. However, the scientific evidence for production losses on Java by surface erosion is poor (Magrath & Arens, 1989). The suggestion to correlate production losses with organic matter losses or nitrogen instead of soil loss may be helpful (Young, 1989).

For Java many old as well as recent studies, cited in the introduction, attribute the low productivity of upland crops to surface erosion. It was even suggested that erosion caused farmers to change to crops such as cassave which are better adapted to lower – erosion induced – soil fertility levels (Magrath & Arens, 1989). The yields in upland agriculture in Java are indeed low, but have been increasing in the last decade (Figure 3; van der Eng, 1988; Pearce et al., 1990). This increase shows that surface erosion at least does not hamper agricultural productivity to a degree that any increase of inputs (fertilizers, improved crop varieties, pesticides) is frustrated. However, it is possible that without surface erosion the growth rates observed might have been higher. Proof has yet to be produced though. Assumptions as made by Magrath & Arens (1989) of a linear annual decrease of 2 to 5% for all of Java cannot be accepted without verification.

The major cause of low production levels in upland food crops is probably the low input level. In particular on sedimentary soils and marls, productivity and financial return are low. This probably reflects more the low natural fertility status and soil depletion by repeated cultivation with low inputs, than a high surface erosion. An overall increase of inputs in upland agriculture is needed to improve productivity, which may also lead to a reduction of erosion by improved ground cover. Soil conservation should not be a separate activity, but should be incorporated in efforts to generally improve the productivity of upland agriculture (Hudson, 1987).

The conclusion from this section is that the low productivity of upland farming systems is in the first place caused by low inputs and not surface erosion. The major problem in rain fed upland agriculture is to improve productivity of small farmers, which should be given the appropriate governmental incentives (Pearce et al., 1990).

Research and watershed policy implications

Many discussion items presented above can only be resolved by research. Research priorities should change from assessing surface erosion in cultivated uplands to analysing other sources of sediment, notably (accelerated) morpho-erosion. With regard to the productivity of upland agriculture the major problem is to introduce improved farming systems, to increase fertilizer inputs and to improve the efficiency of fertilizer uptake by upland crops. Such research findings may have far reach-

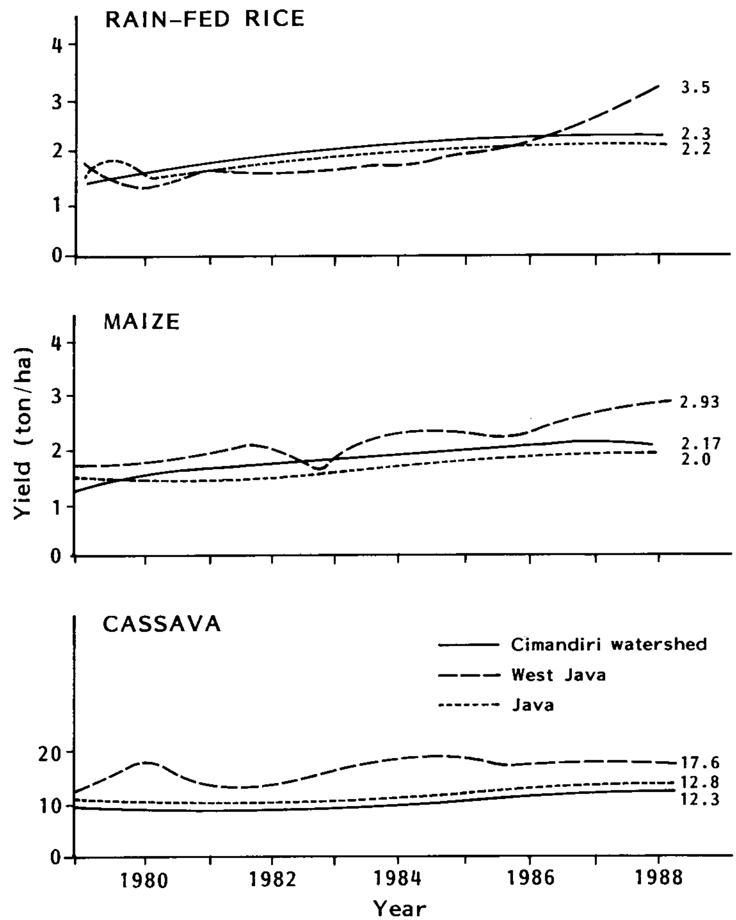

Fig. 3. Changes in productivity of several upland crops in Java, West Java and in the Cimandiri watershed (West Java).

ing consequences for watershed policy. The main issue in watershed management policy on Java at present is (and has been) reforestation and soil conservation in upland agriculture. If, as has been discussed in previous chapters, surface erosion nowadays contributes relatively little to river sediment loads (as a result of soil conservation policies) and has little effect on agricultural yields, watershed policy must be redirected. Priorities should be changed i.e. other sources of sediment must be taken into account and control measures should be designed accordingly. Where natural morpho-erosion contributes significantly to sediment loads, only repeated construction of check dams can control the sedimentation. Where this is not practical or in case it is cheaper to remove sediment from irrigation canals, sedimentation problems should be accepted as a reality in lowland regional development planning.

Conclusions

High river sediment loads in Java cannot only be attributed to surface erosion from upland rain fed agriculture. Ngaguguntur can locally cause high river sediment loads. Roadsides, built-up areas and occasional volcanic eruptions may also contribute significantly to sediment loads, particularly since sediment from these sources directly enters the river system. This may have an important bearing on present efforts of the Indonesian governement to counteract erosion. More efforts should be directed towards the control of erosion from other sources, for example within the domain of civil engineering, i.e. planning and maintenance of roads, roadsides, and other built-up areas. Since sediment loads in many rivers on Java are also determined by uncontrollable events such as volcanic eruptions and morpho-erosion in geologically unstable landscapes, engineering designs for lowland structures must simply take high river sediment loads into account.

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References

Ambar, S., 1986. Conversion of forest land to annual crops: an Indonesian perspective. In: Land use, watersheds, and planning in the Asia-Pacific region. FAO/RAPA Report 1986/3: 95-11.

Anonymous, 1987. Statistical Yearbook of Indonesia 1987. Biro Pusat Statistik, 666 pp.

Bettes, G., 1987. Two-front attack on dam sediment. *World Water* : 42-45.

Bons, C.A., 1990. Accelerated erosion due to clearcutting of plantation forest and subsequent Taungya cultivation in upland West Java, Indonesia. In: R. R. Ziemer, C. L. O'Loughlin & L. S. Hamilton (Eds.). Research needs and applications to reduce erosion and sedimentation in tropical steeplands. *IAHS Publication* 192: 279-288.

Booth, A., 1988. Agricultural development in Indonesia. Asian Studies Association of Australia, Sydney, Southeast Asia Publications 16-9, 120 pp.

Carson, B., 1989. Soil conservation strategies for upland areas of Indonesia. Occasional papers East-West Center 9, 120 pp.

Dames, T. W. G., 1955. The soils of East Central Java. Contribution of the General Agricultural Research Station, Bogor, 155 pp.

DHV, 1990. Konto river project phases 3 & phase 3 extension January 1986-March 1990. Final report Vol. 1: Experiences with watershed management. Republic of Indonesia, Ministry of Forestry, Directorate General of Reforestation and Land Rehabilitation (RRL) and Kingdom of The Netherlands. Jakarta, 141 pp.

Donner, W., 1987. Land use and environment in Indonesia. Hurst, London, 368 pp.

Dijk, J. W. van & V. K. R. Ehrencron, 1949. The different rate of erosion within two adjacent basins in Java. *Mededelingen Algemeen Proefstation Landbouw Buitenzorg* 84:1-10.

Eng, P. van der, 1988. Growth and productivity change in Indonesian agriculture 1880-1985. Faculty of Economics, University of Groningen, Netherlands, 130 pp.

EXSA International, 1989. The study for upland soil and water conservation of the catchment area of the proposed Jatigede reservoir. Draft interim report. Ministry of Forestry Republic of Indonesia D.G. of Reforestation and Land Rehabilitation, Jakarta.

FAO, 1989. Watershed management field manual. FAO Conservation Guide 13/5. Rome, 196 pp.

Gonggrijp, L., 1941. The erosion-research. (In Dutch, with English summary). *Tectona* XXXIV: 200-220.

Haan, J.H. de, 1952. Silt transportation of rivers in Java. Proceedings of the Regional Technical Conference. Flood Control Asia & Far East. *Flood Control Series* 3: 179-184.

Holle, K. F., 1866. A big danger is approaching stealthy. (In Dutch). *Tijdschrift voor Nijverheid en Landbouw in Ned. Indië* 12: 122-134.

Hudson, N., 1987. Changing soil conservation strategies. Proceedings of the International Conference on Steepland Agriculture in the Humid Tropics. Kuala Lumpur, Malaysia, p. 39-72.

Kurnia, U., A. Abdurachman & S. Sukmana, 1986. Comparison of two methods in assessing the soil erodibility factor of selected soils in Indonesia. *Pemberitaan Penelitian Tanah dan Pupuk* 5: 33-37.

Kusumadinata, K., 1979. Catalogue of references on Indonesian volcanoes with eruptions in historical time. Volcanologic Survey of Indonesia. p. 178-189.

Magrath, W. & P. Arens, 1989. The costs of soil erosion on Java: a natural resource accounting approach. Environmental Depart. Work. Paper 18. The World Bank Policy Planning and Research Staff, 68 pp.

Mannaerts, Ch. M. & Nurdin, 1988. Introduction of GIS/ILWIS elements in RTL-RLKT design planning. Workshop on Geo Information System – Integrated Land Watershed Management Information System GIS/ILWIS. Palembang, 6 pp.

Meijerink, A. M. J., 1977. Hydrological reconnaissance survey of the Serayu river basin. *ITC Journal* 4: 646-673.

Meijerink, A. M. J., 1988. Modelling in the land and water domain with a versatile GIS/ILWIS: experiences from a large tropical catchment. In: J. Bouma & A. K. Bregt (Eds.). Land qualities in space and time. Proceedings of a symposium organized by ISSS, Pudoc, Wageningen. p. 73-87.

Palte, J. G. L., 1989. Upland farming on Java, Indonesia. Ph. D. Thesis, University of Utrecht, Netherlands, 251 pp.

Pearce, D., E. Barbier & A. Markandya, 1990. Sustainable development; economics and environment in the world. Edward Elgar Publishing Limited, England, 217 pp.

Repetto, R., 1986. Soil loss and population pressure on Java. *Ambio* 15 (1): 14-18.

Rijsdijk, A., L. A. Bruijnzeel, C. N. Bremner, E. G. Katee & C. Kukuh S., 1990. Sediment sources and their evaluation in the Upper Konto watershed, East Java, Indonesia. In: R. R. Ziemer, C. L. O'Loughling & L. S. Hamilton (Eds.). Research needs and applications to reduce erosion and sedimentation in tropical steeplands. *IAHS Publication* 192: 391-392.

Rutten, F., 1917. On denudation rates on Java. (In Dutch). *Akademieverslagen Amsterdam* XXVI: 921-930.

Scidmore, E. R., 1899. Java the garden of the East. Reissued by Oxford University Press 1984, Oxford, 339 pp.

Smiet, A. C., 1990. Forest ecology on Java: conversion and usage in a historical perspective. *Journal of Tropical Forest Science* 2-4: 286-302.

Sollewijn Gelpke, J. H. F., 1901. In response to Staatsblad 1878 no. 110. (In Dutch). Batavia, Landsdrukkerij, 177 pp.

Trimble, S. W., 1981. Changes in sediment storage in the Coon Creek basin, Wisconsin. *Science* 214: 181-183.

Wiersum, K. F., 1980. Erosion, rural development and forest on Java. (In Dutch). *Landbouwkundig Tijdschrift* 92: 338-345.

World Bank, 1988. Indonesia. Forest, land and water: issues in sustainable development. Country Department V. Asia Regional Office, 136 pp.

Young, A., 1989. Agroforestry for soil conservation. Commonwealth Agricultural Bureaux International Wallingford, England, 276 pp.