

FOURTH INTERNATIONAL CONFERENCE ON GEOMORPHOLOGY - Italy 1997
Session: Tropical Geomorphology

MARK RUSE (*) & MERVYN PEART (**)

PRELIMINARY OBSERVATIONS ON THE SPATIAL VARIABILITY OF FALLOUT CAESIUM-137 AT REFERENCE SITES IN HONG KONG

ABSTRACT: RUSE M. & PEART M.R., *Preliminary observations on the spatial variability of fallout Caesium-137 at reference sites in Hong Kong*. (IT ISSN 0391-9838, 1999).

Caesium-137 (^{137}Cs) tracing of sediment movement depends substantially on a valid assessment of ^{137}Cs reference values. Recent research suggests that ^{137}Cs is more spatially varied than previously assumed. The range of ^{137}Cs values at and between reference sites, and environmental controls on ^{137}Cs behaviour are prime topics for study. The present research investigates reference sites in the monsoonal tropics of Hong Kong. There was doubt about the use of ^{137}Cs in such areas, sustained by the paucity of ^{137}Cs studies in the Tropics and the potential lack of ^{137}Cs here due to global air circulation patterns. This paper shows that the technique is applicable in the Hong Kong environment.

As rainfall controls ^{137}Cs fallout, a large range of mean annual rainfall within a small area makes Hong Kong a good location to test ^{137}Cs variability. Three input sites representing a wide range of rainfall totals are reported here. The uneroded status of an input site is tested by producing a profile of ^{137}Cs totals in 2 cm increments; the form of the profile reflecting ^{137}Cs movement in the soil. The results illustrate the difficulties of using a simple model of profile distribution as confirmation of a site's stability. They also confirm the difficulty of finding sites that have experienced no significant disturbance in the past four decades.

Ten core samples and the profile point value were used to assess ^{137}Cs variability across the input sites. These data permit an evaluation of sampling methodology. The present results suggest that a large sample number is required to express the mean input value at a site. If this is not to impede routine use of the ^{137}Cs technique, further investigations of sampling methodology are needed.

KEY WORDS: Fallout ^{137}Cs reference values, Site selection and sampling, Monsoonal tropics, Hong Kong.

CONTEXT

An empirical understanding of hillslope sediment movement is important to geomorphology, particularly in

studies of sediment production and budgets, and soil conservation (cf. Walling, 1990; Morgan, 1985). The standard approach to its study includes monitoring erosion and deposition processes on hillslopes (Lehre, 1981) or on controlled erosion-plots (Moldenhauer & Foster, 1981). An alternative is to use caesium-137 (^{137}Cs) as a tracer of sediment movement. As this technique is reviewed elsewhere (eg Walling & Quine, 1995), only a brief introduction will be given here.

Caesium-137

^{137}Cs is an artificial radionuclide derived solely from the nuclear energy industries. It has been deposited globally as fallout with precipitation following atmospheric testing of thermonuclear bombs since 1952 and, in some areas, accidental releases of nuclear material (e.g. the Chernobyl accident of 1986).

The logic behind the use of ^{137}Cs as a tracer is straightforward. ^{137}Cs fallout is assumed to have been uniformly distributed across the landscape, with qualifications for controls on precipitation. As fallout was deposited over an extended period, its initial distribution will reflect large-scale spatial patterns of rainfall (de Jong & alii, 1982). Upon reaching the soil, ^{137}Cs becomes almost irreversibly adsorbed to soil colloids (Lomenick & Tamura, 1965) and remains in place as the colloid is transported. Thus soil- ^{137}Cs values reflect sediment movement totals that are aggregated for around 40 years. In practical terms, the technique compares favourably with other sediment monitoring techniques. It can also be used to measure deposition rates in lakes (Pennington & alii, 1976) and floodplains (Walling & He, 1994), and, where reference values are known, to fingerprint sediment sources (Peart & Walling, 1986).

Reference values and their variability

The use of ^{137}Cs as a tracer depends substantially on use of an input value against which the altered inventories of

(*) Department of Geography and Geology, Hui Oi Chow Building, University of Hong Kong, Pokfulam Road, Hong Kong.

The authors would like to thank the Nanjing Institute of Geography and Limnology, Academia Sinica, Nanjing, PRC, for their work in obtaining the gamma spectrometry results presented here. Funding from the C.R.C.G is gratefully acknowledged.

field samples are measured. However, actual fallout totals from precipitation monitoring are rarely available in proximity to a site. Furthermore, uncertainties about the use of precipitation totals as a surrogate are usually too large; for example, studies have variously related ^{137}Cs input to mean annual rainfall (Basher & Matthews, 1993), to storm-controlled rainfall (Kiss & *alii*, 1988), and to orographic rainfall (Cox & Fankhauser, 1984).

In resolution, input values are usually obtained from soil ^{137}Cs totals at a reference site that can reasonably be considered stable (Campbell & *alii*, 1988). The acceptability of the site is judged by measuring the profile of ^{137}Cs values with depth. A suitable profile will show most of the ^{137}Cs concentrated in the surface layers. Early reports provided a standard concept of ^{137}Cs quantities decreasing exponentially with depth at the rate of approximately 60% per cm of depth (Campbell & *alii*, 1988). Detailed characteristics of the profile will be controlled by the soil's ability to adsorb ^{137}Cs (Livens & Loveland, 1988) and to resist subsequent colloidal movement. As ^{137}Cs redistribution continues through time, more complex profiles are developing on sites that still fulfill the criteria of stability. Thus profiles are increasingly being reported as having a certain proportion (eg 75 or 80%) within a certain depth of the surface (eg 10 cm), with an exponential decrease below the given depth (eg Walling & Quine, 1995, Owens & Walling, 1996).

As the input or reference site value is the basis for all calculations of sediment movement, its reliability is crucial for successful tracer studies. Recent work suggests that the spatial distribution of ^{137}Cs at reference sites is more vari-

able than previously assumed (Wallbrink & *alii*, 1994; Sutherland, 1996). There is a need for research into the range of ^{137}Cs values at input sites, and in particular, the number of samples needed to assess the variability of ^{137}Cs totals correctly (Sutherland, 1996).

STUDY AREA CHARACTERISTICS AND ^{137}Cs IN THE TROPICS

Though Walling and Quine (1995) called for an improved indication of regional ^{137}Cs inventories, there remain few tropical studies (eg Quine & *alii*, 1992; Garcia-Oliva & *alii*, 1995; Forsyth, 1996: from health physics, Pham Zuy Hien & *alii*, 1994; Cox & Fankhauser, 1984). This lack of data, coupled with tropical aircirculation patterns, cast some doubt on the potential for ^{137}Cs tracing in such areas. Indeed, Lowe (1978) recorded very low soil ^{137}Cs levels in West Malaysia.

Located in the monsoonal tropics of the Northern Hemisphere, Hong Kong is a good location to study the spatial variability of ^{137}Cs . The influence of a seasonal tropical weathering environment, clay mineralogy of relatively low ^{137}Cs adsorbancy and a low soil organic content may be critical to ^{137}Cs behaviour in the soil. The topography of Hong Kong is of interest to the discussion of controls on ^{137}Cs input. There is a large range of mean annual rainfall totals (1400 to >3000 mm) within a small area (*ca.* 1000 km²) (see figure 1) because of its steep relief, and variability of ^{137}Cs between sites is presumed to be high.

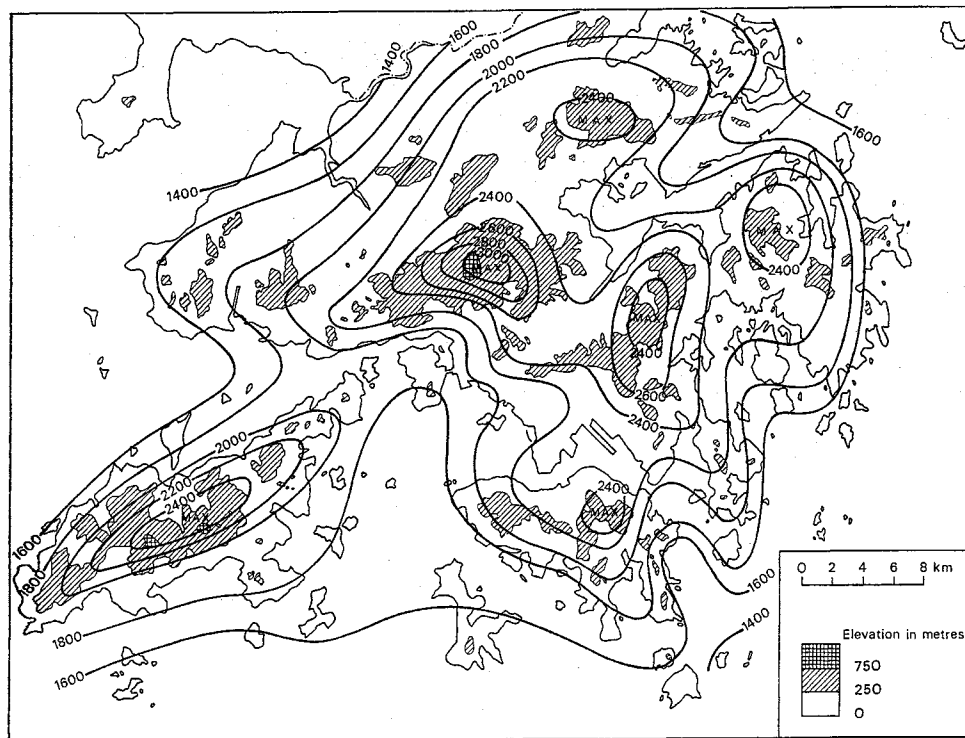


FIG. 1 - Map of Hong Kong showing mean annual rainfall totals (mm) for the period 1953-1982 (from Lee & Kwan, 1984).

Hong Kong also has a distinct ^{137}Cs fallout history. For example, Tso & alii (1987) suggest that the Hong Kong Observatory's fallout record is dominated by input from the Chinese bomb tests of 1963-1980, resulting in a later peak input period than many Northern hemisphere locations (cf. Cambrey & alii, 1982 in the UK). Furthermore, the influence of Hong Kong's monsoonal climate on fallout totals is little known, though it may be significant; the trace quantities of Chernobyl fallout in 1986 were apparently delayed by southerly winds and borne by northern monsoon winds (Tso & alii, 1987).

SITE SELECTION

A programme to select a number of input reference sites must take into account the nature of the local environment. In the present programme, sites reflecting different rainfall totals were selected following the guidelines of Campbell & alii (1988). Thus they were relatively flat, had no run-on and showed general indications of stability. Additional criteria used here included selection of sites with a regolith of at least 30 cm depth (though the Shek O site is an exception), with few trees or shrubs (to avoid ^{137}Cs concentration by canopy interception, Bunzl & Kracke, 1988) and relatively low stone content. These sites have been checked against air photographs to extend the control of sites back to the 1950's.

However, Hong Kong has a complex land-use history. Clearance of subtropical forest at ca. 3000 years BP influenced much of the territory's soils (Grant, 1960). Another clearance around the time of the Japanese Occupation of 1941-1945 instigated severe erosion in certain areas. Intensive rural activities such as paddy farming, phytomass harvesting and burning have recently been replaced by uncontrolled development of scrap yards and ship container stores. Coupled with the topography of steep relief and the practical difficulty of sampling in thick vegetation, identification of suitable sampling locations has been difficult. For example, while the hill at Tai Che Leng Tung in the Sai Kung Country Park appears suitable for sampling, the surface is marked by exposed boulders, old temporary structures, army foxholes, a large footpath and the impact of cow herding.

To best control site stability, sites with a known history were sought. A number of 1940's military structures might have provided physical confirmation of stability. However, field investigation of over 10 sites recorded only inaccessibility or active disturbance. Other sites chosen for this ongoing research programme include weather stations, golf courses and hilltops in the Country Parks. While some selected sites have, of necessity, smaller area than the ideal site, reliance is placed on the profile data to test site stability.

CONFIRMATION OF SITE STABILITY

To investigate site stability, soil was sampled from selected sites by taking 2 cm increments to a depth of 30 cm,

using a 20x30 cm scraper frame (after Campbell & alii, 1988). Samples were oven dried, hand crushed, and sieved to obtain the 2 mm fraction. This fraction was assessed for ^{137}Cs content using an HPGe gamma spectrometer, counting for at least 40 000 sec. All data were obtained at the Nanjing Institute of Limnology and Geography, Academia Sinica bar the Shek O profile. The latter data were obtained using equipment of the Hong Kong University's Radioisotope Unit: 2 samples repeated at Nanjing supported the depth distribution presented.

As mentioned above, the calibrated totals of ^{137}Cs with depth are used to assess input site stability. Three examples from Hong Kong are given here. The site locations (fig. 2) can be compared with figure 1 as an approximation of likely ^{137}Cs input patterns.

The first two profiles (figs. 3 and 4) were sampled from a spur behind the granodiorite hill of Kwun Yam Shan and a low hilltop near the village of Pak Tam, Sai Kung Country Park. Both profiles exhibit significant down-profile declines in ^{137}Cs totals, indicating that the sites have been stable. 80% of the ^{137}Cs loading is found in the uppermost 6 cm for Kwun Yam Shan and 8 cm for Pak Tam, with peak values in the surface increment. The disparity between the two total ^{137}Cs loadings, the former of 1565.30 Bq m^{-2} , the latter of 866.08 Bq m^{-2} , gives preliminary confirmation of the importance of rainfall for ^{137}Cs input totals in Hong Kong. Measurement precision ranges from ± 1.04 to $\pm 0.25 \text{ Bq kg}^{-1}$. ^{137}Cs concentrations in the two profiles show that the ^{137}Cs -tracer technique is applicable in Hong Kong.

The third profile (figure 5) was sampled at the Upper Golf Course of the Shek O Country Club, Shek O, in an area that was reported by Club staff as not having been altered since its initial construction in 1925. An area of rough grass was selected as being flat, topographically elevated and free from the flooding that affects the Lower Course. The ^{137}Cs data illustrate the value of taking a profile to test the stability of reference sites. ^{137}Cs is absent from all but the 10-12 cm increment, immediately above the weathered rock surface. The total ^{137}Cs loading (158.81 Bq m^{-2}) is lower than the other two sites, as might be expected from the mean annual rainfall totals (figure 1) and indeed the site may have a full ^{137}Cs loading. For example, the non-standard input profile may reflect the addition of soil to the course surface after ^{137}Cs fallout ended (in the early 1980's), despite reports by the course staff that topdressing had not been practiced at the Course. The ongoing research programme aims to establish the relationship between soil ^{137}Cs values and rainfall totals at a larger number of sites to investigate such difficulties.

SPATIAL DISTRIBUTION OF ^{137}CS

Having confirmed site stability, ^{137}Cs variability across a reference site should be assessed to produce an accurate ^{137}Cs input value (Sutherland, 1991). In the present programme, the ^{137}Cs content of ten core samples of 30 cm

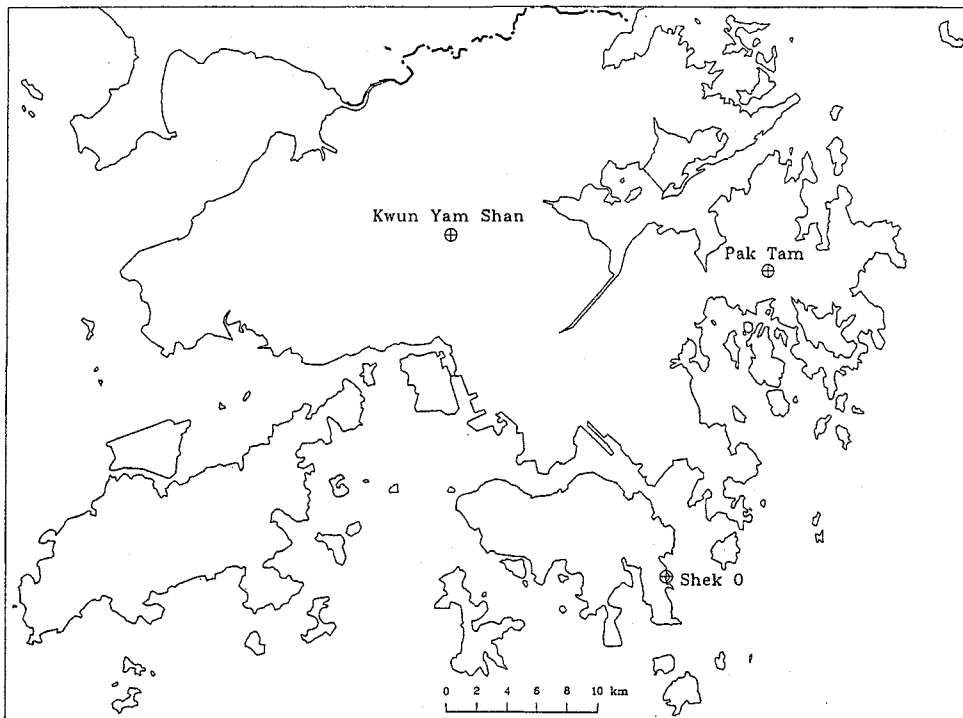


FIG. 2 - Map of Hong Kong showing locations mentioned in text.

depth are assessed at each input site, sampled at approximately 1 m intervals around the profile location. The point values for Kwun Yam Shan range from 2.39 ± 0.47 to $9.43 \pm 1.12 \text{ Bq kg}^{-1}$, with a mean value of $1646.76 \text{ Bq m}^{-2}$ and a coefficient of variation of 39.86%. The Pak Tam site val-

ues range from 2.71 ± 0.36 to $5.58 \pm 0.54 \text{ Bq kg}^{-1}$, with a mean value of 898.33 Bq m^{-2} and a coefficient of variation of 19.51%.

Practical difficulties associated with sampling the indurated soil at Pak Tam with a sledgehammer and metal core

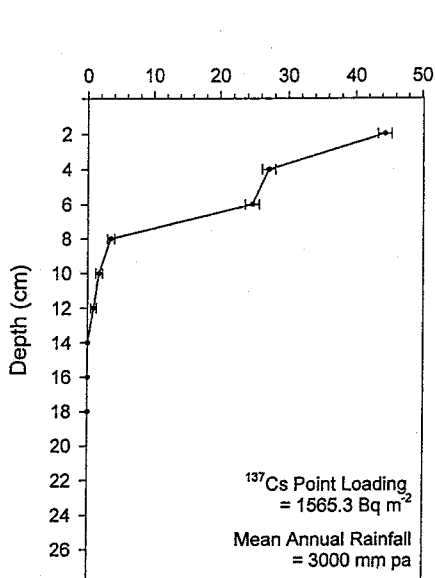


FIG. 3 - ¹³⁷Cs Depth Distribution. For Kwun Yam Shan Reference Site.

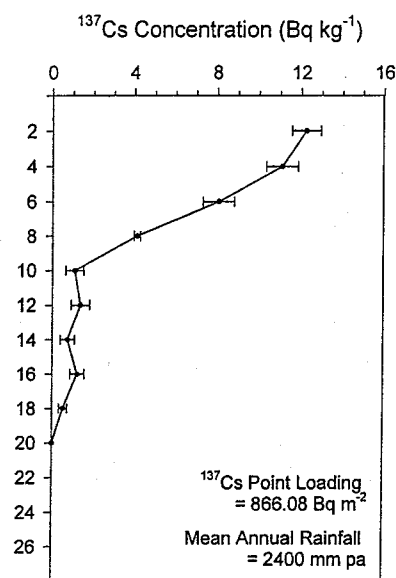


FIG. 4 - ¹³⁷Cs Depth Distribution. For Pak Tam Reference Site.

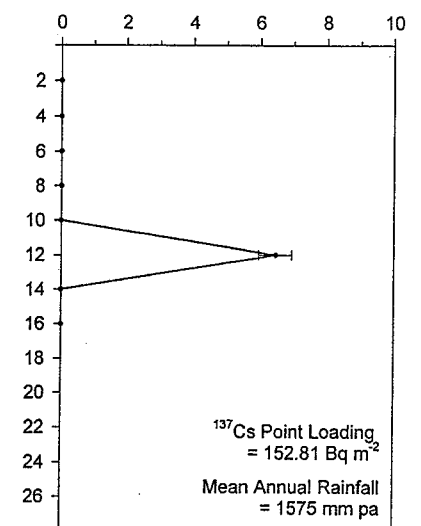


FIG. 5 - ¹³⁷Cs Depth Distribution. For Shek Wu Hui Reference Site.

resulted in shallower core samples than usually sampled in this project. While 7 samples extended to 19 cm and therefore reached the maximum depth to which ^{137}Cs was recorded in the profile, 3 reached only 14 cm. Some underestimation of the ^{137}Cs point values at these points may be expected. Over 95% of the ^{137}Cs content of the profile is recorded in the uppermost 14 cm of soil, however, and thus it is suggested that underestimation is negligible. This example confirms the value of taking a ^{137}Cs profile as an indication of core-depth suitability. The Shek O cores were not measured.

Coefficients of variation of these sites (11 samples including the profile point value) are not particularly high when compared to other locations (see reviews by Sutherland (1996) and Owens & Walling (1996)). Owens & Walling (1996) postulated that higher values of variability in Zimbabwe (48.9 and 67.2%) reflected the low ^{137}Cs values of the Tropics and more-variable soil properties. Work is being undertaken to evaluate the role of soil properties in controlling ^{137}Cs distribution in Hong Kong. However, the sample number required to express the mean ^{137}Cs total of the site, calculated after Fredericks & alii (1988), remains exceptionally high. While only 12 samples are needed at Pak Tam, the higher coefficient of variation at Kwun Yam Shan would require 80 samples to express the mean. At even 12 samples to express the mean value, the required machine time is considerable. Sample bulking must be considered if the technique is to be cost effective, although bulking results in the loss of important information on ^{137}Cs variability at a site.

CONCLUSIONS

This paper introduces methodological aspects of a study assessing spatial variability of fallout- ^{137}Cs at reference sites in Hong Kong. Results to date confirm that there has been sufficient ^{137}Cs input in this monsoonal tropical environment for tracing sediment movement. The ^{137}Cs values of different sites followed the pattern expected for environments of a steep rainfall gradient. The importance of careful site selection and the need for both a profile and point measurements to test site suitability and sampling methodology has been illustrated, particularly with the high spatial variability of ^{137}Cs at reference sites. If such caution is needed for each tracer study, it follows that time and cost requirements are increased. This has repercussions for the potential of the ^{137}Cs technique, particularly for large scale or reconnaissance projects. Given the demand for greater understanding of sediment movement in areas such as tropical soil conservation, further research is needed on the nature and controls of ^{137}Cs variability and suitable methodologies for its study.

REFERENCES

- BUNZL K. & KRACKE W. (1988) - *Cumulative deposition of ^{137}Cs , ^{238}Pu , $^{239-240}\text{Pu}$ and ^{241}Am* . Am. Journ. Environ. Radioact., 8 (1), 1-14.
- BASHER L.R. & MATTHEWS K.M. (1993) - *Relationships between ^{137}Cs in some undisturbed New Zealand soils and rainfall*. Aust. Journ. Soil Res., 31, 655-63.
- CAMBRA Y R.S., PLAYFORD K. & LEWIS G.N.J. (1982) - *Radioactive fallout in air and rain: results to end of 1981*. UK Atomic Energy Authority Report AERE-R 10845.
- CAMPBELL B.L., LOUGHRAN R.J. & ELLIOTT G.L. (1988) - *A method for determining sediment budgets using caesium-137*. In: *Sediment Budgets* (Proc. Porto Alegre Symp., December 1988). IAHS Publ. No. 174, Wallingford, UK, pp. 171-179.
- COX M.E. & FANKHAUSER B.L. (1984) - *Distribution of fallout cesium-137 in Hawaii*. Health Physics, 46 (1), 65-71.
- DE JONG E., VILLAR H. & BETTANY J.R. (1982) - *Preliminary investigations on the use of ^{137}Cs to estimate erosion in Saskatchewan*. Canadian Journ. Soil Sc., 62, 673-83.
- FORSYTH T.J. (1996) - *The use of caesium-137 measurements of soil erosion and farmers perceptions to indicate land degradation amongst shifting cultivators in Northern Thailand*. Mt. Res. Develop.
- FREDERICKS D.J., NORRIS V. & PERRENS S.J. (1988) - *Estimating erosion using caesium-137: I. Measuring caesium-137 activity in a soil*. In: *Sediment Budgets*. Proc. of the Porto Alegre Symposium, December 1988. IAHS Publ. No. 174, 225-231.
- GARCIA-OLIVA F., MARTINEZ LUGO R. & MAASS J.M. (1995) - *Long-term net soil erosion as determined by ^{137}Cs redistribution in an undisturbed and perturbed tropical deciduous forest ecosystem*. Geoderma, 68, 135-147.
- GRANT C.J. (1960) - *Soils and agriculture in Hong Kong*. H.K. Govt. Printer, Hong Kong.
- KISS J.J., DE JONG E. & MARTZ L.W. (1988) - *The distribution of fallout caesium-137 in southern Saskatchewan*. Journ. Environment. Quality, 17, 445-52.
- LEE B.Y. & KWAN W.K. (1984) - *30 - year mean rainfall in Hong Kong 1953-1982*. R. Observatory Technical Note, 70.
- LEHRE A.K. (1981) - *Sediment budget of a small California Coast Range drainage basin near San Francisco*. In: *Erosion and sediment transport in Pacific Rim Steeplands*. Proc. Christchurch Symposium. IAHS Pub. No. 132, Wallingford, UK, pp. 124-139.
- LIVENS F.R. & LOVELAND P.J. (1988) - *The influence of soil properties on the environmental mobility of caesium in Cumbria*. Soil use a. management, 4 (3), 69-75.
- LOMENICK T.F. & TAMURA T. (1965) - *Naturally occurring fixation of ^{137}Cs on sediments of lacustrine origin*. Proc. Soil Sc. Soc. Am., 29 (4), 383-385.
- LOWE B.G. (1978) - *Levels of ^{137}Cs in soils and vegetation of West Malaysia*. Health Physics 34, 439.
- MORGAN R.P.C. (1985) - *Soil erosion measurement and soil conservation research in cultivated areas of the UK*. The Geogr. Journ., 151, 11-20.
- MOLDENHAUER W.C. & FOSTER G.R. (1981) - *Empirical studies of soil conservation techniques and design procedures*. In: Morgan R.P.C. (ed.), *Soil conservation: problems and prospects*. Wiley, Chichester. 13-29.
- OWENS P.N. & WALLING D.E. (1996) - *Spatial variability of Caesium-137 inventories at reference sites: an example from two contrasting sites in England and Zimbabwe*. Appl. Radiat. Isot., 47 (7), 699-707.
- PEART M.R. & WALLING D.E. (1986) - *Fingerprinting sediment sources: the example of a drainage basin in Devon, UK*. In: *Drainage basin sediment delivery*. Proc. Albuquerque Symp., August 1986. IAHS Publ. No. 159, 41-55, Wallingford, UK.
- PENNINGTON W., CAMBRA Y R.S., EAKINS J.D. & HARKNESS D.D. (1976) - *Radionuclide dating of the recent sediments of Belham Tarn*. Freshwater Biology, 6, 317-331.

- PHAM ZUY HIEN, NGUYEN THANH BINH, TRUONG Y, VUONG THU BAC & NGUYEN TRONG (1994) - *Variations of Caesium Isotope concentrations in air and fallout at Dalat, South Vietnam, 1986-91*. Journ. Environ. Radioactivity, 22, 55-62.
- QUINE T.A., WALLING D.E., ZHANG X. & WANG Y. (1992) - *Investigation of soil erosion on terraced fields near Yanting, Sichuan Province, China, using caesium-137*. In: *Erosion, Debris Flows and Environment in Mountain Regions*. Proc. Chengdu Symp., July 1992. IAHS Publ. No. 209, Wallingford, UK, 155-168.
- SUTHERLAND R.A. (1991) - *Examination of caesium-137 areal activities in control (uneroded) locations*. Soil technology, 4, 33-50.
- SUTHERLAND R.A. (1996) - *Caesium-137 soil sampling and inventory variability in reference locations: a literature survey*. Hydrological Processes 10, 43-53.
- TSO M.Y.W., CHAN M.W. & POON C.B. (1987) - *External irradiation dose arising from Cs-137 fallout in Hong Kong*. In: *Proc. Workshop Occupational and Environ. Radiat. Protection, December 1987*. University of Hong Kong, 12-18.
- WALLBRINK P.J., OLLEY J.M. & MURRAY A.S. (1994) - *Measuring soil movement using ¹³⁷Cs: implications of reference site variability*. In: *Variability in Stream Erosion and Sediment Transport*. Proc. Canberra Symposium. IAHS Publ. No. 224, Wallingford, UK, 95-102.
- WALLING D.E. (1990) - *Linking the field to the river: sediment delivery from agricultural land*. In: Boardman J., Foster I.D.L. & Dearing J.A. (eds.), *Soil erosion on agricultural land*. BGRG Symposia series, John Wiley, Chichester, UK.
- WALLING D. & HE Q. (1994) - *Rates of overbank sedimentation on the flood plains of several British rivers during the past 100 years*. In: *Variability in Stream Erosion and Sediment Transport*. Proc. Canberra Symposium. IAHS Publ. No. 224, Wallingford, UK, 203-210.
- WALLING D.E. & QUINE T.A. (1995) - *The use of fallout radionuclides in soil erosion investigations*. In: *Nuclear and related techniques in soil/plant studies and sustainable agriculture and environmental preservation*, International Atomic Energy Agency, Vienna.