Large-scale Residential Developments as a Factor in Environmental Change in Japan

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雑誌名	The science reports of the Tohoku University. 7th series, Geography
巻	43
号	1
ページ	1-12
発行年	1993-06
URL	http://hdl.handle.net/10097/45200

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Abstract In order to contribute to comprehensive recognition of environmental impact of large-scale construction works for residential development in Japan, this paper has analyzed both the changing magnitude and rate of artificial landform transformation made in the developments in recent Japan and their natural, socio-economic and technologic backgrounds. Both total area developed and total volume of earth moved artificially, which have been selected as relevant attributes for the environmental geomorphological analysis, show marked historical changes. Although the changes had been generally interpreted in terms of changing socio-economic situation and technologic development, this paper has in addition investigated the actual situation of development in earthwork machinery in detail and interpreted its effect on the selection of geomorphic location for development and on the intensification of the rate and magnitude of landform transformation. The new trend of use of geomorphic resources, which had been supported by the technologic development in the period of high economic growth, was maintained in the following period of economic depression. However, new issues from the viewpoint of environmental conservation has been presented and some alternative or improved measures of the use of geomorphic resources for residential development are required. Further accumulation of basic data on certain environmental attributes as demonstrated in this paper is necessary for the consideration of new measures also.

Key words: Anthropogenic geomorphology, Environmental geomorphology, Geomorphic resources, Construction works, Residential development, Physical urbanization.

1 Introduction

Large-scale construction works for various development purposes have provided considerable direct transformation of land and have also induced indirect changes in diverse aspects of environment. It is necessary for comprehensive recognition of environmental impact of such works to make an analysis of the magnitude and frequency of the works on the basis of reliable environmental attributes. In order to demonstrate an example of environmental-geomorphological assessment of large-scale construction works, this paper investigates both the changing magnitude and rate of artificial landform transformation made in the large-scale residential developments

THE SCIENCE REPORTS OF THE TOHOKU UNIVERSITY, 7TH SERIES (GEOGRAPHY)
Vol. 43 No. 1, June 1993. 1-12.

in recent Japan and their technologic background in its relation to both natural condition and socioenconomic situation.

2 Changes in topographic location of built-up areas and their environmental implication

The general trend for the Japanese cities to be located in the lowlands and neighboring low terraces[1] on the mountainous islands, as illustrated in Fig. 1, has attracted the attention of Western geographers such as Trewartha (1934), who visited Japan in 1926. The trend was further demonstrated by Saito (1965) in the survey of topographic location of the all Densely Inhabited Districts (DID)[2], which are considered to be almost equivalent to the built-up areas, in 1960. The results show that about 90% of total area of DID is located in the lowlands and terraces. Considering small patches of terraces included in the neighboring hills and mountains in the survey, the figure may increase up to 95%.

Around the same year, 1960, however, a new trend of topographic location for the Japanese urban areas seems to have emerged in several metropolitan zones. In the rapid urbanization which proceeded particularly in the period of high economic growth, urban residential areas began to expand to the hills which had been rarely appropriated for urban use (Tamura 1976). In popular-type residential developments in the hills and low mountains in Japan, an assemblage of various forms of natural hillslopes are remodelled into several levels of flats through intense cut and fill operation (Fig. 2). Natural landsurfaces with natural or seminatural forest and soil

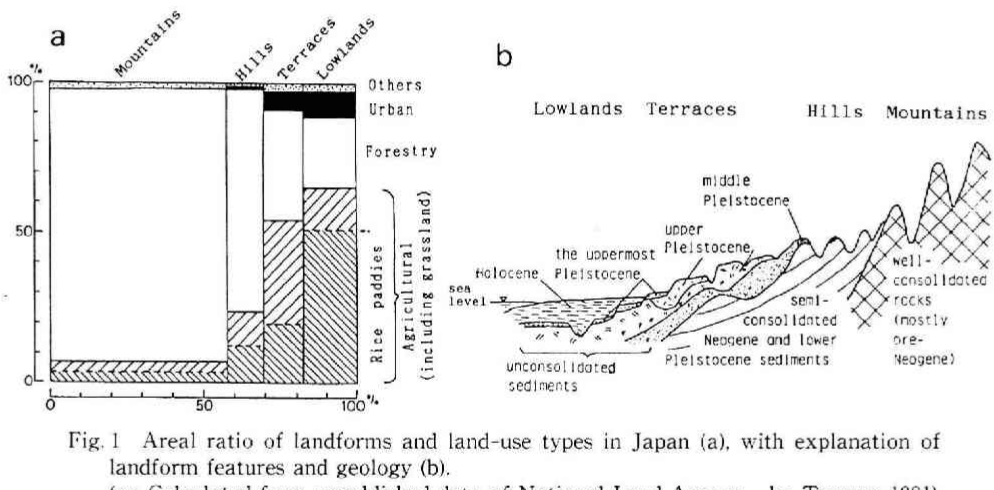

Fig. 1 Areal ratio of landforms and land-use types in Japan (a), with explanation of landform features and geology (b).
(a: Calculated from unpublished data of National Land Agency. b: Tamura 1981)

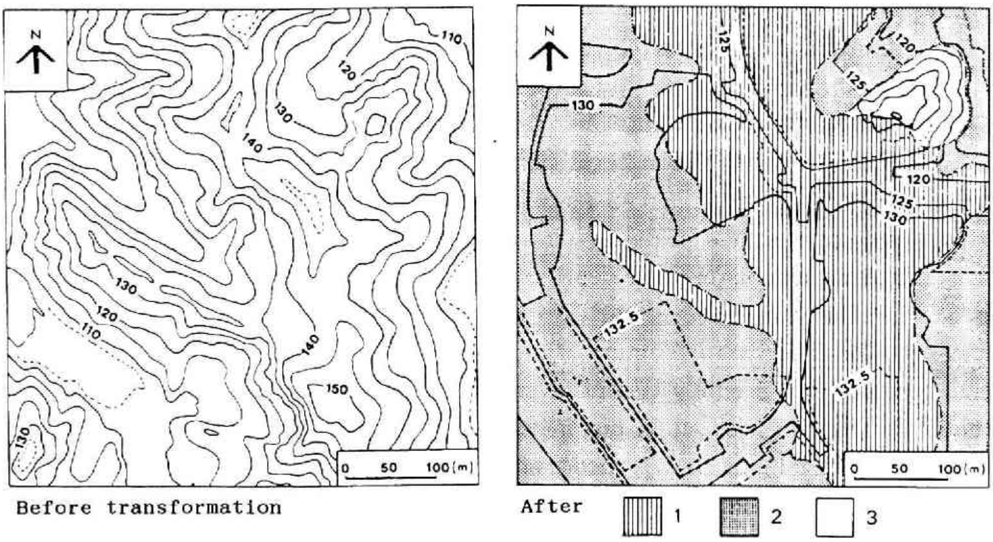

Fig. 2 Typical landform transformation for large-scale residential development in the hills of Japan. (Tamura *et al*. 1983)
1 : Artificial cut zone, 2 : Artificial fill zone, 3 : Not-transformed zone.
(A part of the Tama Hills, west of Tokyo)

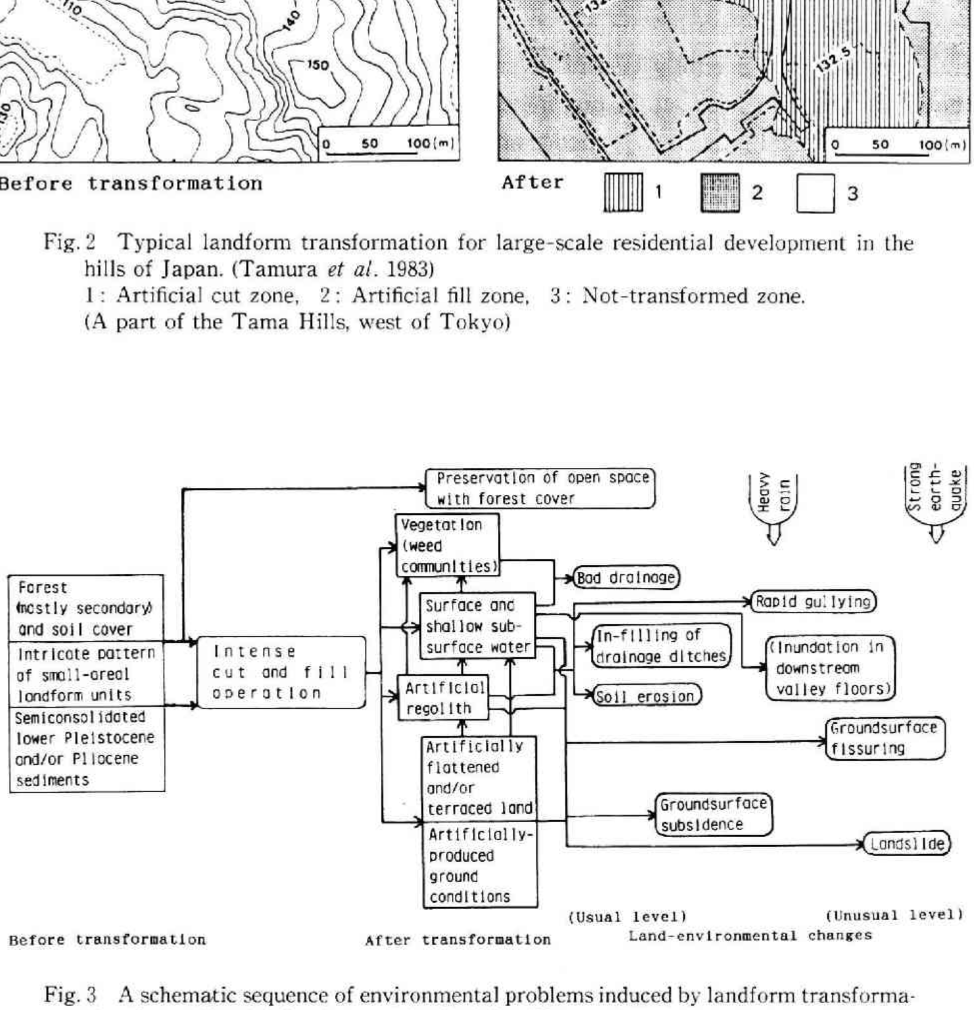

Fig. 3 A schematic sequence of environmental problems induced by landform transformation for residential development in the hills. (Tamura 1983)

cover rarely remain in the above-type developments. The intense landform transformation has thus inevitably induced compound environmental changes which are various in scale and magnitude and sometimes involve hazards as illustrated in Fig. 3 (Tamura 1983).

3 Preparation and processes of basic data

Because most available data on the residential developments in extensive areas have been prepared for the socioeconomic and administrative purposes, a kind of reinterpretation from the viewpoints of physical aspects is necessary for the investigation of the magnitude and rate of artificial land transformation in the developments. The keys for the reinterpretation are given in the pilot study in which detailed data on earthwork are compared with general data on location and area of each development site.

Investigation of topographic change by the use of scheme drawings on a scale of 1 : 500 to 1 : 1,000, as well as more direct information on earthwork if available, presents volume of earth removed or added artificially in each development site. The double of the above volume per area of the development site provides an average depth of artificial cut-off or thickness of artificial fill-in within the same development site. The doubling should not be made for estimation of the average depth in development sites located in the lowlands because they receive fill-in or piled-up operation without significant cut-off. It is only in extreme cases that residential developments are made by cut-off operation only[3)].

Such detailed investigation as above in several tens of large-scale residential development sites in the Tokyo metropolitan zone (Takeuchi and Yoshioka 1982) gives the following figures as the normal average depth of cut-off or fill-in in development sites located in respective medium-scale geomorphic units[1)] : 1 m in the lowlands, 3 m in the terraces, 8 m in the ordinary hills, 10 m in the high hills and low mountains. The figures make possible estimation of total volume of artificially moved earth on the basis of the area of development sites classified according to the medium-scale geomorphic units where the sites are located.

The basic data of the area, the topographic location which was classified to the four medium-scale geomorphic units, the age, and some other attributes of the large-scale residential development sites were provided in the nationwide survey made by the Working Group for Anthropogenic Geomorphology (Kadomura 1981). The first-order analysis of the data (Tamura *et al.* 1983 ; Tamura 1983) revealed the changing trend of the total area and topographic location of the large-scale residential developments made in the 20 years since 1960 in Japan. Although the above type data for the subsequent period have not been prepared, not so significant change in the situation has been suggested by the trend of the nation-wide total area of housing-site development shown in an official statistics which includes the smaller development sites without any information of their topographic location.

Utilizing the results as above, the present paper aims at advancing volumetric investigation of artificial landform transformation for residential development.

4 Changes in magnitude of earthwork for large-scale residential developments

The diagram A of Fig. 4, which was first presented by Tamura *et al.* (1983), shows the remarkable increase of the share of the hills in lands used for residential developments in accordance with the increase of the total area developed for residential sites in Japan, which is shown by thin bars (B1) in the diagram B of Fig. 4. The share reached 40% in the late 1960s whereas the hills occupy only 15% of the total national land area of Japan. The trend of concentration of residential development sites in the hills did not decline after the decrease of the total development area since the mid-1970s.

The net increase of the area developed in the hills means much more increase of volume of earth moved artificially. Using the normal average depth as mentioned in the preceding chapter, volume of artificially moved earth is calculated on the basis of the total area and topographic distribution of development sites, as shown by thick bars (B2) in the diagram B of Fig. 4. The rate of increase in volume significantly exceeds that in area.

Therefore, as a line (C1) in the diagram C of Fig. 4 shows, the average cut-depth or fill-thickness of all large-scale residential development sites in Japan in the early 1970s becomes 1.4 times of those in the early 1960s, and the reduction of the total area for development in half, which took place in the late 1970s, does not accompany the significant decrease in the average cut-depth or fill-thickness.

The regional difference in the average cut-depth or fill-thickness is well demonstrated in the contrast between the Tokyo and the Osaka metropolitan zone as represented in the diagram B of Fig. 4. The Osaka metropolitan zone records the smaller area for devolopment but the larger volume of artificially moved earth than the Tokyo metropolitan zone. It is of course due to the more frequent use of the hills and low mountains for residential development in the Osaka zone where the shares of the terraces and lowlands are smaller than those in the Tokyo zone. The further higher concentration rate of residential development in the hills is recorded in the Sendai metropolitan zone (Tamura *et al.* 1983).

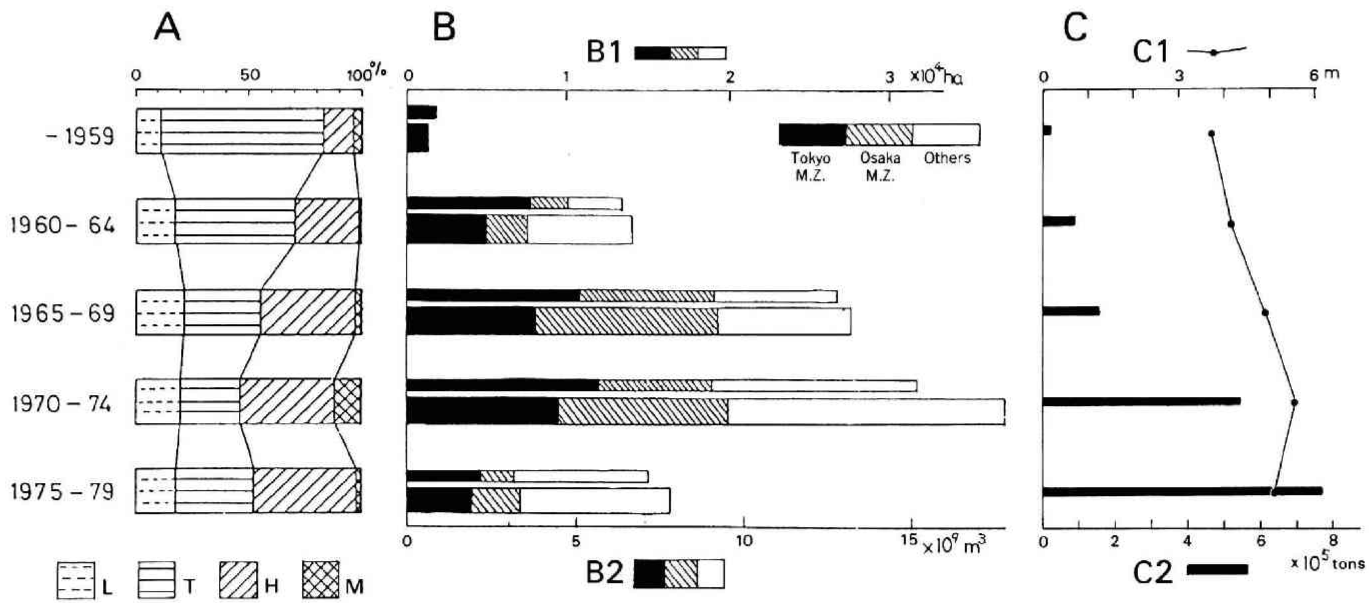

Fig. 4 Changes in the use of landforms and magnitude of landform transformation for large-scale residential development and their technologic background (Tamura *et al*. 1983 and Tamura 1991)

A: Areal proportion of landforms used for large-scale residential development sites (bigger than 50 ha in a site) in Japan.

B: Magnitude of landform transformation in large-scale residential development. (estimated from **A**)

B1: Total area developed.

B2: Total volume of earth moved artificially. The Tokyo and the Osaka metropolitan zone are defined as the zones within 50 km radius from Tokyo and Osaka Railway Station, respectively.

C: Technologic background for large-scale earthwork.

C1: Average cut depth or fill thickness in large-scale residential developments. (calculated from **B1** and **B2**).

C2: Total weight of shovel-type excavators at work (average of five years). (estimated from JCMA and MITI statistics)

5 Overview of the development in heavy machinery for earthwork

The extension of urban residential areas to the hills since the 1960s has been greatly supported by a technologic development. The development in heavy machinery for earthwork has made cut and fill operation more easy particularly in the hills which are mostly composed of Neogene Tertiary or lower Pleistocene semiconsolidated sediments or deep-weathered granitic rocks and have low but rather complicated relief features (Tamura 1976, 1981). Although the geologic and topographic features had hindered the urban use of the hills when earthwork had depended on manpower, the features have been converted into rather favorable condition for flattening which is almost necessary for residential development in ordinary fashion in Japan, in the situation of spreading of heavy machinery.

The modern heavy machinery for earthwork typified by a bulldozer and a power shovel was first introduced from the United States to Japan after the World War II and used in those days principally for public works such as the construction and repairing of dams, rivers, ports, roads and railways, and as large-scale reclamation from lagoons and shoals. Application of the machinery for residential development works in which private enterprises take considerable part became significant since around 1960.

Production of the shovel-type excavators, which are one of the necessary machines for transformation of landforms composed particularly of un- or semiconsolidated sediments and deep-weathered rocks, increased from 124 in 1952 to 10^3 in 1960, 10^4 in 1970 and, intervened by temporal decrease in 1973/74/75 and 1980/81/82, 8.2×10^4 in 1987. Since 1968, about 45 to 90% of newly produced ones have been exported and the import of the same type machine has been negligible (JCMA 1959, 1969, 1979, 1989). Therefore, the total number of shovel-type excavators at work in each year can be estimated from both the statistics of production and export of the machines and on the reasonable assumption of the average life span of each same-type machine as 4 to 5 years. The number reached 10^3 in the late 1950s and increased with a pace of becoming ten times in several years to 10^5 in the mid- or late 1970s. Ministry of Construction and Ministry of International Trade and Industry estimate that about 2.8×10^5 shovel-type excavators were at work in 1989 in Japan.

Not only the total number but also the size of the earthwork machinery has markedly increased. The most popular size of shovel-type excavators was of the class below 0.5 m^3 in 1952. Production of the 1.2 m^3 class machines became significant in late 1960 and bigger machines of 4.4 m^3 appeared in 1975. On the other hand production of smaller machines of 0.2 to 0.3 m^3 class has also become popular since around 1973. Recent trend in the production of shovel-type machines is the diversification of size.

In consideration of the trend in number and size as above, average total weight of shovel-type excavators at work in each year, which is interpreted to indicate the changing power of heavy machinery for landform transformation in Japan, has been estimated. It exceeded 2 or 3×10^4 tons in the end of the 1950s, 2 or 3×10^5 tons in the end of the 1960, and 10^6 tons in the end of the 1970s, respectively. The bars (C2) in the diagram C of Fig. 4 presents the figures in the average of every five years.

The diagram shows the remarkable increase in the early 1970s. The rate of annual increase of the shovel-type excavator production indicated by total weight records its maximum in 1969/70 as 224%. It is obvious that the rapidly increased heavy machinery as above made possible the expansion of total development area and volume of artificially-moved earth shown in the diagram B and the increase of average cut-depth or fill-thickness shown by a line (C1) in the diagram C. Although the decrease of the total area developed, the total volume of earth moved artificially, and the average cut-depth or fill-thickness in the late 1970s does not correspond with the absolute decrease of the total weight of heavy machinery at work in the same period, the lowering of increase rate of the total weight of machinery in the period is remarkable. The rate of annual increase of shovel-type excavator production indicated by total weight records its minimum in 1973/74 as 79%.

6 Evaluation of the natural, socioeconomic, and technologic factors in the landform transformation for the large-scale residential developments

The intensification of landform transformation for large-scale residential development (B1 of Fig. 4) is of course the result of, and on the other hand resulted in, the rapid concentration of population to the metropolitan zones, which is apparently a consequence of the high economic growth of Japan since around 1960. The increasing demand for residential areas in metropolitan zones was particularly concentrated to the hills surrounding the previously urbanized areas which had been mostly located in the lowlands and terraces (A of Fig. 4). In addition, rapid reduction of demand for charcoal and fuelwood due to the increasing supply of kerosene and gas in the late 1950s has promoted the urbanization in the hills in the subsequent period, because the secondary forests from which most charcoal and fuelwood had been supplied are mostly located in the hills and low mountains surrounding traditional settlements (A of Fig. 1).

The particular concentration of residential development to the hills provided the marked increase of volume of artificially moved earth (B2 of Fig. 4). It should not be overlooked that the hills of Japan have been certain topographic and geologic features (B of Fig. 1) which had formerly hindered the urban use but have provided rather suitable resources for urban use under the condition of developed and spreading heavy earthwork machinery (Tamura 1983).

The retardation of large-scale residential development in the late 1970s is a direct effect of so-called oil crisis. However, the trend of concentration of residential development to the hills, which had become prevalent in accordance with the rapid increase of total development area since the beginning of the high economic growth and had contributed to the increase of volume of earth moved artificially, did not change to decline in the period of retarding economic growth when total development area decreased markedly. The fact suggests that the new trend is not only a simple consequence of the high economic growth but also affected by the change in utilization and evaluation of land environment or geomorphic resources particularly of the hills (Tamura *et al.* 1983).

This paper has revealed that the change has become possible and has been promoted by the increase in the power of earthwork machinery as indicated by the total weight of shovel-type excavators at work (C2 of Fig. 4). Continuous increase of power of earthwork machinery is almost parallel to the changing trend of the share of the hills in the land used for large-scale residential development, which does not correspond to the changing pattern of total area developed particularly in its declining phase.

7 Concluding remarks

Construction works for large-scale residential development in recent Japan has been analyzed under the intention of assessing its environmental implication as a whole. Total area developed and total volume of earth moved artificially, as well as the areal ratio of medium-scale geomorphic units used for residential development, have been selected as relevant attributes for the environmental geomorphological analysis. These attributes are correlated each other. Changing socioeconomic and technologic situations which had affected the residential development have been also reviewed. Particularly, technologic development has been overviewed using the estimated total weight of shovel-type excavators at work as an effective indicator.

The increasing rate of total volume of earth moved artificially exceeded that of area developed, which also increased rapidly, and was almost parallel to that of total weight of the machines during the 1960s. In the early 1970s the increasing rate of total weight of the machines exceeds that of volume of artificially moved earth. Total weight of machines did not decrease in the mid- and late 1970s when both total development area and total moved earth volume, particularly the former, decreased to less than half of those in the preceding period. The ratio of residential development in the hills, which had increased in accordance with the increase of the total area developed, also did not decrease in the mid- and late 1970s.

The trend revealed as above is in general interpreted as follows: the growing socioeconomic activity demands technologic development which enables the use of unused natural resources and that the new trend of use of resources supported by the newly developed technique does not simply decline in the following depressing phase of socioeconomic activity.

The new trend of residential development concentrated in the hills, which has become prevalent since the high economic growth in the 1960s and did not decline in the economic depression in the mid- and late 1970s, has provided the enormous volume of artificially moved earth. It has induced various direct and indirect changes in earth-surface environment. In addition to the concern for disasters which are sometimes provoked in the intensely transformed zone of the newly developed residential sites (Tamura 1980), the issues on conservation of zones with natural or seminatural vegetation cover in and around the residential development sites have attracted the public attention (Matsui *et al.* 1990, Tamura 1993b). It is requested to provide a new approach to the environmental planning for residential development (Matsui *et al.* 1990).

For the progress toward the new approach, preparation of basic data on certain environmental attributes, as demonstrated in this paper, is necessary. The attributes and the basic data for them are, however, unfavorably served by the currently established statistics systems as indicated in Chapter 3. Further application of combined remote sensing and GIS techniques is expected to direct and effective collection and process of the basic data.

Acknowledgment

This paper is modified from that read at the International Symposium on Environmental Change and GIS, Asahikawa, Japan, August, 1991. The basic data on landform transformation were prepared by the Working Group for Anthropogenic Geomorphology in the Association of Japanese Geographers (Kadomura 1981) and first analyzed by Tamura *et al.* (1983) and Tamura (1983). Supplement of data particularly on the development in heavy earthwork machinery and the analysis of volume of earth and power of machinery were mainly made in the research titled "Man's role in environmental change" supported financially by the Grant-in-Aid for Scientific Research on Priority Areas, Ministry of Education, Science and Culture, in 1990, 1991 and 1992 (No. 02243102, 03227102 and 04209102), headed by T. Tamura. A part of the results was reported in Tamura (1991, 1992, 1993a). Thanks are due to Prof. Osamu Nishikawa, Rissho Univ., an organizer of the Scientific Research on Priority Areas "Geographic Information System for environmental change in modern Japan", for conducting the research project and to Mr. Yasuyuki Uchida, Director of Research Division, Japan Construction Mechanization Association, for providing information on the development of heavy earthwork machinery.

Notes

1) The Japanese Islands are composed of the following four medium-scale geomorphic units: mountains, hills, terraces, and lowlands; where the lowlands imply alluvial and coastal plains developed in Holocene time, the terraces are the somewhat raised plains formed mostly in late Pleistocene time, and the hills are hilly but relatively low-lying lands (generally having local relief less than about 300 m) composed chiefly of Neogene Tertiary or lower Pleistocene sediments or elevated (typically more than several tens of meters higher than adjacent late Pleistocene terraces) and dissected terraces of mostly mid-Pleistocene age. The terminology, explained more in detail in Tamura (1976, 1981), is used for the description and analysis of geomorphic setting in this paper (refer Fig. 1 also).
2) Densely Inhabited Districts, abbreviated as DID, have been delineated for presenting pure urban areas in the Population Census of Japan since 1960 and are defined as an area within a smallest administrative division, that is composed of a group of contiguous enumeration districts in each population census, each of which has a population density of about 4,000 inhabitants or more per square kilometer, and whose total population is 5,000 or more.
3) An extreme case of very large-scale residential development which has been made through cut-off only has been in progress in the hills behind the previously urbanized area of Kobe. Enormous volume of earth material produced there is transported and used for extensive land-fill for new wharf construction along the northern rim of Osaka Bay (Tanaka *et al.* 1983; Okimura *et al.* 1992).

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