FACTORS AFFECTING HUMAN CASUALTIES DUE TO HEAVY RAIN AND STRONG WIND

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Abstract

Human casualties are greatly affected by various kinds of factors which have influences on behavior, mentality and preparedness of people against hazards. The factors are regionally of natural and social characteristics, hazard experiences, time of impact, period, kind of secondary natural event and so on. Effects of these factors on casualties due to typhoon, flood, storm surge, strong wind, landslide and debris flow are estimated using past hazard data.

Clear correlations between the number of damaged houses and casualties are recognized for all kinds of natural hazards. The regression coefficients clearly show the effects of the factors on casualties quantitatively. The number of deaths due to typhoon is represented by a power function of the central atmospheric pressure and the radius of typhoon circle at landing time. The exponent obtained for the typhoons that landed during midnight in Central Japan is 1.4 times as large as that during daytime and early evening. Relationships between the number of deaths and the amount of rainfall, flood discharge, basin gradient and household density are obtained for Nishinippon Flood in 1953. Equations which relate the death rate of flood and storm surge to the depth of innundation are derived.

1. Introduction

In establishing regional disaster prevention programs, it is of fundamental importance to predict the scale of damages caused by primary natural forces such as heavy rain, strong wind and earthquake of a given intensity. The relation between the scale of damages and the intensity of these primary external forces, however, is not necessarily obvious since various factors including secondary natural events affect the process in which the external forces cause damages. Specifically, unlike damages done to structures that are fixed on land, those done to people who act according to will and judgement are subject to human and social factors. Accordingly, the external forces of a given intensity may cause widely varying scale of human casualties depending on these factors. For example, the scale of human casualties may be substantially reduced by such means as enhanced preparedness against hazards, prompt evacuation in emergency, and actions to prevent damages from spreading out. These activities, along with awareness and judgement that prompt them, in turn depend on various external or general factors such as social characteristics of the region, geographical conditions, hazard experience, time of impact, period, type of hazard, the degree of informationalization and so on. In order to reduce the scale of human casualties, it is necessary to analyze these factors since they determine whether casualties increase or decrease. The purpose of this paper is to demonstrate, with a particular emphasis on explaining quantitatively the role of these factors, the relation between the intensity of the external force and the scale of human casualties caused by such hazards as typhoon, storm surge, flood and landslide, using statistical data on the damages due to these hazards of the past. In the case of so-called "wind-water hazards" that are caused by heavy rain and strong wind as the primary external forces, the relation between the external forces and damages is not simple because the direct damaging impact is put forth by the secondary events such as flood, landslide and debris flow, which take place locally in relation to the entire area where the external forces operate. Moreover, unlike earthquakes, wind-water hazards are not a totally unpredictable event and thus the scale of human casualties are likely to be much affected by human factors such as judgement or actions taken immediately before the event.

In order to understand factors determining the scale of human casualties, this paper adopts the method of evaluating quantitatively the relevant factors on the basis of the relation between the external force and the scale of human casualties obtained from a rather macroscopic viewpoint using data on the damages due to various hazards of the past, while it could also be an effective method to accumulate samples of detailed individual case study on hazards of the past. We are to select those hazards with large-scale human casualties in order to obtain statistically meaningful results. However, we are led to include hazards of the long past as well since the frequency of large-scale hazards is low. This creates a serious problem of how to take into account the effects of changes in social factors over time on the quality and the scale of damages when we are to link the results with prediction of the future. Furthermore, it would not be sensible to generalize without qualifications the results obtained from the sample whose size is in no way sufficiently large. Nevertheless, in order to prepare for natural hazards which strike infrequently and are hard to predict, it will be at least necessary to get an idea about what scale of damages would possibly arise from the multitude of adverse conditions or by how much damages could be lessened when things go well, namely the extreme values of damages and the range of values over which the coefficients of the equation relating the external force and damages may take on the basis of hazard samples of the past.

It would be clear-cut if we could use physical quantities such as intensity of rainfall, speed of wind and magnitude (on the Richter scale) of earthquake as an indicator of the intensity of the primary event. However, when the secondary event, that is local in relation to the primary event, generates the direct damaging impact, there seldom exists a meaningful relation between these primary physical quantities and the scale of human casualties. For this reason we use instead the number or ratio of damaged houses when appropriate physical quantities are not available. The Meteorological Agency provides us with the seismic scale as a measure of the intensity of earthquake vibration at a given location. The seismic scale is based on the ratio of collapsed houses: for example, intensity of degree 6 indicates that less than 30 per cent of houses will collapse and that of degree 7 indicates more than 30 per cent of collapsed houses. Such a scale is justified on the ground that the damaging impact of earthquake vibration is subject to diminution or amplification depending on the distance from the focus of earthquake and the kind of ground, ant that with such diminution of amplification it operates upon structures above the ground, uniformly at a given location and globally in the operating area. Strong wind is another example of the damaging impact that operates uniformly at a given location and globally in the operating area. The process in which heavy rain causes damages is quite different from these two cases. However, if only human casualties are taken into consideration, the intensity of the external force operating on the inhabited area of a certain geographical region may be reflected to a considerable extent in the number of damaged houses that are fixed on land; no large-scale damages will be done when the external force operates on the uninhabited area. As will be shown later, the correlation between housing damages and human casualties is generally recognized in the cases of wind-water hazards and earthquake hazards. Even if in some cases the number or ratio of damaged houses is not an appropriate indicator of the intensity of the external force, it will be a useful measure to estimate the interaction of various factors; we may put it on either coordinate axis when various data are to be related.

The local governments that include a big city in their jurisdiction are conducting estimation of damages caused by natural hazards, mainly earthquake hazards among others. In the case of earthquake the physical process that starts with the emergence of the force, then reaches the ground surface and ends up with housing damages is fairly simple in comparison with that of heavy rain. For this reason, various equations are available relating the magnitude (on the Richter scale) of earthquake with the scale of housing damages. Accordingly, if we obtain the relation between housing damages and human casualties, we will be able to establish the link between the intensity of earthquake and the scale of human casualties. In a separate paper the author will report on the scale of human casualties due to earthquake and tsunami (tidal waves).

2. Damages due to Wind-Water Hazards in General

First, we compare wind-water hazards with various types of accidents. Figure 1 shows the trend in the number of deaths due to hazards and accidents that happened in Japan during the 15-year period 1965-1979. There are clear year-to-year fluctuations of a large amplitude in the death rate of wind-water hazards. The fluctuations are even greater than those of mountaineering accidents which tend to happen more infrequently and whose chances and scales largely depend on natural conditions. Since, in contrast, the death rates of fire and other accidents maintain more or less constant values while showing clear long-run trends, namely declining trends with the exception of fire, it is possible to predict the number of deaths from a macro viewpoint. Wind-water hazards too show an overall declining trend of a fairly large scale during this period. The number of deaths due to wind-water hazards is in the order of a few in one million, which is almost at the same level as that of mountaineering accidents. This is of course subject to the possibility that the number would jump to the level of traffic accidents if large-scale hazards such as those which accompanied Isewan Typhoon take place.

Figure 2 shows the relation between the frequency of various types of natural hazards and the number of deaths caused by them. A clear difference is found between earthquake and wind-water hazards in terms of the average annual frequency and the relative frequency of large-scale casualties, namely the difference in the intercepts and the degrees of steepness of the negatively-sloped curves. If, however, data from the years of 1945-1965 are included, the relative frequency of large-scale casualties due to wind-water hazards would be slightly higher since large-scale casualties were commonplace in those years.

The quantity and intensity of rainfall are the principal measures indicating the intensity of the external force. However, rainfall itself, which is the primary event, does not directly cause damages; the water permeates through the ground surface, travels down the ground, converges to a certain spot under the ground, and generates the secondary event such as flood, landslide and debris flow in a very small neighborhood in relation to the entire area of rainfall or even in a neighborhood outside the rainfall area at times; these secondary events bring about damages of varying scale depending on the type of the secondary events. Therefore, the relation is not generally clear between the intensity of rainfall and the scale of human casualties when damages are caused by rainfall. However, if we look at a quantity of the macro level, namely annual total amount of rainfall received in Japan as a whole, the relation between the amount of rainfall and the scale of human casualties becomes considerably clear; presumably differences in individual and regional characteristics of various hazards would be averaged out (see Mizutani 1968).

Figure 3 shows the relation between the annual total number of deaths due to typhoon and heavy rain in the entire country and the total amount of rainfall during the 20 years of 1960-1970 (computed from the data on annual rainfall reported by the 127 meteorological observatories all over Japan excluding those located in islands and mountains). A clear correlation is recognized with the exception of a couple of data points. The last large-scale hazards were those which accompanied Isewan Typhoon that caused over 500 deaths in 1959. Since then the number of deaths has fallen to a lower level with the year of 1960 as a turning point. Figure 3 deals with the years after 1960. As seen in Figure 1 as well, there is a diminishing trend in the number of deaths for recent years. In Figure 3 if we look at the groups of years divided into three periods as shown in the figure, we notice that the data points corresponding to the period of 1960-1964 are plotted over the range where the number of deaths is relatively large, whereas the points corresponding to the period of 1975-1979 are plotted over the range with the relatively small number of deaths. This indicates a declining trend over time. While the regression equation provided in the figure covers the entire period (1960-1979 excluding 1961 and 1967), the regression constant and coefficient would take on different values depending on the time period if we look at data more in detail. The average annual rainfall turns out to be 21.7 x 10^4 mm as computed with the data from those 127 observatories: approximately 200 deaths would result from the amount of rainfall of the average year using the regression equation. In 1967 hazards due to the seasonal rain front were followed by a large-scale drought, and accordingly the number of deaths turned out larger relative to the amount of rainfall.

In the subsequent demonstration of numerous correlations the regression equation furnished in each figure should not be taken as fixed; regression constants and coefficients ought to take different values depending on the relevant factors such as time, period and region.

A sufficient allowance should be given to these values in consideration of the fact that data on damages tends to lack desirable accuracy. Dispersion of data points is an aid to estimate the range of values over which the regression constant could take. Thus scatter diagrams with large dispersion are also provided. The regression line is provided as a complementary means for reading off the correlation more easily.

There exists a lower limit to the amount of rainfall that could cause water-hazards. This lower limit varies almost in accordance with regional differences in the annual rainfall, being smaller in northern Japan and greater in western Japan. It follows that we could alternatively use that part of rainfall which exceeds the average annual value, instead of the total amount of rainfall, to indicate the intensity of this external force, rainfall. Figure 4 shows the correlation between the number of deaths due to typhoon and heavy rain and the excess amount of rainfall over the average annual value (the excess value being computed by adding up individual values of the excess rainfall which are obtained from those observatories among 127 whose annual rainfall exceeded the respective average annual values). The regression line with a very steep slope fits a cluster of data points corresponding to those years with the large number of deaths due to nighttime strike of hazards such as the cases of Isahaya Gou (Isahaya Heavy Rain), Kanogawa Typhoon, Isewan Typhoon, 36·6 Baiu-Zensen Gou (heavy rain caused by the seasonal rain front in June 1961). When adverse conditions exist, it is presumed that a dramatic increase in the number of deaths is possible by a slight increment in the intensity of the external force. Data points corresponding to other years exhibit a correlation represented by the regression line with a flatter slope. In this case too, data points corresponding to the period of 1975-1979 are plotted in the range of relatively small number of deaths.

If we limit our scope and look at a relatively small geographical region, for example, a city, then we would expect that the correlation would be more easily found between the intensity of rainfall and the scale of human casualties, since regionality of natural and social factors becomes irrelevant. However, the number of data would be insufficiently small because the frequency of such intensive floods or debris flow that could cause deaths is extremely low within such a small geographical region. Figures 5 and 6 show a correlation between the intensity of rainfall and the number of inundated houses in the cities of Nagoya and Yokohama, respectively. Such a relation is easier to be found in big cities, which have the high frequency of inundation due to overflowing of the internal water. The number of inundated houses due to the internal water overflow is used as an example of the indicator of damages that has a clear relation with the intensity of rainfall, indicator of one of the most fundamental external forces, though it is not the type of quantity that can be related to the scale of human casualties. In the case of the city of Nagoya, a high correlation is obtained when a multiple regression is run with the maximum daily rainfall and the maximum hourly rainfall as explanatory variables. In order to see changes over time, data are divided into two periods, those before and after WWII, and the regression analysis is applied to the two periods: we find the increasing difference in the number of inundated houses between the two periods as the intensity of rainfall rises, reflecting the expanded urban area in the postwar period. As for the city of Yokohama, the number of data is small because for many hazards we cannot obtain data on the damages suffered by the city alone.

When we are to describe the scale of human casualties or make predictions, it is sometimes convenient to use the ratio instead of the absolute number. We know that a correlation generally exists between the number of damaged houses and the scale of human casualties in various types of hazards. Since the number of houses is obviously correlated with the size of population, it follows that there exists a correlation between the ratio of damaged houses and the death rate as well. Figure 7 shows the relation between the ratio of completely-destroyed and washed-away houses and the death rate, by cities, towns and villages, that are involved in various hazards such as flood, debris, storm surge, strong wind and so on. We selected those hazards which struck cities in the years after 1946 and caused 10 or more deaths. However, in the case of wind hazards, those with less than 10 deaths are also included since they usually involve a small number of deaths. Meanwhile, we added for comparison those hazards which struck towns or villages in the years after 1959 and caused 100 or more deaths. We do not separate flood hazards and debris hazards (landslide and debris flow) since their distributions are such that the corresponding data points may be fitted by a single regression line. A large number of deaths is likely to ensue when floods take place at the basin of mountain valleys, washing down a large quantity of debris and trees. By contrast, hazards due to strong wind and storm surge (excluding Isewan Typhon) are plotted in the range of a much lower death rate. The regression equations shown in the figure are for the two groups of hazards: flood and debris hazards in the urban area (Kumamoto Suigai [flood] in 1953, Isahaya Suigai [flood] in 1957, Kobe-Kure Dosha Saigai [debris flow] in 1967, and so on), and strong-wind and storm-surge hazards in the urban area (storm-surge hazards in Osaka due to Typhoon Jane, strong-wind hazards in Okazaki and Nishio due to Isewan Typhoon, and so on). The coefficient of the term log H, that is, the slope of the regression line is approximately unity. Thus almost simple proportionality exists between the death rate and the ratio of completely-destroyed and washed-away houses. This proportionality is also observed in the cases of hazards due to earthquake and tsunami (tidal waves).

In order to show quantitatively the difference in the death rate among various types of hazards, the value of 10^A in the regression equation, $\log D = A + \log H$, is obtained for various hazards by fixing the regression coefficient (slope) at unity (the value 10^A corresponds to the slope of the regression line passing through the origin when plotted against the axes using the ordinary scale). This value is given in the parenthesis (at the southeast corner of the figure). Flood and debris hazards are shown to have the value eigth times as large as that of strong-wind and storm-surge hazards. This means that flood and debris hazards cause the death rate eight times as large as that of strong-wind and storm-surge hazards assuming the identical ratio of damaged houses. Strong wind does more damage to houses than to people due perhaps to the fact that wind operates on a broader area at a given location. This can be seen by comparing damages caused by wind-dominant typhoon and those caused by rain-dominant typhoon. While strong-wind and storm-surge hazards generally involve a small number of deaths in contrast to relatively severe housing damage, there is possibility that disastrous damages might ensue as they did in the case of Isewan Typhoon. As shown in the figure, for the cities, towns and villages of the deltaic region at the innermost part of Ise Bay, that were struck by the storm surge caused by Isewan Typhoon, the value of 10^A is approximately 16 times as large as that of strong-wind and storm-surge hazards (with a low casualty ratio) and about twice as large as that of flood and debris hazards.

In the figure regression lines and the values of 10^A are provided for comparison from the data on earthquake hazards in the urban area and Sanriku Tsunami Hazards in the year of 1896. Earthquake vibration too is that type of the external force which operates on a broader area at a given location and accordingly brings about relatively severe housing damage. The value of 10^A for earthquake hazards is approximately one half of that for flood and debris hazards. Meanwhile, the actual scale of human casualties is likely to become larger in the case of earthquake hazards. Sanriku Tsunami Hazards of 1896 was a disaster with 27,122 deaths. About 50 towns and villages along the Sanriku coastal regions stretching over the two prefectures of Iwate and Miyagi, suffered such extraordinary scale of human casualties. The 10^A value is 10 times as large as that of flood and debris hazards.

The slope of the regression line showing the relation between the number (or ratio) of damaged houses and the number (or ratio) of deaths turns out slightly greater than unity when earthquake hazards and wind-water hazards are combined. This can be interpreted as implying that human casualties would increase, instead of in simple proportion, by a slightly greater amount than the increase in the damaging impact which is put forth on a stretch of urban districts (inhabited area), aggravating the damages due to the hazards. Population density is a factor which should affect the scale of human casualties. However, no relation is obtained from the data by cities, town and villages; it is conceivable that the measurement of area might not be appropriate.

3. Typhoon Hazards

The intensity of typhoon is indicated by the central atmospheric pressure and the radius of typhoon circle, whose general expressions are given by, for example, "intensive and large-scale" and "moderate and medium-scale." Since typhoon usually diminishes in its intensity very rapidly after landing, the vicinity of a landing point of typhoon tends to suffer major damages. Takahashi (1954) demonstrated the correlation between the scale of damages and the "engineering ratio" at landing time. This ratio, which indicates kinetic energy being lost by friction per unit of time, is proportional to the product of the central atmospheric pressure raised to the power of 1.5 and the square of the radius of the greatest circular isobar. Mizutani (1976) showed that the human casualty rario is affected by the location and time of landing on the basis of this investigation of the relation between the engineering ratio at landing time and the number of deaths. Here we scrutinize the relation between the intensity of typhoon and the scale of human casualties using additional data on typhoons in the period of 1972-1982.

At times we cannot avoid some degree of arbitrariness in measuring the radius of the greatest circular isobar, for subjective judgement is called for when isobars of typhoon are far from being perfectly circular. Therefore, in order to make it as objective as possible, we use in a consistent manner the same type of weather charts and measure all over again the radius of the greatest circular isobar of 88 typhoons which either landed or approached the mainland and caused damages during the entire period of 1946-1982.

The squared radius of the greatest circular isobar given in the definitional identity of the engineering ratio indicates the area of typhoon circle. If we want to relate this to the scale of human casualties, however, the relevant quantity should be the area of that part of land which the external force is operating upon. This consideration leads the author to conclude that fixing the exponent of the radius at the value of 2 is not appropriate and to abandon the use of the engineering ratio. Instead we will invoke multiple regression analysis, in search for the relation between the intensity of typhoon and the scale of human casualties, using the central atmospheric pressure and the radius of the greatest circular isobar as explanatory variables.

The multiple regression equation reported in Figure 8 is obtained from the data on typhoons that landed during the hours excluding what is called midnight hours. Those which landed during midnight hours are excluded because they tend to involve a very large scale of human casualties. The equation indicates that the number of deaths is roughly proportional to $P^2R^{1.5}$. This contrasts to $P^{1.5}R^2$ in the formula of the engineering ratio. Here, P = (1010 - the central atmospheric pressure at landing time)mb, and R is the radius of the greatest circular isobar. As we notice that a typhoon traveling on land after landing continues to put forth the external force in a strip-shaped region with the width twice the radius of the typhoon, and that damages, however, are concentrated on the neighborhood of the landing point because it is weakened fairly rapidly after landing, the result seems quite reasonable that the exponent of R takes on a value between 1 and 2; the exponent is presumed to indicate the size of the region on which the external force operates.

Figure 8 shows the relation between the intensity of typhoon, indicated by $P^2R^{1.5}$, on the horizontal axis and the number of deaths on the vertical axis for all 88 typhoons. Those typhoons which landed during non-midnight hours (indicated by a light circle) are distributed in the neighborhood along the regression line with the slope of 45 degrees. The human casualty ratio, namely the number of deaths relative to the intensity of typhoon, increases as we move in the upward and leftward direction in the graph whose axes are logarithmically scaled. Plotted at the upper left region of the graph are those typhoons which landed during midnight hours along with those which brought about storm-surge hazards to big cities (Typhoon Jane and Isewan Typhoon). Exceptions, though small in number, are those which have a high human casualty ratio despite the fact that they landed during non-midnight hours: Typhoon Ruth landed in the evening and caused severe damages during midnight hours at a region far from the landing point; Typhoon 5907 involved a large number of deaths for its intensity because it crossed the mainland at an extraordinary speed after landing early in the morning. We should not take it for granted that whenever a typhoon lands during midnight hours the human casualty ratio would be high; that is not the case, nor should it be made so. We could prevent such casualties by means of prompt evacuation on the basis of the efficient transmission of typhoon-related information. As seen in the figure, about one half of those typhoons which landed during midnight hours involved the same level of human casualty ratio as that of those which landed during the hours of morning-10 p.m. The landing points of these typhoons are found to be in most cases Kyushu or Shikoku (indicated by a dark triangle). It is conjectured that the human casualty ratio is small as a result of people's preparednesss against typhoon well-established in these regions, which would reflect the reality that people there are routinely struck by typhoons. The typhoons which struck during the years of 1945-1954 or those which caused major damages at regions other than Kyushu or Shikoku.

The regression line with a steeper slope shown in Figure 8 is obtained from data on the typhoons which landed during midnight hours on Kinki Region or on all other regions east of it and caused a large number of deaths. The regression equation is given by the power function of $P^2R^{1.5}$ with the power 1.4, as indicated in the figure. This implies that the number of deaths would increase at an increasing rate as the intensity of typhoon increases. Those typhoons with severe damages due to storm surge are plotted in the neighborhood along this regression line. Suppose that a medium-scale typhoon with the central atmospheric pressure of 960 mb and the radius of the greatest circular isobar of 400 km landed on Kinki Region or on some other region east of it. Then the regression equation tells us that the number of deaths would be 25 if it struck during the hours of morning-10 p.m., whereas the number would be 220 if it struck during midnight hours. When a typhoon lands during midnight hours, there is thus a possibility that the number of deaths could jump to a value 10 times as large as that in the case of daytime landing.

Figure 9 shows the human casualty ratio by landing time using the graph whose axes are equidistantly scaled, in order to show more clearly the difference in the human casualty ratio according to landing time. Those typhoons with an extremely large casualty ratio concentrate during the hours of 10 p.m.-2 a.m. Meanwhile, four major typhoons are excluded: Typhoon Jane and Isewan Typhoon brought about severe storm-surge hazards to big cities; Typhoon Ruth and Toyamaru Typhoon caused large-scale damages at places far from landing points. In the latter two cases, major damages were caused during midnight hours.

Figure 10 shows the correlation between the intensity of typhoon at landing time and the number of the injured. The dispersion of data points is fairly large reflecting perhaps a low degree of accuracy in identifying injured persons. The values of 2.8 0.9 obtained from the multiple regression are taken on the horizontal axis, which indicates the intensity of typhoon at landing time. Those typhoons with severe storm-surge hazards are seen to have very large numbers of the injured. As for the typhoons which landed during midnight hours, the tendency of a relatively large number of the injured is noticeable, though it is not as conspicuous as in the case of the number of deaths. In the meantime, it is conceivable that chances would be greater in nighttime than in daytime for injured persons to die due to delays in the rescue operation in emergency.

In Figure 11 the correlation is shown between the intensity of the typhoon at landing time and the number of damaged houses. This highest correlation is obtained in the multiple regression when $P^{4.8}R^{0.5}$ is used as the indicator of the intensity at landing time. It is known that the maximum speed of wind is greater the lower the central atmospheric pressure, and that the number of damaged houses is proportional to the speed of wind raised to the power of some large value. This may well explain the result that P has a large exponent. The dispersion of data is considerably larger because the number of damaged houses would differ depending on whether wind or rain is a dominant force even if typhoons have an identical intensity. Most typhoons with a large number of damaged houses are accompanied by severe storm surge.

The human casualty ratio entails changes over time due to such factors as improved forecasting capabilities of typhoon and transmission of the forecast, enhanced preparedness with respect to evacuation and preventive means and changes in social environment. Figure 12 shows year-to-year changes in the human casualty ratio which is defined as the ratio of the number of deaths to the intensity of typhoon at landing time ($P^{2}R^{1.5}$). The solid line indicates a long-run trend in terms of the three-year moving average for the typhoons which landed during the hours of morning-10 p.m. The human casualty ratio remained at a high level until the 1950s, and then came a turning point of year 1960, after which it has been maintaining a relatively low level without a major change. This should not be interpreted as implying that no significant progress has been made in reducing human casualties during the past 20 years. The typhoons which landed during midnight hours on Kinki Region or any region east of it are separately (by dots) shown in the figure in consideration of that they in many cases involved an extraordinarily large human casualty ratio. A declining trend is recognized despite a small number of data points. The regression equation in Figure 8, which plots those typhoons which landed during the hours morning-10 p.m., is obtained from the data on typhoons for the entire period. When it is divided into the period before 1959 and the period after 1960, the regression coefficient would be 2.08×10^{-3} for the period before 1959, whereas it would be 0.98×10^{-3} for the period after 1960. Thus the human casualty ratio for the period after 1960 has been reduced to almost one half of the level for the period before 1959.

Figure 13 shows year-to-year changes in the housing damage ratio which is computed in a similar fashion to the human casualty ratio. A long-run declining trend is obvious despite the existence of several large humps. Much of this trend may be attributed to the improvement in the quality of building. When we compare the size of regression coefficient, we notice that the housing damage ratio for the decade 1973-1982 dropped to the level one fifth of that for the decade of 1946-1955.

4. Flood Hazards

Generally a small number of deaths results from floods that take place at the basin of large rivers. A large number of deaths tends to result from so-called flash flood which takes place at the basin of mountain valleys or in the piedmont area with a high-speed flow of water washing away a large amount of debris and trees. Indicators of the intensity of flood include the depth of inundation, flow speed and flux. While these physical quantities are presumed to have a correlation with the scale of damages, it is hard to be detected because the range over which the force operates, namely flooding range, is generally narrow; particularly flash flood takes place only locally.

As mentioned above, the number of damaged houses may be considered as reflecting the intensity of damaging impact that is actually put forth upon people and community of a region. Figures 14 and 15 respectively show the correlation between the number of damaged houses and the number of deaths in the cases of Isahaya Flood in 1957 and Kanogawa Flood in 1958. These are severe flood hazards which took place at the basin of mountain valley or of the piedmont area during the hours after 10 p.m. and caused a large number of deaths. The number of deaths due to Isahaya Flood reached 815 in Nagasaki Prefecture and that due to Kanogawa Flood reached 970 in Izu Region of Shizuoka Prefecture. Many of the deaths were caused by flooding water while some caused by landslide or debris flow were also included.

Housing damage is classified into "the completely-destroyed," "the half-destroyed" and "the washed-away" (though there is another category, "the partially-destroyed," it is excluded since damage is very slight). In computing a single measure which would indicate the scale of housing damage, the convention is simply to take the weighted average of the completely destroyed and the washed-away with the weight of unity respectively, and the half-destroyed with the weight of 0.5. However, if we want to express indirectly, using the number of damaged houses, the intensity of the damaging impact that is actually put forth upon human life, the author thinks that the weights ought to differ from those used as the expression of the scale of damaged houses itself. In the case of earthquake, for example, almost no death is caused in half-destroyed houses. Moreover, the intensity and quality of the operating force must differ depending on whether houses are destroyed on the spot or washed away.

For this reason the author tried many correlation analyses between the number of deaths and the number of damaged houses by giving various weights to the washed-away and the half-destroyed respectively, and then adding them to the completely-destroyed to obtain the weights that generate the largest correlation coefficient. The correlation is found to be the highest when weight 2 is given to the washed-away and weight 0 to the half-destroyed (that is, the half-destroyed is ignored) for those floods severe enough to cause a large number of washed-away houses as in the cases of Isahaya Flood and Kanogawa Flood. Similarly a high correlation is obtained in the case of storm-surge hazards due to Isewan Typhoon when a weight slightly greater than 2 is given to the washed-away. Meanwhile, the result shows that an identical weight should be given to the completely-destroyed and the washed-away in the case of debris hazards. This difference may be attributable to the difference in the quality of operating matters, water and debris. It is therefore presumed in the case of debris hazards that a sufficiently large damaging impact is already put forth upon human life when houses are completely destroyed. The difference in the correlation coefficient, however, is small if we restrict the values of the weights to a range that may be considered reasonable (roughly 1.5-2.5 for the washed-away and 0-0.5 for the half-destroyed). On the basis of these results, Figures 15 and 16 show a correlation between the number of deaths and the value on the horizontal axis which is obtained by adding 2 times the number of washed-away to the number of the completely-destroyed.

It is conceivable that we may obtain more easily the relation between natural factors and damages due to flood if we employ a hydrographic unit, namely basins, instead of administrative units such as cities, towns and villages. At the end of June 1953, northern and central Kyushu suffered large-scale hazards with nearly 1,000 deaths due to the active seasonal rain front that generated heavy rainfall in the amount of 1.000 mm causing floods in many rivers such as the Chikugo River and the Oita River. Since the data on damages that were compiled according to basins are available in the case of this disaster, we now investigate factors involved in the scale of human casualties using these data. The relevant basins are shown in Figure 16. The Chikugo River has the largest basin area of 3.000 km^2, whereas the Kasegawa (River) has the smallest area of 300 km^2. Located in the midst of the lower Shirakawa (River) basin where the damages were gravest, the city of

Kumamoto was struck by a raging flow of flood discharge containing volcanic ashes that were washed down from Mt. Aso, with the number of deaths reaching 286 in the city.

First, we obtain the relation between various hydrographic quantities, which indicate the intensity of flood, and the number of damaged houses, which is so to speak the primary damage. Since the scale of damages generally depends on the intensity of the event in its peak, immediately comes to our minds the use of the maximum flux recorded on each river. It is also convenient if we indicate the quantity which corresponds to the flux by the product of a basin area and a total amount of rainfall received within the basin, for example, the average total rainfall of a basin; we can then include a rainfall factor. While there are various ways of indicating the basin gradient, the most convenient is the value (inclination ratio) computed as the difference between the maximum and minimum altitudes, divided by the extended length of a river (excluding small and medium degrees of winding in the riverbed). No matter how large the intensity of flood thus indicated is, no damage would arise without the object being damaged. We then adopt the average household density of a basin as a factor which indicated damage potential.

Figure 16 shows the results of multiple regression analysis using as a dependent variable the number of damaged houses (the completely-destroyed plus the washed-away) and as independent variables the average household density of a basin and the intensity of flood that is indicated by the product of three terms, the average total rainfall of the basin, the basin area and the inclination ratio. In Figure 17, we take as explanatory variables the average household density of the basin and the maximum flux. In both cases, a highly significant correlation is obtained. To link the number of damaged houses thus obtained and the number of deaths, we can use the correlation shown in Figure 18. The regression equations shown there do not have general applicability because of data accuracy or characteristics of the basin in question. However, we may generally agree that the scale of human casualties is related to the damage potential factor as well as the factors indicating the intensity of the external force, despite our reservarions as to the way these factors are derived.

5. Storm-Surge and Strong-Wind Hazards

A disaster of over 5,000 deaths was caused by Isewan Typhoon that struck at night on September 26, 1959. Aichi Prefecture suffered the severest damages with the number of deaths reaching 3,260. Most of the deaths were due to the storm surge which took place in the Bay of Ise. In the inland region damages were caused by strong wind and debris. Here we will obtain the difference in the scale of human casualties according to the type of hazards and geographical location, using data (reported by cities, towns and villages) on damages suffered by cities, towns and villages of Aichi Prefecture.