Consequences of the river valley bottom transformation after extreme flood (on the example of the Niida River, Japan)

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Abstract. Detailed study of different sections of floodplain was undertaken in the Niida River basin (Fukushima Prefecture) after an extreme flood event which occurred in the middle of September 2015. The upstream part of the basin is located in the area with very high level of radionuclide contamination after the accident at Fukushima Dai-ichi NPP. Field and GIS methods were used, including direct measurement of the depth of fresh sediment and its area, with soil descriptions for the typical floodplain sections, measurement of dose rates, interpretation of space images for a few time intervals (before and after flood event) with the following evaluation of spatial changes in deposition for different floodplain sections. In addition, results of quantitative assessment of sedimentation rates and soil radionuclide contamination were applied for understanding the effect of extreme flood on alluvial soils of the different sections. It was established that the maximum sedimentation rates (20-50 cm/event) occurred in the middle part of the lower reach of the Niida River and in some locations of the upper reaches. Dose rates had reduced considerably for all the areas with high sedimentation because the top soil layers with high radionuclide contamination were buried under fresh sediments produced mostly due to bank erosion and mass movements.

1. Introduction

Extreme flood events are very typical of small mountain river basins in different parts of tropical and sub-tropical landscape zones [1, 2, 3, 4]. They usually result in both intensive erosion and sediment deposition on the river valley bottom [5, 6, 7, 8, 9]. Also, sedimentation rates considerably influence alluvial soil formation and contamination, depending on the sources of sediment [10, 11]. Detailed study of different sections of floodplain was undertaken in the Niida River basin (Fukushima Prefecture) after an extreme flood event which occurred in the middle of September 2015, when 385-456 mm of precipitation fell during 6 days with maximum 200 mm/day at the end of typhoon. The objectives of the study are: 1) to evaluate the erosion/deposition processes and their spatial changes in different sections of the river floodplain, with particular attention to the low reaches of the Niida River, and 2) to assess changes in alluvial soil contamination in comparison with the level of contamination before the extreme flood.

2. Material and methods

The Niida River basin has the total area of 248 km² and is located on the eastern part of the Fukushima prefecture. Level of initial radionuclide deposition after the FDNPP accident varies considerably along
the Niida River with maximum contamination in its southwestern part (the Hiso River basin), with decrease in both northern and eastern directions. All previously used agricultural lands of the headwater uplands both in depressions and on hillslopes have been abandoned since spring 2011 immediately after the accident. Intensive decontamination work (complete removal of the contaminated upper topsoil layer for the long-term storage) is underway now starting from the northwestern part of the basin. Coastal lowlands were not seriously affected by the radionuclide fallout. Agricultural lands in this part of the basin are still in use. The Niida basin is characterized by wet monsoon climate with highly variable total annual precipitation (1300-1500 mm). Less than 5-7% of precipitation falls as snow. The alluvial sandy and loamy sandy soils are typical of the river floodplain. They are characterized by high moisture content and stratification with interlayers of light loam. More detailed description of the Niida river basin can be found elsewhere [12, 13].

Field and GIS methods were used, including direct field measurements of the depth of fresh sediment and its area with soil descriptions for the typical floodplain sections, measurement of dose rates; interpretation of space images of the river valley for a few time intervals (before and after flood event) with the following evaluation of spatial transformation of the river bottom, including river channel and different floodplain levels. Finally, area of three types of valley bottom modifications were distinguished. The first type is erosion sections, which appeared because of bank erosion. The second type is the deposition section which was associated with formation of new floodplain area (point bars). The third type is sedimentation area on the pre-existing floodplain. Only areas with high rate of sedimentation rates (>5 cm per event) were included in this group.

3. Results and discussion

Results of quantitative assessment of sedimentation rates were used for understanding the effect of extreme flood on alluvial soils of the different reaches. The sedimentation rates in the upper part of the Niida River basin within intermountain depressions depended on the type of the channel. They are in the range 10-15 cm (one order of magnitude higher than the mean annual) for the artificially canalized channels with concrete embankments and levees, which are the dominant type for main rivers draining the basin headwaters upland depressions. However, sedimentation rates are only 1-3 cm for the uppermost section of the artificially canalized channels. Some valley reaches within uplands depression have wider channels, but unconfined by levees or embankments (though there can be levees on one or both sides but remote from the channel along the higher floodplain or low terrace level). Here in some section within the floodplain there was extremely high deposition of sand and pebble material with an average depth of 30-40 cm and a total weight of 400-500 tons which, in fact, amounts to one tenth of the total measured flow volume of suspended sediments.

The most detailed study was undertaken for the lower reach of the Niida River located within the coastal lowlands. It was possible to divide the lower reach into three sections according to decreasing of the channel gradients towards the river mouth. Evaluation of areas which had undergone by bank erosion, in-channel deposition and active overbank sedimentation was undertaken for each section and presented for the different types of channel, determined according to the river channel classification [14, 15] (table 1).

It was found that bank erosion is particularly high at the section 1, because of the high energy of the flow after the exit of the Niida river from the mountains to the coastal plain in particular in the river reaches with straight type of channel (table 1, figure 1). Generally, erosion prevails the in-channel deposition for all sections of the lower reach of the Niida river except meandering channel type at the section 3 (table 1). However, the meandering type of channel is characterized by the relative equilibrium relationship of erosion and in-channel deposition even at the section 1 with the most active valley bottom transformation including overbank sedimentation (figure 2; table 1).
Table 1. Mean areas of the lower reach of the Niida river valley bottom affected by bank erosion, in-channel deposition and intensive overbank sedimentation

| Type of channel | Bank erosion, m² | In-channel deposition, m² | Floodplain sedimentation, m² |
|-----------------|------------------|--------------------------|----------------------------|
| Section 1 *     |                  |                          |                            |
| Meandering      | 16732            | 7178                     | 32970                      |
| Braided         | 13228            | 608                      | 21615                      |
| Straight        | 14983            | 1196                     | 7894                       |
| Section 2       |                  |                          |                            |
| Meandering      | 36431            | 13144                    | 79499                      |
| Braided         | 10691            | 2290                     | 19523                      |
| Section 3       |                  |                          |                            |
| Meandering      | 14562            | 19713                    | 71510                      |
| Braided         | 7473             | 1675                     | 18776                      |
| Straight        | 3232             | 369                      | 644                        |

* Section of the river valley bottom of the lower reach were separated according to the decrease of the river channel gradient towards the mouth.

Figure 1. The erosion (1), deposition (2) and sedimentation (3) zones appeared after extreme flood at the section 1 (semi-mountain sub-reach) within the straight type of the Niida River channel.
Figure 2. The erosion (1), deposition (2) and sedimentation (3) zones appeared after extreme flood at the section 1 (semi-mountain sub-reach) within the meandering type of the Niida River channel.

Figure 3. The erosion (1), deposition (2) and sedimentation (3) zones appeared after extreme flood at the section 1 (semi-mountain sub-reach) within the braiding type of the Niida River channel.
The erosion (1), deposition (2) and sedimentation (3) zones formed after extreme flood at the section 3 (plain sub-reach) within the braided type of the Niida River channel.

The braided type of the river channel is characterized by the different modification of the river valley bottom depending on the river channel gradient. Active erosion was identified for the braided channel at the section 1 (figure 3), while intensive in-channel deposition was observed at the section 3 (figure 4). It is necessary to stress that overbank sedimentation at the lower reach of the Niida River leads to the reduction of the dose rate, even though the dose rate was low initially because of sand-gravel grain size of the sediment. Dose rates were reduced by 3-5 times for all the floodplain sections in both upper and lower reaches of the Niida River with high sedimentation rate because the top soil layers with high radionuclide contamination were buried under fresh sediments produced mostly due to bank erosion and mass movements.

4. Conclusions
The detailed assessment of geomorphological and radioecological consequences of the extreme flood in the Niida River basin allows to conclude that different exogenic processes (landslides, scree, bank erosion etc.) were the main sediment sources for the river sediment discharge. Maximum channel deformations were observed within the lower reach of the Niida River because of extremely high energy of the stream with maximum water and sediment discharges. However, sedimentation rates on the floodplain of the upper reaches of the Niida River were also one order of magnitude higher than the mean annual rates. Finally, extreme event contributed to the serious reduction of the dose rate of the river bottom except for some high floodplain levels where sedimentation rates were negligible.

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