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The Influence of Pulp and Paper Mill Sewage on the Chemical Composition Sediments of the Kondopoga Bay of Lake Onega

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Abstract

The Kondopoga bay has been a sewage recipient of the Kondopoga pulp and paper mill, since 1929. The aim of this study is to show the effect of pulp and paper mill sewage on the sediment quality, to demonstrate the dynamics of sediment organic pollution spreading in 1964 - 2010. Presently, the study area of Kondopoga bay is divided into three zones. The sediments of zone I, located near the pulp and paper mill, consist of very slowly decomposable waste matter. The sediments of zone II, located at 4 km away from pulp and paper mill, differ from the rest by intensive salts flux across the sediment-water interface. Accumulation and transformation of organic suspended substances is observed in the deepest area (zone III). The change of the chemical composition of the sediments showed the tendency of polluted sediments extension and spreading of organic pollution all over the Kondopoga bay. Transformed organic suspended substances come from the bay in the open part of Lake Onega.

Keywords: sediments, pollution, anthropogenic eutrophication

1. Introduction

The sediments can be a good indicator of lake ecosystem, as they integrate all processes from water column. The research of sediments is one of the ways of monitoring the anthropogenic pollution of large lakes. Very often, the effect of human impact in a lake with a complicated geomorphology does not show in areas subject to pollution. It takes a big volume of water mass a long time to change the water chemical composition. Therefore, it is difficult to assess the anthropogenic influence by traditional methods based upon only water samples analysis. The effects of pollution are reflected upon sediment quality, changes in its chemical composition. Chemical analysis enables us to mark the areas with considerable changes in natural conditions is to obtain information for further environmental research.

1.1 Study Area

Lake Onega is one of the largest lakes in Europe (S=9720 km^2, V=291.2 km^3). Bottom relief and the morphology of Lake Onega shoreline are very complicated. This is the reason why the ecosystem of the area is heterogeneous. The Kondopoga bay, the deepest bay of Onega Lake, has been exposed to large-scale pollution. The mean depth of the bay is 21 m, with a maximum depth of 82 m, and water volume of about 4.3 km^3. The coasts are complicated crystal rocks forming rocky breakages. Complex relief and a great variety of depths are characteristic of the bottom. There is a shallow part in the north (depth $<$ 20 m) and a deep part in the center of the bay (depth $>$ 30 m). Numerous islands and the beach are natural barriers, separating the bay from Large Onega and slowing down water exchange with the lake. The Suna River flows into the north-eastern part, near the Kondopoga pulp and paper mill. That provides specific conditions for dilution and distribution of sewage.

2. Materials and Methods

The study is based on comparative analysis of original sedimentary chemistry data for the period of 1964-2010. The sediment samples were taken at 12 lake stations (Figure 1). The sampling of the upper 0-5 cm stratum of sediments was performed with the birge Ekman grab or gravity corer of original construction. The water content, pH, Eh, plant pigments, ammonium nitrogen, labile phosphorous, petroleum hydrocarbons, manganese, iron were analysed in wet sediments. The loss on ignition, organic carbon, total nitrogen and phosphorous were analysed in dry sediments (Belkina, 1999).

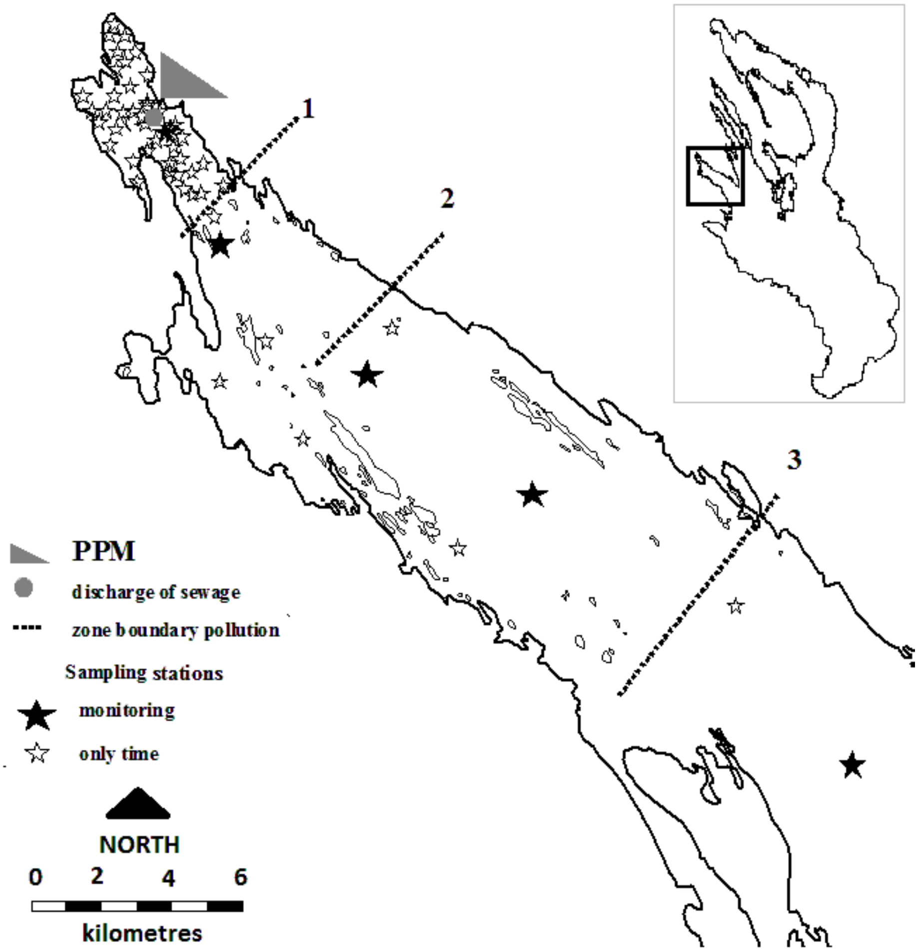

Figure 1. Kondopoga Bay of Lake Onega. Location of sampling stations and boundary of zones of pollution (1, 2, 3), PPM - Kondopoga pulp and paper mill

3. Results and Discussion

The bottom sediments in the Kondopoga bay vary from stones to clay silts. Their distribution is related to water depth, bottom topography, water dynamics and the distance from the source of pollution. The investigated sediments are mainly aleuritiuc silts mixed with ore, clay and waste of pulp and paper production. Wood waste and decaying fibril mass of cellulose are found in the area of the mill (dominating fractions 0.05-0.01 and 0.01-0.001 mm). The presence of cortex, arboreal fibbers and paper residue is characteristic of all the bottom sediments in the northern part of the bay. The sediments originating from the pulp mill are gray ooze with black inclusions and gas. The length of oxic brown layer on the upper layers sediments increases with the distance from the point of discharge. The stratification of sediments specifies the seasonal character of sedimentation processes (Belkina 2005, 2011; Vasilqeva, Davydova, & Belkina, 1999).

The results of the research of the chemical composition of Kondopoga bay sediments, indicates the spreading of organic pollution sediments over the entire area of the bay.

The sediments of the bay as compared with those in Lake Onega are characterized by very high water content. As a result of the swelling process of waste paper, water content in the sediments in the northern part near PPM reaches 96.5 % d.w.. It gradually decreases away from the mill. In the deepest areas it varies from 90.2 to 92.6 %, the average value - 91.2 %.

The sediments differ by the high contents of organic matter with very a wide atomic ratio of C:N (from 21 up to 82). Geological structure, bottom relief, hydrological regime and anthropogenic pollution influence irregular distribution of organic compounds (OC) at the bottom. OC contents in sediments decrease and Eh of sediments increase with the increase of the distance from the Kondopoga pulp and paper mill.

A research over forty years showed the tendency of polluted sediments area extension (Belkina, 2005). Change of sediment chemical composition is closely connected both with the intensity of the effect and with quality of the wastewater of the mill (Figures 2-5).

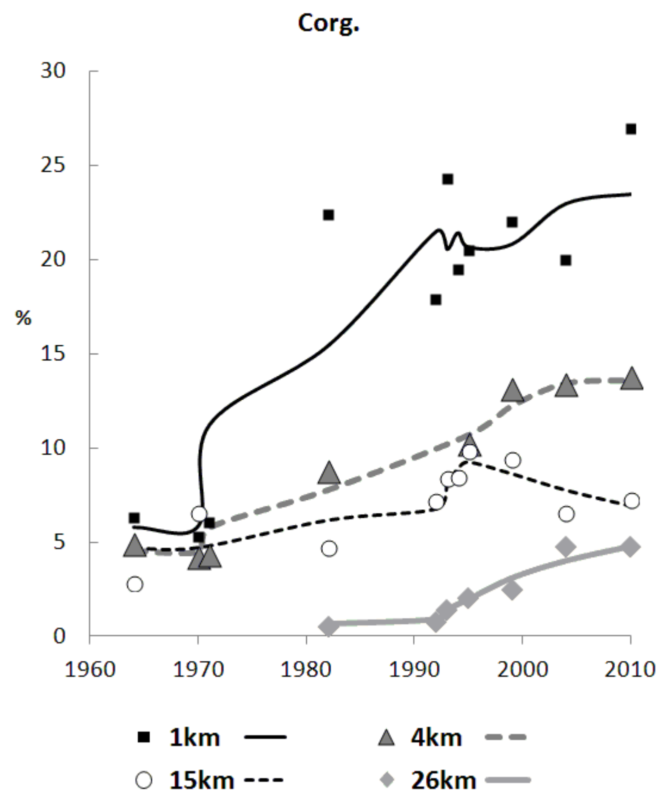

Figure 2. Change of $C_{org.}$ of sediments from the distances of point discharge PPM in 1964-2010

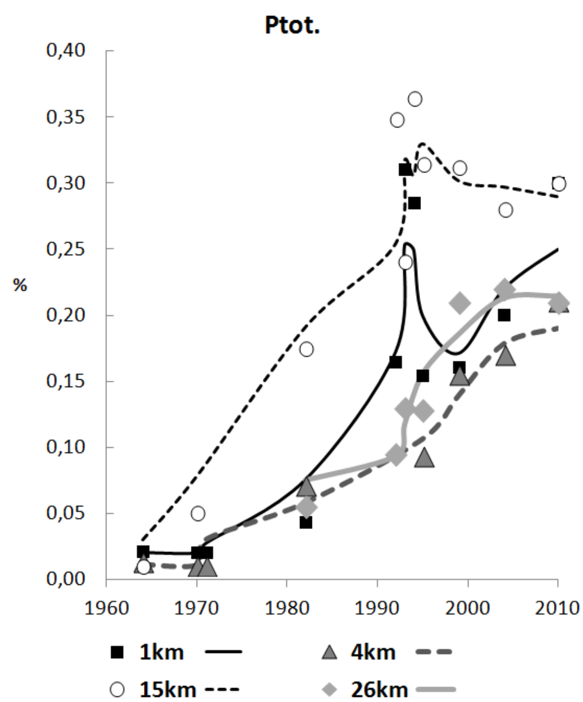

Figure 3. Change of $P_{tot.}$ of sediments from the distances of point discharge PPM in 1964-2010

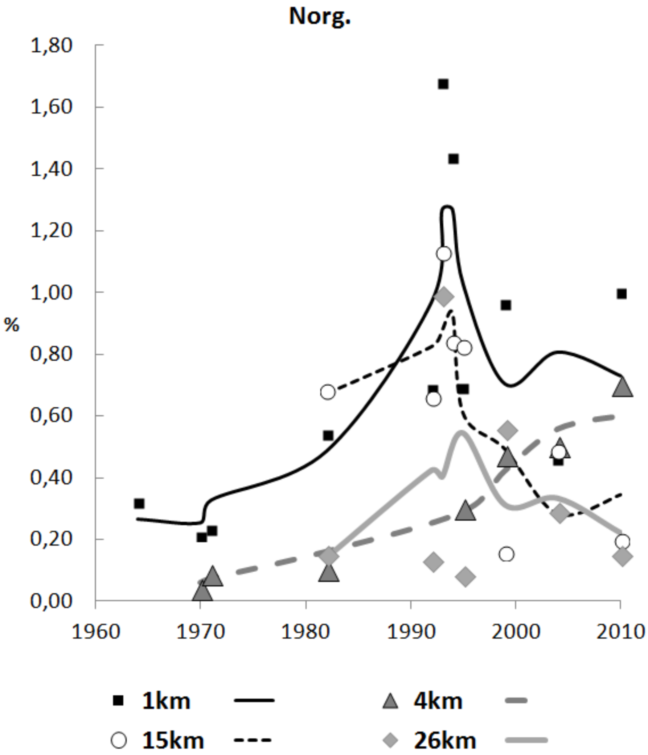

Figure 4. Change of $N_{org.}$ of sediments from the distances of point discharge PPM in 1964-2010

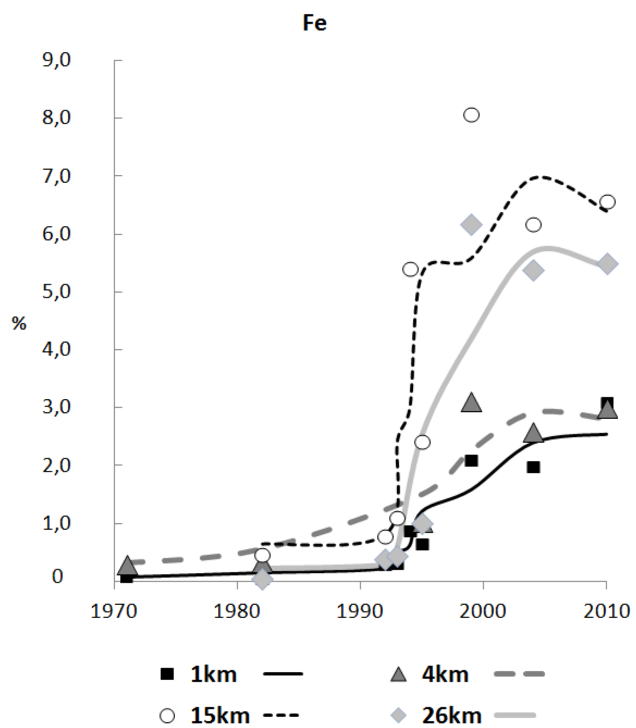

Figure 5. Change of Fe of sediments from the distances of point discharge PPM in 1970-2010

Until early 60's there was no sewerage system on the mill. The polluted area was 3 km^2.

In 1970's this area has increased from 3 up to 17 km^2. The zone of polluted sediments occupied all the northern part of the bay, and further it was distributed along the western coast . The deep-water dilution discharge and biology treatment system were installed in 1979 and in 1983. It resulted in the increase of anthropogenic influence in the bay (Vasilqeva et al. 1999).

Presently, the study area of Kondopoga bay is divided into three zones of accumulation suspended solid of waste water PPM (Figure 1). The chemical composition of sediments was used to assess the area of pollution. Zone I is situated near the mill: the sediments consist of very slowly decomposable waste matter. Concentration and the qualitative structure OC has almost not varied since 1983, when intensive accumulation sludge was detected here for the first time. The content of $C_{org.}$ - 22 % d.w., phenol - up to 24 mkg·g^{-1}d.w., content of N is the highest - 0.98 % d.w. (the third is N_{NH4}, $N_{org.}$ is 1.4 % from OC). The steady increase of C, P contents in sediments is likely to be connected with the quantitative and qualitative composition of the waste water PPM. The reason of maximal concentrations of N and P in early 90's (Figures 3, 4) is abundant dumping during the period of debugging sewage treatment systems.

Zone II located 4 km away from the mill: the sediments are distinguished intensive salts flux across the sediment-water interface. The increase of the concentration of C, P, N, Fe in sediments was detected there (Figures 2-5). Accumulation and transformation of a technogenic OC in sediments resulted in creation of internal load at a level of zone I. Concentrations of petroleum hydrocarbons are maximal (0.3 % d.w.). The oxygen demand by sediments is 2.8 g·m^{-2} per day. A high content of vegetative pigments (110 mkg·g^{-1}d.w.), vertical distributions of P-fractions in sediments (values of the accumulation of Fe-bound phosphorus) indicate a more intensive anthropogenic eutrophication process.

Zone III situated in the deepest area. The specific character of flows during certain phases of the hydrological cycle is the stimulating factor promoting accumulation of organic suspended products in oozes of the central area. On the average, contents of OC and P there have increased twofold, Fe - threefold (Figures 2-5). The content of $C_{org.}$ has changed from 6 up to 9 %, N - from 0.3 up to 0.7 % d.w. The concentration of $N_{org.}$ and Mn currently decrease.

Allochthonous character of the formation of organic matter in sediments are shown on the output from the bay (C:N=40). Concentration of C, P, Fe have increased by 2-3 times (Figures 2-5).

Lake Onega is oligotrophic lake with oxidizing water regime. Waste water contains large amounts of suspended organic compounds that accumulate around PPM. Their decomposition requires a large amount of oxygen, whereby occur anaerobic conditions in sediments and bottom waters. The sediments of zone I and II differ from the rest by reducing conditions and intensive biogenic flux across the sediment-water interface (Figure 6). The value of the nutrient load in zone I up to 1.4 mg P and 1 mg N per sq m per day, which corresponds to the values characteristic of the bottom sediments eutrophic lakes. The input of nutrients from the sediment increases the process of eutrophication of the Bay.

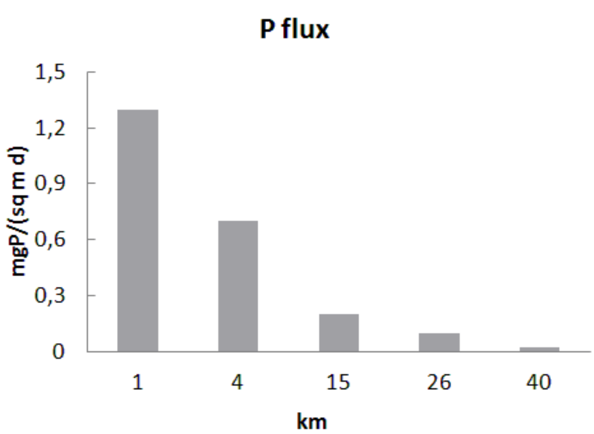

Figure 6. Change of internal phosphorus loading from the distances of point discharge PPM

4. Conclusion

The change of the chemical composition of the sediments showed the tendency of polluted sediments extension and spreading of organic pollution all over the Kondopoga bay. It indicates the anthropogenic eutrophication process. Transformed organic suspended substances come from the bay in the open part of Lake Onega.

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