INCLUSION OF ECOHYDROLOGY CONCEPT AS INTEGRAL COMPONENT OF SYSTEMIC IN URBAN WATER RESOURCES MANAGEMENT:
The City of Lodz Case Study, Poland

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ABSTRACT

Urbanization involves excessively forceful impact on habitats, often including their extinction and replacement with artificial structures. These transformations disrupts flow paths of energy, water and matter, within and between adjacent ecosystems, re-directing them into unsustainable, human-originated tracks. These transformations pose major ecological consequences for ecosystems functioning. Changes of hydrological, biogeochemical and ecological processes in catchments are reflected in freshwaters – the receivers of deregulated, extreme runoffs and accelerated flow of matter from disrupted natural cycles. Additionally, degradation of water habitats handicap their resilience – the ability to maintain oscillations within boundaries defined by steady state. Consequently, ecosystems functions and ability to provide services may be permanently amended.
Selection of two catchments in the city of Lodz (Poland) allowed tackling a comprehensive scope of water related issues in the city and translation of ecohydrology concept tested in laboratory and micro-scale experiments into meso- scale validation. The project addresses use of ecohydrology for: i) adaptation of small city rivers and catchments for interception of large stormwater and pollution loads, ii) elaboration of comprehensive concept of wastewater treatment plant management addressing issues of sewage sludge utilization, biomass production, and river rehabilitation, and iii) providing socio-economic feedbacks to the city inhabitants based on use of ecosystem resources of regenerated urban ecosystems.
The strong socio-economic component of the project involves formation of a "Learning Alliance" group, which ensures the relevance of the undertaken activities to local needs and conditions and develop mechanisms for efficient implementing results of the recent ecohydrological research into practice.
The paper will provide an overview of the activities undertaken by the University of Lodz, ERCE and the City of Lodz Ofiicce within the framework of the UNESCO IHP/MAB joint activities and EU 6 PF SWITCH Project.

1. INTRODUCTION

1.1. Perspectives for application of ecohydrology in cities

Urbanization involves excessively forceful impact on habitats, often including their extinction and replacement with artificial structures. These transformations disrupts flow paths of energy, water and matter, within and between adjacent ecosystems, re-directing them into unsustainable, human-originated tracks. Such transformations pose major ecological consequences for freshwaters which are the receivers of the deregulated, extreme runoff and accelerated flow of water and matter from disrupted natural cycles (Zalewski, 2000a). These changes directly affects water quality and quantity in degraded catchments. Additionally, degradation of water habitats handicaps resilience of freshwater ecosystems – their ability to maintain oscillations within the steady state. Consequently, ecosystems functions and ability to provide services may be permanently amended (Krauze & Wagner, 2007). This directly affects human health and wellbeing in cities.

Degradation of environmental processes can not be compensated by application of only technological solutions, which do not address efficiently the effects of degradation of the elements of natural cycles in catchments (Zalewski, 2000b). Reduction of impacts, such as minimizing pollution or water detention, together with rehabilitation of freshwater habitats are the foremost and fundamental conditions. However considering the intensity of urban impact, they do not suffice (Zalewski &

Wagner, 2005). Those measures should be supported by simultaneous procedures allowing reduction of degradation symptoms occurrence at the level of impact, by augmenting assimilative capacity of ecosystems. Thus the need for cost-efficient, integrated solutions extending technical systems for urban water management with ecological measures, that may not only improve the quality of environment but also lower costs of management and rise economic income for society (Wagner-Lotkowska at al, 2004).Such measures are considered by ecohydrology approach (Zalewski et al., 1997, Zalewski 2000b), postulating using ecosystem properties as management tool in water resources management.

Ecohydrology is a transdisciplinary approach, using the understanding of relationships between hydrological and biological processes at the catchment scale to improve water quality, biodiversity and sustainable development (Zalewski 2006). The approach implementation is based upon restoration and maintainence water circulation patterns, nutrient cycles and energy flows at a catchment scale towards optimization of the ecosystem services for society. The concept has been so far applied in variety of semi-natural and medium-disturbed catchments (e.g., Wagner-Lotkowska et al., 2005, Agostinho et al., 2005, Wolanski et al., 2006), while it's testing in the city landscape still reminds to be a challenge. Therefore, the presented project hypothesizes, that organizing the energy, water and matter pathways in cities, following the rules governing processes in the natural ecosystems, may allow to control the analogical processes in urban ecosystems, compensate effects of intense degradation in other sections of the catchments and increase assimilative capacity of environment against condensed human impact. This approach is based on three fundamental tenants: i) using synergies between catchment water cycle and dynamic of it's biotic component, ii) harmonizing existing and planned hydrotechnical solutions with ecological biotechnologies, and iii) integrating complementary synergistic measures at all scales (Zalewski, 2006).

1.2. The City of Lodz – environmental context

The City of Lodz is a city of 800 thousands inhabitants (agglomeration of 1 million inhabitants), located in central Poland. The city area is divided into 18 catchments drained by small urban streams (average flow < 1 m3 s-1) with relatively high slope of stream channels (5-7 ‰). During the industrial revolution in the early 30's of the XIX century, the streams were channelized and turned underground, becoming a part of storm water system. These changes together with compacted historical development reduced water retentiveness in the landscape and streams, what particularly evidences during storm events, through increased the flow peaks in the streams. Since Lodz is equipped with a mix drainage system - combined in the centre, old part of the city and separated sewage and stormwater systems in the new, outskirt sections - the efficiency of sewage treatment is periodically diminished.

1.3. Sokolowka river

The Sokolowka river, crossing the northern part of the city and representing a typical urban storm water receiver. The river's natural flow gradually disappeared, being nowadays supplied mostly by around 50 storm water outlets. The main channel was regulated by concrete slabs, to straighten the course and deepen the bed for purpose of runoff detention. Nevertheless, the middle section of the river valley located in the outskirts of the city, has maintained semi natural character. Patches of meadows, wetlands and forests made this section appropriate as a pilot area for analyses best ecohydrological river rehabilitation options. Reservoirs situated in the Sokolowka River receive nutrient-enriched stormwater, which increases their trophic state. According to bottom-up concept, this stimulates phytoplankton growth and appearance of algae or cyanobacterial blooms, which may cause limitation of ecosystem services (limit biodiversity of aquatic habitat, their recreational values) and if toxic, constitute potential hazard to users as possible carcinogens and tumour-promoters.

1.4. Ner river

The study area is located in the protective zone of the Wastewater Treatment Plant (WWTP) in Lodz in the catchments of the Ner River. The river is polluted with municipal and industrial wastewater from the Lodz agglomeration and the water quality was classified as 4th and 5th class (WIOŚ, 2005). The treated sewage (with the average outflow of 2,5 m3/s) is disposed into Ner River of natural flow about 0,3 m3/s. Consequently, the river floodplain have been severely contaminated with heavy metals and organic compounds (Andrzejewska, 2002; Koszek, 2000). The total metal concentration of studied floodplain soils is ranging from: 11 to 598 mg/kg for Zn, 7 to 390 mg/kg for Cr, 7 to 121 mg/kg for Cu and 11 to 93 mg/kg for Pb and is positively correlated with organic matter content (Bocian, unpublished data). Decrease of water use and sewage disposal after industry collapse within the last 15 years, lowered groundwater level and accelerated mineralisation of cumulated organic matter in aerobic condition at the floodplain. This resulted with leaching of heavy metals from the soil and caused serious threat of their cumulating in food chains in agriculturally used floodplain sections.

WWTP produces 70 000 ton of sewage sludge (200 tons/24 h), which causes additional economic and ecological issue. The sludge undergoes fermentation and has little water content (about 21% of dry matter). The sewage is stored on the lagoon located near the building of WWTP. The forming biogas is desulphurized and burned in the heat and power generating plant for the WWTP purposes. The composition of sewage make it possible to use it for non-food agricultural, for example in short rotation forestry (energetic willow plantation), if the heavy metals content is kept within the limits according to the polish legislation. The sludge contains high concentrations of nutrients, as the efficiency of total nitrogen and total phosphorus purifying are 59,7% and 87,2% respectively (data from WWTP, 2002).

2. OBJECTIVES

The project objectives are to develop scientific basis for integrating ecohydrology into the Integrated Urban Water Management in the city of Lodz, to reach the following final objectives:

- i) adaptation of small city rivers and catchments for interception of large stormwater and pollution loads,
- ii) elaboration of comprehensive concept of wastewater treatment plant management addressing issues of sewage sludge conversion into biomass, and river rehabilitation,
- iii) providing socio-economic feedbacks to the city inhabitants based on use of ecosystem resources of regenerated urban ecosystems.

Selection of two pilot catchments allowed tackling a comprehensive scope of water related issues specific for the city and validate ecohydrology concept tested in meso- scale in two pilot projects (Zalewski & Wagner, 2006):

- Project 1: Restoration of a municipal river for stormwater management, increase of water retentiveness and improvement of quality of life – the Sokolowka river.
- Project 2: Sewage system management for environment quality and positive socio-economic feedbacks - the Ner River.

3. METHODS

3.1. The Sokolowka River sampling

Surface water samples were collected weekly from April to December 2006 at 10 sampling stations at the Sokolowka River and 5 at it's reservoirs (Figure 1).

During the sampling water temperature, pH, conductivity and oxygen concentration were

measured. Total phosphorus (TP) and phosphate phosphorus (P-PO4) were measured by the ascorbic acid method (Golterman et al., 1978). Total nitrogen was analyzed using persulfate digestion method (method no. 10071; HACH, 1997). Nitrate nitrogen (N-NO3) was determined using the cadmium reduction method (method no. 8039; HACH, 1997) and the ammonia nitrogen (N-NH4) – the phenate method (Golterman et al., 1978). Chlorophyll a concentration was estimation by method based on acetone extraction and determination by spectrophotometry (Lawton et al. 1999).
Hydrological parameters were measured twice a month in November and December 2006 at 3 sampling stations using the current meter (Valeport BM002) method.

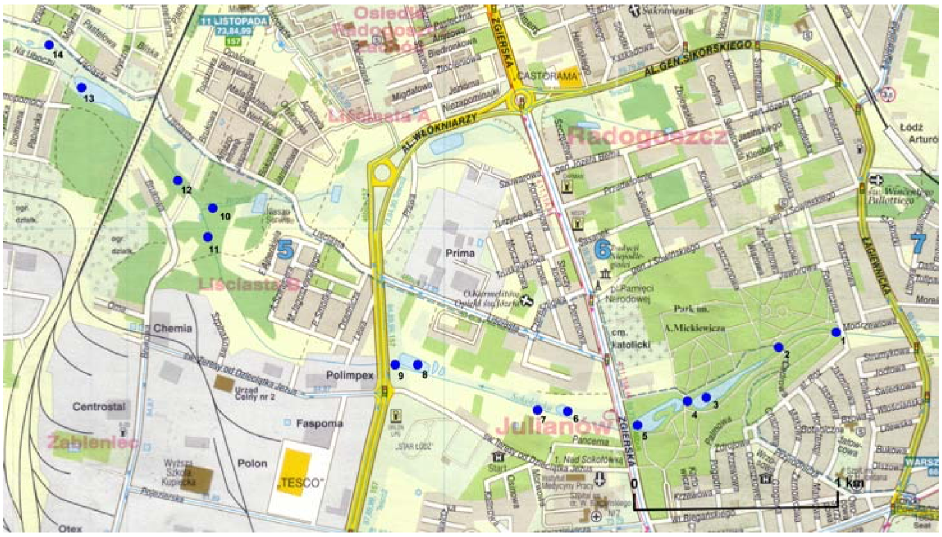

Figure 1: Location of the sampling stations (blue circles) along the Sokołowka River.

The collected data are being quantitatively and qualitatively analyzed towards understanding of spatiotemporal patterns of pollution dispersion and appearance of eutrohication symptoms and establishment of the hierarchy of parameters determining dynamics of the reservoirs ecosystems.

3.2. The Ner River –Waste Water Treatment Plant

The activities related mostly to monitoring of 64 ha experimental willow plantation established in 2004 (Bocian, 2004) in the area of restricted exploitation of the WWTP (Figure 2). The plantation is divided into 4 experimental fields (I, II, III, IV) planted with different varieties of energetic willow: I: Salix viminalis clones; II: Tordis (Salix schwerini x S. viminalis) x S. viminalis; III: Salix viminalis gigantea; IV: Salix viminalis (clone 192).

The applied dose of sewage sludge was calculated based on the regulations of the decree of the Ministry of the Environment (Dz.U.Nr 134, position 1140). The dose of 11,5 tons/ha/years of sewage sludge was applied, which is equal to the 3-year dose. The maximum doses have been limited by the heavy metal content.

The dry biomass (d.w.) of plant material was estimated four times during the field seasons (July, August, September, October 2006) by weighing of dry collected plant material after the vegetation season according to Ostrowska et al. (1991) and Chmielewska (1955).

The survivability of *Salix viminalis* on the plantation were measured on each experimental field by calculation the difference between the planted number of cuttings and the number of the cuttings survived after the first year of grow.

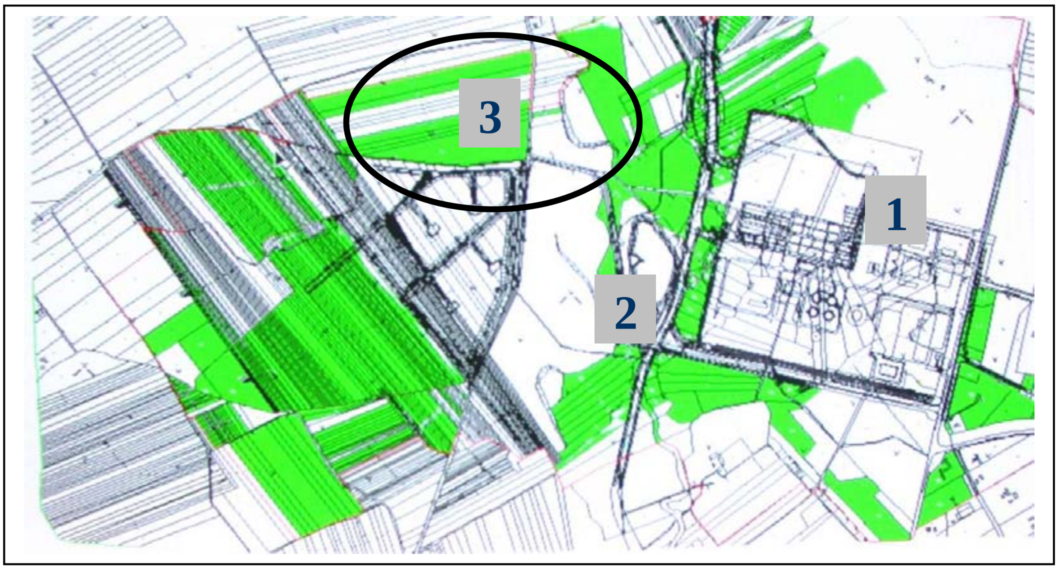

Figure 2: Location Localization of willow plantation (authors: The City of Lodz Office): 1 – The main building of Water Treatment Plant; 2 – The sludge lagoon; 3 – The experimental willow plantation.

The concentrations of the following heavy metals: Zn, Ni, Pb, Cd, Cu, Co, Cr were determined in the plant tissues using the atomic absorption spectrometry (AAS) in the laboratory of the Technical University of Lodz.

The soil samples were taken from each experimental field from depths of 0 – 25 cm. The concentrations of the following heavy metals: Zn, Ni, Pb, Cd, Cu, Co, Cr were determined in the sludge and soil mixture using the atomic absorption spectrometry (AAS) in the laboratory of the Technical University of Lodz.

4. RESULTS AND DISCUSSION

4.1 The Sokolowka River

Concentrations of total phosphorus and total nitrogen in reservoirs situated in the Sokolowka River exceed the border values for eutrophication of reservoirs (0.1 mg P/l and 1.5 mg N/l (OECD 1983). Annual average of TP concentrations ranged between 0.30 and 0.40 mg/l but the maximum values reached 1.84 mg/l at Station 6. Whereas annual average TN concentrations in reservoirs were between 1.53 and 2.46 mg/l, and maximum values of 18.9 mg/l occurred at Station 5.

Chlorophyll a concentrations (Figure 3) confirmed eutrophic character of reservoirs (8-25 mg/m3) and some of them are hypertrophic (>25 mg/l) (Zalewski and Wagner 2004). Annual average of chlorophyll concentrations ranged between 20.2 and 48.1 mg/m3 but maximum values reached 260 mg/m3 at Station 8.

Annual average TP concentrations in river ranged between 0.21 and 0.85 mg/l but the maximum values reached 3.30 mg/l at Station 2, whereas in reservoirs were between 0.30 and 0.40 mg/l but the maximum values reached only 1.84 mg/l at the Lower Pond. The differences between minimum and maximum values are observed for the first two stations. Moreover the first two stations are characterized by the similar level of average and the same time high level of TP concentration [mg/l]. The similar situation is in the case of the station number 14. The remaining stations (between 3 and 13) are relatively less differentiated.

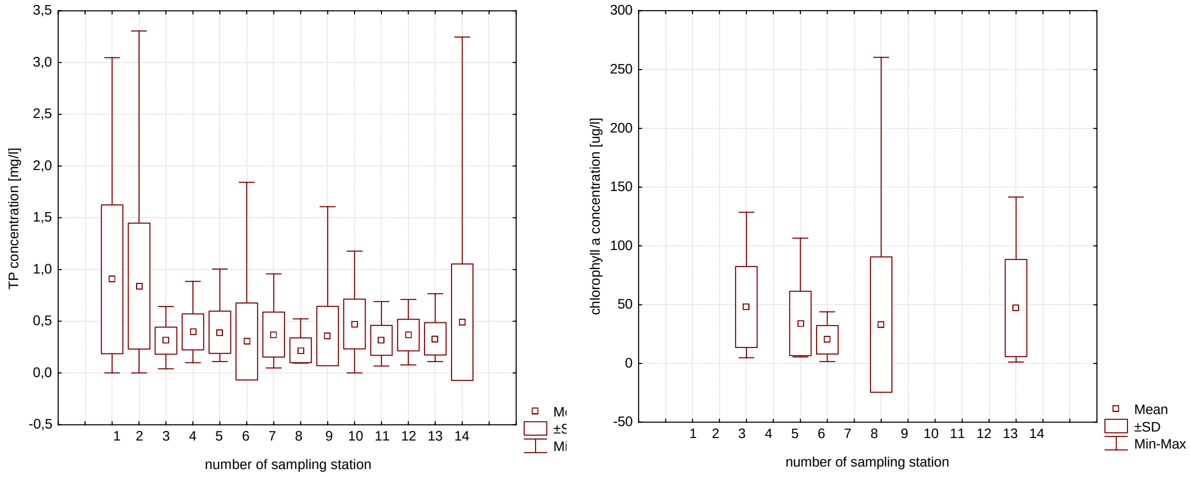

Figure 3: Total phosphorus (at river and reservoirs) and chlorophyll a (reservoirs only) concentrations at Sokołowka.

Annual average TN concentrations in river were between 2.57 and 7.34 mg/l, and maximum values of 18.9 mg/l occurred at Station 4, whereas in reservoirs were between 1.53 and 2.46 mg/l, and maximum values reached 14.6 mg/l at Station 5. The situation in the case TN concentration [mg/l] is much more differentiated. The difference between average level are higher and the distance between minimum and maximum value are larger. The results indicate that average concentration of total nitrogen and total phosphorus were higher in the Sokołowka River then in reservoirs situated on river (decreased in reservoirs but increased in river between reservoirs).

The highest nutrient concentrations were observed at first and second sampling stations along the river in the typically municipal area. The high levels of nutrients in urban area can arise from a variety of potential sources including septic tank seepage, combined sewer overflows or sanitary sewer overflows.

The main aim of this demonstration projects is established hierarchy of parameters influencing on enhance carrying capacity of existing reservoirs against eutrophication symptoms. Through regulation of the water dynamics in the various parts of a river basin, we can influence its hydrokinetic processes, physical-chemical properties, and in consequences biota dynamics.

Reservoirs situated at the Sokolowka River differ from each other in their properties: diversity of reservoirs age, the light intensity, and quantity of the external nutrient supply. It is able to observe how different ecosystem reacted to stress. Despite of the highest external load at Station 3, the chlorophyll a concentration spanned a similar range as the rest of reservoirs. In this long, old reservoir located at the park, phytoplankton growth was limited by isolation and high pressure of zooplankton. The lowest chlorophyll concentration was observed at Station 6, which can be explained by high density of macrophytes in this reservoir of several years. Whereas the maximum of chlorophyll concentration was observed at Station 8, which resulted from accumulation phytoplankton bloom transported from Station 6 by stormwater.

One of function of reservoirs cascade is improving water quality in the Sokolowka River. Obtained primary results appear to confirm this hypothesis. The TP and TN concentrations decreased after flowing across reservoirs. The highest reduction of nutrient concentrations was observed at first reservoir at Station 3. The TP concentration of 0.77 mg/l at Station 2 was reduced to 0.30 mg/l at Station 3. Stormwater outlets located between the reservoirs, contribute to further decreasing water quality.

4.2. The Ner River and WWTP

Traditional sewage treatment plants often do not possess sufficient efficiency and face high costs of construction and exploitation which has to be carried by local communities. Extending the sewage treatment by constructing willow plantations and wetlands results in more efficient reduction of pollutant loads and sludge utilization problems and generate additional benefits. Implementing willow plantations may reduce problem of sewage sludge utilization and may contribute to water quality improvement (if applied in constructed wetland systems). Additionally, it provides alternative sources of energy (bioenergy) and thus revenue for local economy while reducing outflows of capital for fossil fuel use. The production of bioenergy can result with quicker return of the invested capital through a short rotation time of the plantation and high planting density. The preliminary calculations shows, that wood chips from short rotation forestry (SRF) of the area to be established in the project, can cover the energy needs for municipal buildings in the City of Lodz and eliminate problem of sewage sludge utilizing (Bocian, 2004). In the case of the Lodz City, high concentration of heavy metals in the sewage sludge, restricts possibility of it's application in the field, unless their concentration has been decreased in the source. It is also necessary to investigate the efficiency of heave metals remediation by plants, which was one of the goals of the study.

The highest concentration of heavy metals for the sludge sample was noted for Zn, Cu, Ni, Pb and Cr. This results from high loads of these compounds in sewage derived from some industrial companies and transport pollution. Figure 3 shows the concentrations of Zn, reaching values of about 1732 mg/kg d.w. The content of Hg was the lowest: the average value was about 3,9 mg/kg d.w. (Fig. 8).

Both in the soil and plant samples, the highest concentration of heavy metals were detected for Zn and Pb. The range of heavy metals total content in willow tissues (branches) was between 42,95 mg/kg d.w ÷ 35,84 mg/kg d.w. (Fig. 4). The values differed between species.

The efficiency of heavy metals uptake by plants was analyzed based on the relationship between the initial content in the soil (CS_0) and it's increase in the plant tissues (CV_1). The highest rates were observed for Pb, Cd and Zn (Fig. 5). The absorption rate depended on the initial heavy metals quantity in the soil and absorbing capacity of plants.

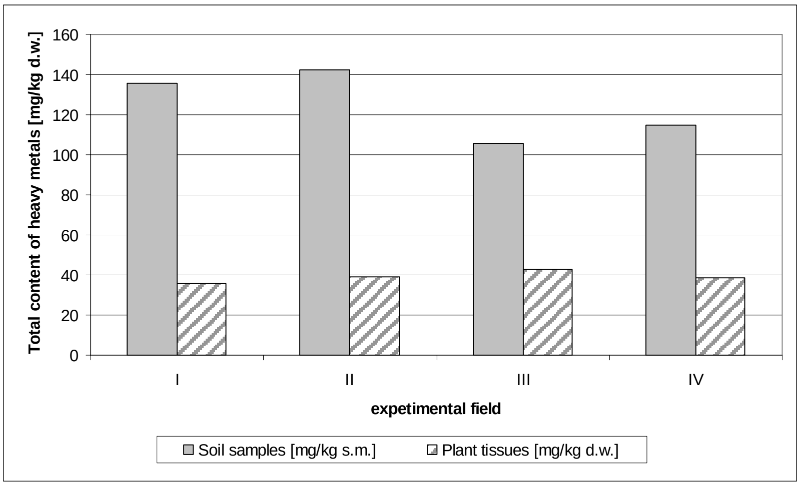

Figure 4: The average content of the total heavy metals in the plant tissues and in the soil samples on the four analyzed area with different clones of energetic willow

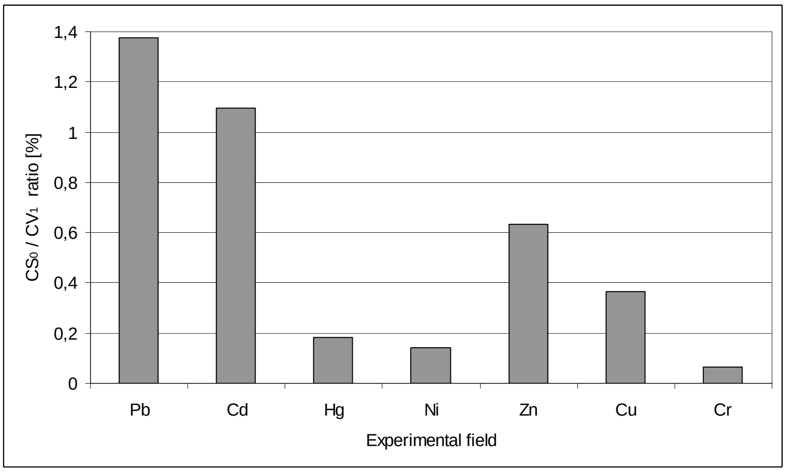

Figure 5. The efficiency of heavy metals uptake of by willow energetic from soil.

Energetic willow plantations, except for providing alternative source of bioenergy, what is concordant with of the Directive on the promotion of electricity produced from renewable energy sources in the internal electricity market (77/2001/EC), may improve the quality of the environment, contribute to reduction of the sewage sludge utilization issues and contribute to economic equation of the treatment plant operation. However the differences in biomass production, heavy metal remediation and survivability between the varieties of willow shows, that for achieving ecological and economic effects, selection of a variety best adapted to local conditions is of crucial importance. The estimation of the actual efficiency of the plantation will also require integration of the ecological effect (incl. efficiency of the area reclamation) and economical effect (including bioenergy production), as well as further estimation of the ecological effect. The future study will include evaluation of the soil microorganisms activity (soil metabolisms, Platen &Wirtz, 1999), role of rhizosphere (rhizotron, rhizobox), soil toxicity (Phytotoxkit Tigret, Microtox) and evaluation of the overall heavy metals and energy balance.

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