CONTAMINATION OF THE ROOT VEGETABLES WASH WATER AND ITS TREATMENT EFFICIENCY

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Growing volume of washed vegetables in Europe and Lithuania means that more drinking water is consumed and more wastewater is produced. Farmers, who engage in washing vegetables, face the problems of wastewater treatment, wastewater storage and utilization. Wastewater released to the environment from their farms would meet hygiene and environmental protection criteria. The aim of the study was to assess the contamination of the root vegetable wash water and to evaluate the possiblity of cleaning of wastewater in the land-based treatment system consisting of one constructed wetland and two biological ponds. The contamination of wastewater, produced by washed root vegetables, in Lithuanian farms was measured according to suspended solids (SS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen and total phosphorus. Pollution of the wash water and wastewater was evaluated comparing the mean values with legislative limit values and with typical sewage contamination values. In all farms wastewater of initial root vegetables washing was treated in settling basins. Wastewater of one carrots washing farm was treated in the land-based wastewater treatment system consisting of surface flow constructed wetland and two biological ponds. Efficiency of the wastewater treatment in this system was according to suspended solids 90%, BOD_7 – 97%, COD_{Cr} – 92%, total nitrogen – 98% , total phosphorus – 97%. The result shows, that the natural wastewater treatment system is suitable for farms, that wash and produce vegetables, but before releasing wastewater to the environment, it has to be settled.

Keywords: root vegetables, treatment efficiency, wash water.

INTRODUCTION

Increasing supply of the washed and „ready to eat" vegetables to the market causes issues of the huge volumes of fresh water used and large quantities of wastewater generated in the processing that requires special treatmen for the vegetable producers. For washing of different kinds of vegetables 2.4 - 11 m^3t^{-1} of water is used (Olmez, 2013). Finnish researchers report lower quantities. In their tested facilities, 1.5 to 5 m^3 of water was consumed for 1 tonne of finished product. Total water consumption was higher in plants where the vegetables were completely treated and lower, where washing and packaging were carried out (Lehto et al., 2014).

Wash water of the root vegetable contains soil particles, peels and other organic materials, also pesticide residues and pathogenic microorganizms (Mebalds, Hamilton, 2002; Kirby et al., 2003; Henze, Comeau, 2008; Olaimat, Holley, 2012; Alohali, 2015). Commonly the root vegetables washing process consists from several steps (Fig. 1). The first step is dry removal of soil which efficiently reduces amounts of soil particles in the washwater wastes. The initial washing usually is performed in a batch tank. Polishing stage usuallly is aplied for futher cleaning of the root vegetables in order to remove soil residuals and the upper skin if it is neccessary. The last step before packaging is a final wash. In this step clean potable water always is used in order to ensure food safety. The reuse of wash water waste from later step could be applied for the initial first wash step after appropriate treatment when reducing chemical and microbiological contamination to the appropriate level (Rozema, 2016; Mebalds, Hamilton, 2002).
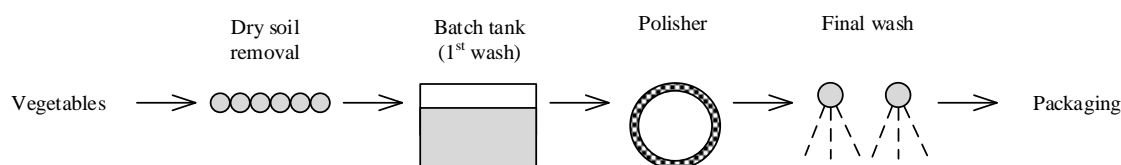

Figure1. Principle flowchart of root vegetable washing process (HMGA Water Project, 2015)

There does not exist the only one efficient method in washwater wastes treatment as it depends on various factors, such as step of the waste water treatment process, futher usage of washwater wastes or discharge waste water to the natural water bodies, also soil texture and amount, contamination level of wastes and their composition.

Settling can reduce suspended solids amounts up to 80%. Results of studies showed that settling (solid removal) was effective only for vegetables washwater waste what contained big amount of coarse particles of sand, peels and other large particles of the organic mater, but was ineffective for waste water containing colloidal particles, clay and dissolved solids. Coagulation and flocculation can significantly increase removal efficiency of the colloidal particles and solids from various wash water. Dissolved air flotation could be floating materials such as charged organic materials removal from the wash water (Zytner, Warriner, 2016).

Usually vegetables producing farms are located in rural areas, natural treatment technologies such as constructed wetlands (CW), biological ponds are suitable for treatment of its wash water. Land-based treatment systems are relatively inexpensive and low-maintenance option to compare with technical treatment systems. Also operation of such systems is low-cost. Their are used widely in agricultural manufacture, such as wastewater from dairy milk houses (VanderZaag et al., 2010; Wood et al., 2015; Rozema et al., 2016), piggeries (Stone et al, 2004; Poach et al., 2004). Bosak et al. (2015, 2016a, 2016b) reported on the performance of different types of land-based systems for treatment of potato farm wash water. Navaro et al. (2013), Puchlik (2016) analysed the treatment of wastewater of fruit and vegetable processing in constructed wetlands. Soroko (2003, 2007, 2011) investigated efficiency of treatment of wastewater from small fruit and vegetable processing plants in CW.

After demand for washed vegetables arose in Lithuania, farms that wanted to realise their production and remain competitive had to install vegetable washing systems. Growing volume of washed vegetables means that more drinking water is consumed and more wastewater is produced. Farmers who engage in washing vegetables face the problems of wastewater treatment, wastewater storage and utilization. Vegetable washing and processing farms in Lithuania are mostly located in the non-urbanized areas without any access to sewerage and sewage treatment plants. Many farms that wash root vegetables produce insufficiently treated and requiring the more efficient treatment wastewater, which is spread out on the fields in warm period, but is discharged into the surface waters in cold period.

The aim of the study was to assess the contamination of the root vegetable wash water and to evaluate the efficiency of the land-based treatment system of constructed wetland and biological ponds.

OBJECT DESCRIPTION

The four large farms that washed root vegetables such as carrots and beetroots were chosen in different areas of Lithuania. These farms use semi-recycled wash water systems as used wash water is transfered to the settling pond or settling tank. Settled in the pond (tank) wash water continues to be used for the 1st wash and at the first step of the polishing. The potable water is used for the final wash of vegetables (Fig. 2). As a certain amount of excess water is consistently generated, it is stored in the pond and spread out on the fields in warm period.

For washing of root vegetables at the 1st stage recirculating water from settling pond was used: 22 m^3t^{-1} for beetroots, 70 m^3t^{-1} for carrots and as well as 10 m^3t^{-1} for carrots from settling tank. For the 2nd wash – drinking water from wells was consumed (4 m^3t^{-1}, 7 m^3t^{-1} and 2 m^3t^{-1} respectively).
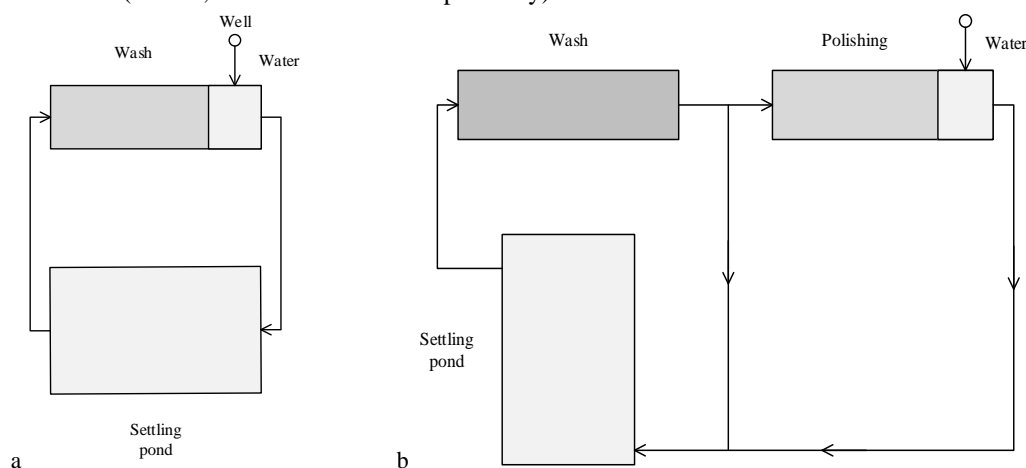

Figure 2. Principle flowchart of root vegetable washing process: a – beetroots, b - carrots

One of the investigated carrots washing farms has the land-based treatment system consisting of surface flow constructed wetland and two biological ponds. There the water from the settling tank is discharged to the pond, then it is supplied to surface flow CW with marsh vegetation, and finally, discharged into the second pond (Fig.3).
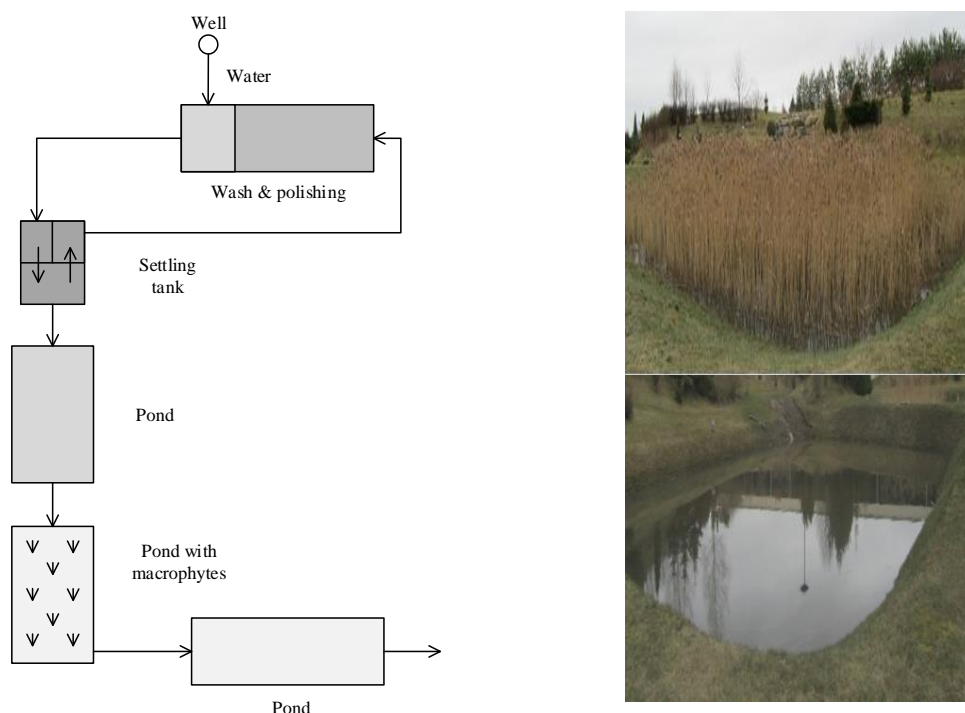
Figure 3. Principle flowchart of the carrot washing and land-based wastewater treatment system consisting of surface flow constructed wetland and biological ponds and their general view

Samples of root vegetable wash water were taken at all stages of the processing activity and wastewater treatment for a total of 12 visits over a one year period. The collected samples were analyzed for water quality parameters.

METHODOLOGY

Samples of wash water and wastewater were collected monthly according the standartized methodologies in 2016.

Chemical analysis was performed acoording approved methodologies and standards: BOD_7 was evaluated according oxygen consumption measured by by oximetric method (ISO 5815-1:2003; ISO 5814:2012), $ChDS_{Cr}$ – by titrimetric oxidimetric method (ISO 6060:2003; ISO 8467:2002); pH and electrical conductivity (EC) - by potentiometric and conductometric methods (ISO 10523:2008; ISO 7888:1985); total P - spectophotometrically at the wavelenght 390 nm) (ISO 7887:2011); Kjelhdal nitrogen – by cathalytic oxidation with analyzer TOC-V, Shimadzu, Japan (EN 1484:1997; ISO 8245:2000; EN 12260:2003, BS 6068-2.83:2003; ASTM D7573 – 09).

Results of the analyses were processed by statistical methods. Contamination of the wash water and wastewater was evaluated comparing the mean values with legislative limit values and with typical sewage contamination values.

Wastewater treatment efficiency was calculated in terms of concentration reductions (Regulation..., 2006):

$$E = \frac{C_{in} - C_{out}}{C_{in}} \cdot 100\% \tag{1}$$

where C_{in} and C_{out} were the concentration of a given contaminant in the inflow or outflow sample, $mg \cdot l^{-1}$.

RESULTS AND DISCUSSION

Root vegetables waste water contamination depends on the level of dirt on the washed vegetables, used washing process and waste water treatment scheme. Vegetable wash water is contaminated the most by organic compounds during their processing (polishing, peeling). Vegetable processing wash water BOD makes up of around 90% of all BOD during vegetable preparation to the market (Mundi et al., 2015). Due to large amounts of organic compounds, it causes not only increase in BOD, but also increase in amounts of phosphorus and nitrogen (Lehto et al., 2014).

Analysis of root vegetable wash water was taken at all stages of the processing activity according to main indices in selected Lithuanian farms. The mean values and range of the carrots and beet root wash water contamination indices at the washing and polishing steps were compared to the typical mean values and legislative limit values (Table 1).

Waste water released to the environment must have neutral or basic pH. Analysed beetroot wash water pH was neutral (pH 6.85-7.64), such waste water can be released to the environment (Regulation..., 2006). Carrot washing and polishing water medium varied from acidic to neutral (pH 4.30 - 7.77). Acidic waste water must be neutralised before releasing to the environment.

Table 1. Mean values and range of the carrots and beet root wash water contamination indices at the washing and polishing steps, typical mean values, and limit values

Quality indices	Carrots wash water		Carrots polishing water		Beet root wash water		Typical values [1,2,3]	Limit values [4,5]
	Mean	Range	Mean	Range	Mean	Range		
pH	6.04	4.30 - 7.77	5.9	4.68 - 7.12	7.25	6.85-7.64	7.5	6.5-8.4* 6-9**
Electrical conductivity, $\mu S \cdot cm^{-1}$	943.5	698-1189	1027	530-1524	1009.5	805-1214	1000	700*
Suspended solids, $mg \cdot l^{-1}$	3898	196 -7600	692.5	296 -1089	1269	88-2450	1475 (850- 2100)	25**
BOD_7, $mg\ O_2 \cdot l^{-1}$	708	297-1119	2368	740-3996	279.5	179-380	1050 (400-1700)	34* 4-6**
COD_{Cr}, $mg \cdot l^{-1}$	2509.5	393-4626	2125	830-3420	458.5	178-739	3275 (650-5900)	125*
Total nitrogen, $mg \cdot l^{-1}$	32.5	4-61	13.5	2-25	34	6.9-61	33.5 (6-61)	20*
Total phosphorus, $mg \cdot l^{-1}$	9.6	0.2-19	1.8	0.1-3.5	6	1-11	17.5 (6-29)	2*

*Discharge to the surfase water bodies, ** in surface water bodies
[1] Lehto et al., 2014; [2] Mundi et al., 2015; [3] Metcalf, Eddy, 2003.
[4] Regulation on Wastewater Treatment, 2006; [5] Description of protection requirements for surface water bodies where can live and breed freshwater fish, 2005.

Electrical conductivity (EC) shows total ions concentration in the solution and its salinity. Drinkable and mineral water EC must be up to 2500 $\mu S \cdot cm^{-1}$ according to Hygiene Norm of Lithuania HN 24:2003 standards (Hygiene..., 2003), and for field watering water – up to 700 $\mu S \cdot cm^{-1}$ (PSO/FAO, 1985). Analysed root vegetables wash water EC did not exceed HN 24:2003 norms, however, field watering water salinity exceeded PSO/FAO norm. Electric conductivity of waste water increases in large magnitude when salts and acids are used in vegetable processing. Table salt sodium ions have a negative impact on soil quality and destroys clay coloid particles.

Wash water of root vegetables, and particularly of carrots, was highly contaminated by sunken materials. It exceeded regular contamination levels 2.5 times. Lowest sunken materials concentration has been observed in wash water after polishing, because at this stage potable water was being used.

Contamination by easily dividable organic compounds is shown by biochemical oxygen demand BOD. According to BOD_7 parameter root vegetables wash waste water are defined as moderately contaminated while carrots polishing waste water – to very contaminated – waste water treatment reglament threshold (34 $mg \cdot l^{-1}$) was exceeded 70 times. Carrot polishing waste water BOD_7 parameter was 3 times larger than wash waste water. This indicated high contamination by organic compounds during washing, what creates good conditions for microorganisms growth. Washing beetroots less small and soluble organic materials are produced because root vegetable peel is not damaged.

Waste water treatment reglament provides boundary COD_{Cr} value as 125 $mg \cdot l^{-1}$ which was exceeded up to 20 times (carrot wash water). COD shows waste waters contamination with all – both easily disolvable and stable organic materials.

Total nitrogen concentration in carrot and beetroot wash water exceeded the boundary value (20 $mg \cdot l^{-1}$) approximately two times, while total phosphorus (2 $mg \cdot l^{-1}$) in carrot wash water exceeded the boundary 5 times, beetroot – 3 times (Regulation..., 2006). However, it was determined that only a trace of these elements mineral compounds were present, what suggests that nitrogen and phosphorus are in constitution of organic materials.

The main objective of primary wash water treatment is to remove hard particles and for organic material contaminants a biological treatment is required (Casani, Knøchel, 2002; Lehto et al., 2014).

As it is evidant from the data root vegetables wash water is excessively contaminated by sunken and organic materials, therefore such water cannot be recycled without further treatment and be released to the environment. After carrying out analysis of wash water technologies in Lithuanian vegetable farms, it was determined that extensive treatment methods were used, based on native water treatment methods and systems: settling ponds and tanks, constructed wetlands, biological ponds. The products are finally rewashed with potable quality water.

Efficiency of root vegetables wash water settling and treatment in land-based system was calculated.

Results of settling efficiency of vegetables wash water according to SS, BOD_7 and COD are presented in Fig. 4.

It has been determined that by treating root vegetable waste water in settling ponds, suspended solids were deposited very well. Settling tank SS treatment efficiency was 2–2.5 times smaller due to smaller surface of the container when comparing to ponds (see Fig. 4). BOD_7 was treated not with sufficient efficiency, likely because organic materials are dissolved. Beetroot COD treatment efficiency was small because their wash water was dominated by mineral particles since beetroots are not polished or peeled. Phosphorus containing compounds precipitate, therefore a part of it can be removed by settling (20–40 %).
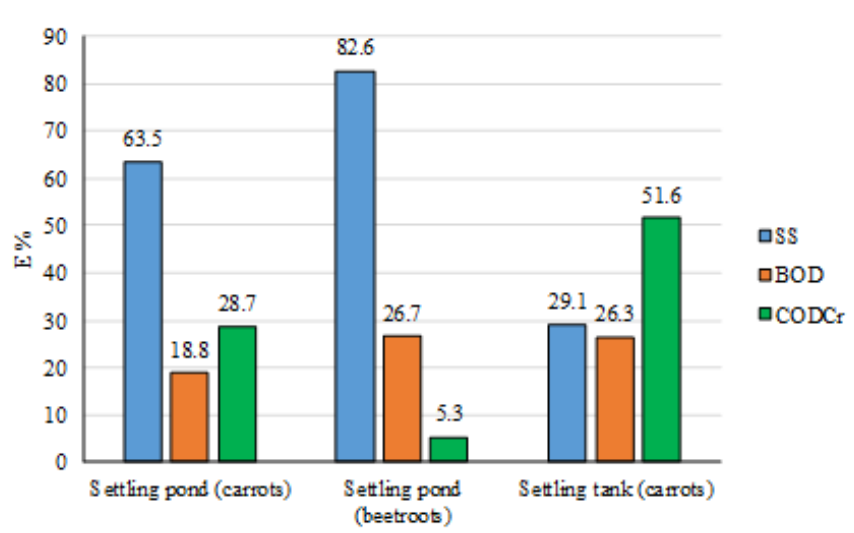
Figure 4. Treatment efficiency of carrots and beetroots wash water in settling ponds and settling tank

Treatment efficiency of carrots washwater in three stages of land-based system – surface flow constructed wetland and two biological ponds according to COD and suspended solids is presented in Figure 5.
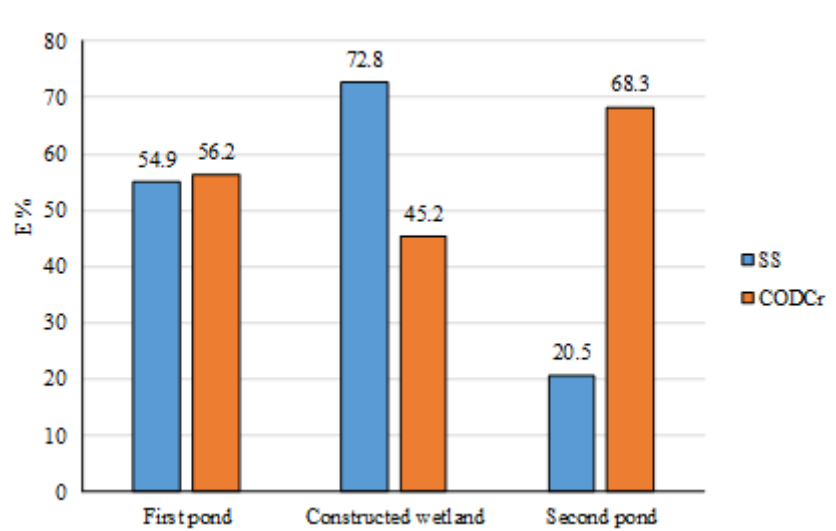

Figure 5. Treatment efficiency of carrots wash water in the surface flow constructed wetland and biological ponds

Total wastewater treatment efficiency of all land-based system (surface flow constructed wetland and two biological ponds) was according to SS 90 %, BOD_7 – 97 %, COD_{Cr} – 92 %, TN – 98 % , TP – 97 %. However, the pollution of outlet from the treatment system by suspended solids still was high (333 mg·l^{-1}) and exceeded 13 times the norm equated to natural surface water bodies (25 mg·l^{-1}). Pollution of influent by nitrogen and phosphorus to the land-based system was low (average TN – 5 mgN·l^{-1} , TP – 2 mgP·l^{-1}), therefore these materials were fully removed in the system.

Effective wash water treatment in settling tanks and native systems were suggested by other authors. In Canada (Ontario state) a multisectioned potato wash water treatment system was used, containing primary treatment section (settling and aeration) and secondary treatment section (constructed wetlands) (Bosak et al., 2015; 2016). Wash water contamination was: according to BOD_5 – 1121 and 558 mgO·l^{-1}, SS – 5234 and 3600 mg·l^{-1}, TN – 222 and 136 mg·l^{-1}, TP – 23.4 and 42.6 mg·l^{-1} accordingly to the first and second year. Due to larger than expected contaminated wash water loads in the first year, treatment system volume was increased from 740 m^3 to 1650 m^3. Sytem efficiency data was obtained: according to BOD_5 – 95 and 99 %, SS – 98 and 99 %, TN and TP – 77 and 99 %, accordingly to the first and second year.

Quality of carrots wash water was studied at the treatment system consisting of the grit chamber, the settling tank and the constructed wetland. On average the efficiency of total COD reduction was 52 % (Kern et al., 2006).

Polish scientists now more than a decade are analysing native systems practical use in vegetable and fruit washing and the recyclability of the wash water. Horizontal and vertical plants ground water filter treatment efficiency was assessed (Soroko, 2003; 2011). Waste water contamination varied from 1500 to 11 800 mg O_2·l^{-1}.

Constructed wetlands with the horizontal subsurface flow also showed acceptable quality values of the treated waste water at the output (Soroko, 2003; 2011; Navarro et al., 2013; Puchlik, 2016). Efficiency of the organic matter removal there varied in the range from 34 to 67 % for BOD_5 and from 31 to 64 % for COD_{Cr} depending on the loading

rates and composition of the organic substances. The constructed wetland with vertical flow revealed a reduction in the value of the BOD_5 in the range from 68.2 % to 86.9 % while COD_{Cr} – from 79.3 % to 82.6 %, and total P removal efficiency was 60.2 % (Soroko, 2003; Puchlik, 2016).

There is none constructed wetlands design that is the most effective for agricultural wastewater, but each design has strengths and weaknesses so hybrid designs may prove to be the most practical (Rozema et al., 2016; Strusevičius et al., 2006; Gasiūnas, Strusevičius, 2005).

CONCLUSIONS

Wash water of carrots is more contaminated as of beetroots due to polishing, wastewater of the vegetables processing is contaminated even more. This causes a larger risk microbiological contamination. For the final root vegetable washing, deep water well water needs to be used and its quality must be within the norms of potable water quality.

Wash water analysis showed that the environment was affected by recirculation systems wastewaters BOD, amount of suspended particles, nitrogen, phosphorus.

Root vegetable wash water are treated with sufficient efficiency by natural methods. Efficiency of the wastewater treatment in the land-based system of surface flow constructed wetland and two biological ponds was according to suspended solids 90 %, BOD_7 – 97 %, COD_{Cr} – 92 %, total nitrogen – 98 %, total phosphorus – 97 %.

The pollution of outlet from the treatment system by suspended solids still was high and exceeded the norm equated to natural surface water bodies. For treated waste water to be released to the environment, there needs to be an increase in the efficiency of treatment of suspended solids.

Further research of the wastewater treatment efficiency have to be performed in the constructed wetlands and biological ponds as efficient treatment technology of vegetable wash water.

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