

Simulating of Nickel Phytoextraction from Contaminated Soils under Salinity Condition Using *Alyssum Murale*

Parastou Malzoumi¹, Mohammad Reza Dallaliyan^{2*}, Elnaz Sabbagh Tazeh³

¹M.S. Student; Department of Agriculture, Faculty of Soil and Water, Tabriz Branch, Islamic Azad University, Tabriz, Iran

²Assistant Professor; Department of Agriculture, Faculty of Soil and Water, Tabriz Branch, Islamic Azad University, Tabriz, Iran

³ Lecturer; Department of Agriculture, Faculty of Soil and Water, Tabriz Branch, Islamic Azad University, Tabriz, Iran

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ABSTRACT

Nickel (Ni) is the most dangerous heavy metals which at high concentrations are toxic to plant and threatening to the health of living organisms and human beings. Phytoremediation is an environmental technology and a cost-effective technique which can detect heavy metal resistant plant species and refine the soil with this method. The country has a wide range of saline soils. Plants tolerant to salinity mainly due to anatomical and physiological conditions can handle high salt concentration. The objective of this study was simulating of nickel phytoextraction from contaminated soils under salinity condition using *Alyssum murale*. Therefore, a model based on the behavior of nickel contaminant in soil and plants were used. Soils were salted with three treatments of salinity (1, 4 and 8 ds/m). *Alyssum murale* seeds were germinated in the pots containing 7.5 kg of contaminated soil. Plants were harvested at three different time periods. The results indicated that soil adsorption isotherm for nickel follows the linear model. The phytoextraction rate of nickel by *Alyssum murale* in EC=1 is zero-order function, EC=4 and EC=8 are first-order homographic function of nickel concentration in soil, respectively. The phytoextraction rate of nickel by *Alyssum murale* shoot in EC=1 is zero-order function, EC=4 and EC=8 are first-order homographic function of nickel concentration in soil, respectively. According to *Alyssum murale* hyper accumulator and more tolerant of high concentrations, uptake by plants decreased with increasing salinity. Therefore, the plant has the ability to grow in saline conditions but with increasing concentration of nickel in soil salinity, growth and nickel uptake by plants was reduced.

KEYWORDS: Soil pollution, Phytoextraction, Nickel (Ni), Salinity and Simulating

1. INTRODUCTION

Degradation and environmental pollution is the result of industrial societies and human society's industrialization [1]. Soil and water resources are precious and sensitive in environment, vulnerable to incorrect administration [2, 3]. Soil due to the complexity of ecological systems is open to a variety of toxins and pollutants [4]. In a classification, sources of pollutant are divided into two categories: point which has a centralized point and usually contains high concentrations of pollutants and non-point which contains lower concentration and wider dissemination range [5]. Currently non-point pollutant sources are considered as the most important factors of water and soil pollution on a global scale, agriculture and transportation have a major role in creating this type of pollutants [6]. The most significant soil contaminants include heavy metals, acid rain and organic materials, heavy metals in recent years due to their chemical properties in soil have been studied intensely. Heavy metals due to non-biodegradable and harmful physiological effects to organisms at low concentrations are of particular importance in environmental pollution [7]. Mobility of heavy metals in soil is low in comparison with other pollutants, so some of these metals after entering to soil become immobile or due to the formation of the sediment phase is accumulating in the environment. Thus, the potential risks of heavy metals to human health and animal are exacerbated in the long-term periods [8]. The most common heavy metals in polluted areas are cadmium, lead, chromium, copper, mercury, nickel and zinc [9, 10]. Nickel as heavy metals, at low concentrations has no toxic effect on plants, but at high concentrations is toxic to plants, more than 50% nickel uptake by plant roots is maintained [11]. Nickel through food, drinking water, inhalation and skin absorption can enter the body, and its high concentrations can cause respiratory problems and decrease immune system of organisms' bodies [12, 13]. Plants that grow in soils rich in metals, due to their high capacity in storage of metals are used as a means to remove heavy metals from the soil. For this reason, researchers have recently developed a novel method to refine ecosystem by using plants called Phytoremediation [14]. Phytoremediation is a technology that can be used to identify metal resistant plant species that are able to accumulate heavy metals and refine the soil with this method [15-17]. Phytoremediation is an environmental and economic technique that is useful for developing countries such as Iran and is considered as a valuable trade [18]. This technology by using the sun's energy, plants and their

*Corresponding Author: Mohammad Reza Dallaliyan (Assistant Professor). Department of Agriculture, Faculty of Soil and Water, Tabriz Branch, Islamic Azad University, Tabriz, Iran; Email: mdalalian@gmail.com

associated rhizosphere microorganisms, removes or decomposes heavy metals such as nickel in soil, sediments, groundwater or surface waters or pollutants in atmosphere [19, 20]. One of the methods of phytoremediation is phytoextraction which is using of metal accumulating plants to absorb metals from the soil and transfer them to shoot [21]. Salinity is one of the most important factors that reduces and sometimes eliminates herb in semi-arid and arid areas [22]. There are highly saline soils in arid and semiarid regions of the world, where this kind of weather can hinder growth and crop yields. Due to the arid and semiarid climate of Iran, nearly 50 percent of cultivated crops are facing various degrees of salinity and alkalinity problems [23]. Levitt (1980) used the term resistance to salt in its broad sense to include salinity tolerance and avoiding salt. In his view, salt tolerance, is obtained when the plants which accumulate salt through special cells such as tumor cells or normal saline react to salinity. Several studies on heavy metals accumulating plants were carried out by researchers. Tapperro *et al.* (2009) studied the interactions of nickel and manganese concentration in nickel hyper accumulation leaves in Alyssum (*A.murale* and *A.corsicum*), the results showed nickel extraction by Alyssum will be reduced with increasing the availability of manganese in plant and Suggested that the nickel hyper accumulation by Alyssum will more likely increase by a manganese transmission system. Today, the use of mathematical models in Phytoremediation of soils contaminated with heavy metals is of value in the identification of Phytoremediation processes and management of contaminated areas [24]. The study was conducted by researchers in this field. Khodaverdi Lu and Homaei (2008) provided models for cadmium and lead using cress and spinach plants that were easily measured parameters and on the other hand include a number of sub-processes of dominant phenomenon. Dallaliyan and Homaei (2011) provided models for cadmium and copper using *Salvia officinalis*. Mahmoudi *et al* (2012) provided models for nickel and lead using Mountain Alyssum. The advantage of Phytoremediation is that it's a green technology and if done correctly it will be both more compatible with the environment and more pleasant for the public in terms of aesthetics. In Phytoremediation there is no need to expensive equipment and specialized staffs and its implementation is relatively simple. This technology can permanently refine a wide range of contaminants in large areas. However, the main advantage of Phytoremediation is its low cast compared with other conventional methods [25]. The objective of this study was simulating of nickel phytoextraction from contaminated soils under salinity condition using *Alyssum murale*.

2. MATERIAL AND METHODS

Modeling Phytoremediation

Model assumptions used in estimating time required for the refining pollutants by plants is provided briefly.

If Phytoremediation rate of pollutant is considered as the amount of pollutant that the plant refines per unit time per unit volume of soil, then:

$$r_o = \frac{d(S\rho_b + C\theta)}{dt} \quad (1)$$

Where r_o ($ML^{-3}T^{-1}$) is Phytoremediation rate of pollutant and t (T) is the time. If Phytoremediation rate of pollutant is so slow that there is a balance between pollutant concentrations in the solid and its concentration in the soil solution, the C and S through soil distribution coefficient K_{SD} (L^3M^{-1}) will connect.

$$K_{SD} = \frac{S}{C} \longrightarrow S = K_{SD} C \quad (2)$$

Soil distribution coefficient is obtained from soil adsorption isotherms.

Assuming θ to be constant by putting equation (2) in (1), then:

$$dC = \frac{r_o}{(K_{SD}\rho_b + \theta)} dt \quad (3)$$

If it takes integral of the differential equation (3), the bound of $C = C_o$ to $C = C_f$ and $t = 0$ to $t = t_r$, then:

$$\int_{C_o}^{C_f} dC = \frac{r_o}{(K_{SD}\rho_b + \theta)} \int_0^{t_r} dt \quad (4)$$

Where C_o : pollutant concentrations at the beginning of the refinement ($M.M^{-1}$), C_f : concentration of contaminants in the soil after the time t_r or arbitrary concentration ($M.M^{-1}$) and t_r : time to refine (T) is.

To determine that r_o is what function of C , In other words, what changes Phytoremediation rate of pollutant (r_o) will make with the changes in pollutant concentrations (C). For this purpose, four kinetic functions (zero-order, first-order function, the first-order homographic function and the second order) should be tested and by placing it instead of r_o , the time required for refining pollutants can be achieved. If r_o is zero-order function of C , r_o will not change by changing of C . Thus, Phytoremediation rate of pollutant is constant, so:

$$r_o = -\frac{\Delta C}{\Delta t} = K_o \longrightarrow r_o = -K_o \quad (5)$$

By inserting the equation (5) in equation (4) and integration of the bound of $C = C_o$ to $C = C_f$ and $t = 0$ to $t = t_r$, then:

$$t_r = \frac{(K_{SD}\rho_b + \theta)}{k_o} (C_o - C_f) \quad (6)$$

Where: K_o is a plant-dependent coefficient and equal to negative value of Phytoremediation rate of pollutant ($ML^{-3}T^{-1}$).

If r_o is first-order function of C , then:

$$r_o = -\frac{\Delta C}{\Delta t} = K_1 C \longrightarrow r_o = -K_1 C \quad (7)$$

By putting the equation (7) in equation (4) and integration of the bound of $C = C_o$ to $C = C_f$ and $t = 0$ to $t = t_r$, then:

$$t_r = \frac{(K_{SD}\rho_b + \theta)}{k_1} \ln \frac{C_o}{C_f} \quad (8)$$

Where: K_1 is a plant-dependent coefficient (T^{-1}).

If it considers the relation between r_o and C as a first-order homographic function that is the filtration rate increases with decreasing of concentration, then:

$$r_o = -\frac{\Delta c}{\Delta t} = \frac{k_2}{c} \rightarrow r_o = -\frac{k_2}{c} \quad (9)$$

By putting the equation (9) in equation (4) and integration of the bound of $C = C_o$ to $C = C_f$ and $t = 0$ to $t = t_r$, then:

$$t_r = \frac{(K_{SD}\rho_b + \theta)}{2k_2} (C_o^2 - C_f^2) \quad (10)$$

Where: K_2 is a plant-dependent coefficient ($M^2L^{-6}T^{-1}$).

If it considers r_o as a second order function of C :

$$r_o = -\frac{\Delta C}{\Delta t} = K_3 C^2 \longrightarrow r_o = -K_3 C^2 \quad (11)$$

By putting the equation (11) in equation (4) and integration of the bound of $C = C_o$ to $C = C_f$ and $t = 0$ to $t = t_r$, then:

$$t_r = \frac{(K_{SD}\rho_b + \theta)}{k_3} \left(\frac{1}{C_f} - \frac{1}{C_o} \right) \quad (12)$$

Where: K_3 is a plant-dependent coefficient ($M^{-1}L^3T^{-1}$).

Coefficients K_o , K_1 , K_2 and K_3 in relations (5), (7), (9) and (11) can be acquired by making regressions. Time measured in soil phytoextraction can be obtained from the following equation:

$$t_r^m = \frac{1}{365} \sum_{i=1}^n \frac{(c_s^{i+1} - c_s^i)}{r_0^{i,j+1}} \rho_b \quad (13)$$

Where: t_r^m : time required for pollutant phytoextraction from soil by year, i : number of applied nickel contamination in the soil, n : number of levels that the distance between the two levels of soil contamination is considered a class. c_s^i : total concentration of nickel in the soil ($M.M^{-1}$) in contamination levels of i , $\rho_b (c_s^{i+1} - c_s^i)$: the total amount of Ni (ML^{-3}), which should be extracted so that soil reach to contamination levels of i from contamination level of $i+1$. $r_0^{i,j+1}$: average of nickel extraction rate measured by plant ($M.L^{-3}.T^{-1}$) for contamination levels of i and $i+1$ and the coefficient of 365 in the denominator for converting time from day to year.

Adsorption isotherms of nickel in the soil

To create the adsorption isotherms of nickel in the soil, 25 ml of a solution of nickel with concentrations equivalent to 50, 100, 150, and 300 $mg.kg^{-1}$ soils were prepared. By using nickel sulfate, solutions of nickel with a

concentration of 2, 4, 6, and 12 mg.l⁻¹ in solution of calcium chloride 0.1 molar were prepared. To prepare adsorption isotherms, one gram of dry soil was weighed on scales and was poured into 50 mL polyethylene centrifuge tubes and to each sample 25 mL of nickel solutions which was prepared at a specific concentration were added. After putting their lid, samples at a laboratory temperature of 25°C for 24 hours in a shaker were extracted (Zhou and Wong, 2001). After a period of time, the tubes were centrifuged for 25 min at a speed of 5000 rpm and the supernatant was cleared with Whatman filter paper 42 [34, 36]. After stirring the samples, nickel concentration was measured by atomic absorption spectrophotometer. With model fitting of linear, Freundlich and Lang Muir Adsorption isotherms on measured values of nickel adsorption at different concentrations of equilibrium solutions, soil distribution coefficient abbreviated (k_{SD}), was obtained [29]. Lang Muir model (14), Freundlich models (15) and the linear model (16) are as follows:

$$C_s = \frac{k_l C_l b}{1 + k_l C_l} \quad (14)$$

$$C_s = k_f C_l^{1/n} \quad (15)$$

$$C_s = K_{SD} C_l \quad (16)$$

C_s : amount of contaminant adsorbed per unit mass of soil (M M⁻¹), C_l : equilibrium solution concentration (M.L⁻¹), b : the maximum amount that can be absorbed, $1/n$: adsorption intensity of Freundlich model. K_{SD} , K_f and K_l : the sorption coefficient of the linear model, the Freundlich and Lang Muir (1.kg⁻¹).

Phytoremediation of nickel

In the study for Phytoremediation of nickel from contaminated soil, alyssum plant (*Alyssum murale*) was used. Experiments conducted on a soil with sandy loam non-contaminated with nickel or other toxic elements (to avoid unwanted stress treatment) and non-saline which was elected from the site of research station of Islamic Azad University of Tabriz, Faculty of Agriculture (located 10 km East of Tabriz) for experiments and in pots with a diameter of 22 cm and a height of 30 was carried out. Soil properties such as soil texture by hydrometer method, percentage of organic matter by oxidation, pH and EC by instrumental method, Field capacity moisture by pressure chamber method were determined based on USDA standards. To determine the weight of the dry soil used in the pots the bulk density was considered 1.4 g.cm⁻³ with respect to the distance of 4cm from the edge of the pot and the amount of soil in each pot was obtained 7.5. To apply salinity treatments to the three levels of less than one (Initial soil salinity), 4 and 8 dS/m, a non-saline soil was used. To apply salinity treatments, by using salt sodium chloride (NaCl) and calcium chloride (CaCl₂) with the same Eq ratio, we prepared water with 4 and 8 dS/m. Then the soil in the pots several times with prepared saline water was saturated to achieve the desired salinity. The level of pollution considering allowable concentration of nickel in the soil is 50 mg.kg⁻¹ of soil [38] 0, 50, 250, 500, 750 mg. kg⁻¹ of soil was considered. Then the salt concentration for nickel sulfate and 7.5 kg of soil were calculated and soil of pots was contaminated. The contaminated soil was left between the conditions of saturation and field capacity moisture for two weeks so that the interactions between pollutants and evolved soil and pollution situations become more natural. After two weeks, the contaminated soil was transferred to 135 pots (the three levels salinity*the three repeats*the one metal*the three time periods*the five Nickel Concentration). To avoid moisture stress, the pots at field capacity moisture content (by weight) were maintained. To avoid the drought stress of seeds planted per pot, short irrigation interval of 24 hours was considered. To reduce evaporation, the pots were covered with perlite. Also, to avoid any nutritional stress, nutrient solution based on Hoagland formula was added to the pot twice a week (regular rotation). Proportional to the growth stages, the plant samples were taken at three different periods (40, 70 and 100 days after planting). Plant samples were washed with distilled water and after measuring the fresh weight of roots and shoots dried at 65 °C for 48 h and weighed again to obtain weight and finally were milled. In this study, total nickel concentrations in plant measured by oxidation method (normal hydrochloric acid 1) and in soil by acid digestion method (4 molar nitric acid, hydrochloric acid and hydrogen peroxide) and Obtained by atomic absorption spectrophotometer [31]. Later by fitting models used in this study on the experimental data and determining the parameters of the model using regression, models to predict the time needed for refining soil contaminated with nickel under salinity levels were developed by plant Alyssum. The validity of the proposed models for estimating nickel refining will be evaluated by quantitative criteria such as the maximum error (ME), root mean square error (RMSE), coefficient of determination (CD), modeling efficiency (EF) coefficient of residual mass (CRM) [24, 26]

$$ME = \max |(T_i^p - T_i^o)|_{i=1}^n \quad (17)$$

$$EF = \frac{\sum_{i=1}^n (T_i^o - \bar{T}^o)^2 - \sum_{i=1}^n (T_i^p - \bar{T}^o)^2}{\sum_{i=1}^n (T_i^o - \bar{T}^o)^2} \quad (18)$$

$$CD = \frac{\sum_{i=1}^n (T_i^O - \bar{T}^O)^2}{\sum_{i=1}^n (T_i^P - \bar{T}^O)^2} \quad (19)$$

$$RMSE = \left[\frac{\sum_{i=1}^n (T_i^P - T_i^O)^2}{n} \right]^{\frac{1}{2}} \quad (20)$$

$$CRM = \frac{\sum_{i=1}^n T_i^O - \sum_{i=1}^n T_i^P}{\sum_{i=1}^n T_i^O} \quad (21)$$

That: T_i^P : estimated time of refining, T_i^O : measured time of refining and n : is the number of samples, and character with macron are the mean values. The lower limit of ME, RMSE and CD is zero and maximum value of EF is one. EF and CRM may be negative. ME value indicates the inefficiency of the model, the RMSE values indicate that model how much more or less than the reality, estimates. CD shows distribution ratio of the measured and estimated values. EF compares estimated values with the average measured values. Negative EF indicates that the average measured values, gives a better estimate of the estimated values. CRM is a standard for measuring model tendency to estimating more or less than the fact. Negative CRM represents an assessment more than reality. If all the estimated and measured data are identical, statistics will be: $EF=1$; $CRM=0$; $ME=0$; $RMSE=0$; $CD=1$ [30].

3. RESULTS AND DISCUSSION

Physical and chemical soil characteristics measured in the study are shown in Table 1. Amounts of soil distribution coefficients for linear models, Freundlich and Lang Muir are shown in Table 2.

Table 1. Physical and chemical analysis of soil

Soil texture	EC _e (ds. m ⁻¹)	OM (%)	θFC (cm ³ .cm ⁻³)	ρ _b (gr.cm ⁻³)	pH	Clay (%)	Sand (%)	Silt (%)
Sandy loam	1	2.8	0.145	1.4	7.3	9.42	74	15.5

Table 2 . Values of soil distribution coefficients obtained from linear models, the Long Muir and Freundlich

Linear (k _{SD})	Freundlich (k _f)	Long Muir (k _i)
195.71	170.65	0.435

Table 3 shows the results of quantitative assessment of the validity of the model fitted to the measured values of nickel adsorption isotherm in the soil. What we can get from Table 3 is the good fitting of Freundlich model and linear model on nickel adsorption isotherm. Due to the simplicity of linear models for obtaining mathematical models of refining time of the soil, we consider nickel adsorption isotherm in the soil as linear. Figure 1 shows the nickel adsorption isotherm.

Table 3. The results of quantitative assessment of the validity of the model fitted to the measured values of nickel adsorption isotherm in the soil

model	ME	CD	CRM	RMSE	EF
Long Muir	48.833	0.495	-0.315	83.986	0.822
Freundlich	71.960	1.163	0.054	14.511	0.994
linear	26.332	0.987	-0.004	1.255	0.999

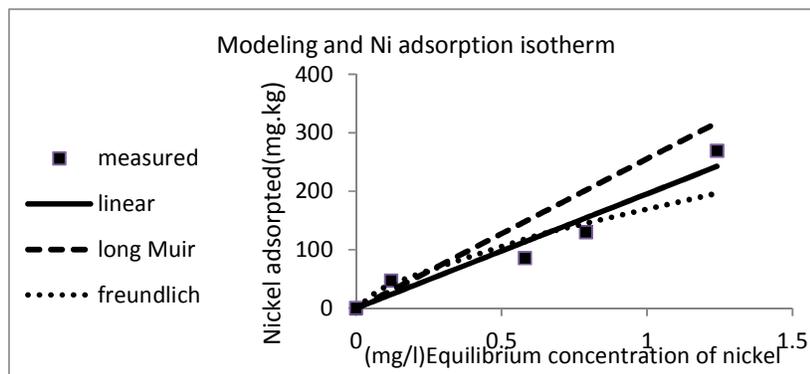


Figure 1. measured values of the nickel adsorption isotherm and the fitting results of Long Muir, Freundlich and linear models

Considering the amount of soil moisture content equivalent to field capacity soil moisture and equal to 0.145, the value of distribution coefficient in a linear model is $0.19571 \text{ (m}^3 \cdot \text{kg}^{-1}\text{)}$, assuming that all reactions were carried out at the same time in 24 hours, and the bulk density was assumed equal to $1400 \text{ kg} \cdot \text{cm}^{-3}$. Table 4 shows the coefficients of K_0 , K_1 , K_2 and K_3 for nickel in Alyssum plant and table 5 in Alyssum shoot in three salinity levels EC=1, EC=4 and EC=8.

Table 4. Coefficients of K_0 , K_1 , K_2 and K_3 nickel phytoextraction using *Alyssum murale* in three salinity levels

Salinity	$k_0(\text{mg l}^{-1} \text{ yr}^{-1})$	$k_1(\text{yr}^{-1})$	$k_2(\text{mg}^2 \text{ l}^{-6} \text{ yr}^{-1})$	$k_3(\text{mg}^2 \text{ l}^2 \text{ yr}^{-1})$
EC=1	1854.038	15.624	1407428.77	0.418
EC=4	655.946	9.876	217372.939	0.236
EC=8	783.494	7.586	351610.263	0.189

Table 5. Coefficients of K_0 , K_1 , K_2 and K_3 nickel phytoextraction using Alyssum shoot in three salinity levels

Salinity	$k_0(\text{mg l}^{-1} \text{ yr}^{-1})$	$k_1(\text{yr}^{-1})$	$k_2(\text{mg}^2 \text{ l}^{-6} \text{ yr}^{-1})$	$k_3(\text{mg}^2 \text{ l}^2 \text{ yr}^{-1})$
EC=1	566.440	4.282	461792.281	0.116
EC=4	92.401	0.847	54038.462	0.021
EC=8	97.158	0.681	44238.444	0.016

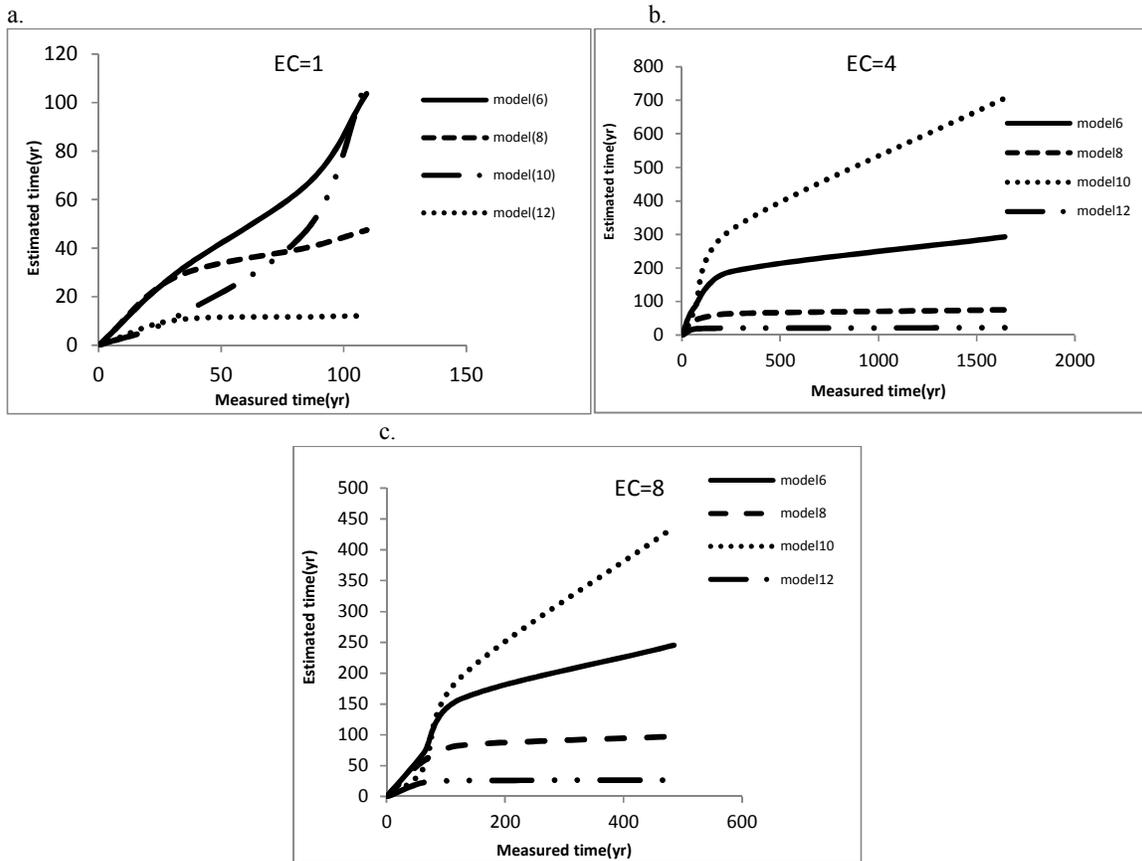


Figure 2. The estimated time required for refining nickel contamination of soil by Alyssum plants using the measured values of their relationships in a salinity level of a) EC=1, b) EC=4, c) EC=8

Figure 2- a, b, and c show the estimated time required for Phytoremediation of nickel contamination using equations 6, 8, 10 and 12 that have been achieved in measured values. Tables 6 shows the quantitative assessment results of validity of relations 6, 8, 10 and 12, in the estimated time required for Phytoremediation of nickel at salinity levels.

The results of table 6 and figure 2-(a) indicate that in the salinity of EC=1 zero-order function to concentration of $750 \text{ mg} \cdot \text{kg}^{-1}$ has a better efficiency. Thus, the concentration of nickel in the soil is zero-order function of nickel concentrations in soil in salinity level of EC=1. The assumption that with increasing nickel contamination in the soil the ability of Alyssum shoot in absorbing it remains constant is more compatible with

the phenomenon. In a research, Dallaliyan and Homae (2011) studied the time required for Phytoremediation of soils contaminated to cadmium and copper by *Salvia*. The results showed that the concentrations of cadmium and copper are zero-order functions of their concentrations in the soil. Mahmoudi *et al.* (2012) studied the time needed for Phytoremediation of soils contaminated to lead and nickel by mountain *Alyssum* plants. The results showed that the zero-order function has better efficiency at estimating time of Phytoremediation of lead from soil by mountain *Alyssum* plants, but for nickel the first-order homographic function and the first-order function are more efficient. The results in table 6 and figure 2-(b) indicate that in salinity of EC=4 to a concentration of 250 mg.kg⁻¹, first-order homographic function is more effective thus, the nickel concentration in salinity levels of EC=4 of soil is the first-order homographic function. As the concentration increases, Phytoremediation rate of nickel reduces and the time required for the nickel phytoextraction will increase with increasing of concentration.

Table 6. quantitative assessment results of the validity of relations in the estimated time required for Phytoremediation of nickel from soil by *Alyssum* plant in three salinity levels EC=1, 4 and 8

EC	Relation	ME	EF	CD	RMSE	CRM
EC=1	(6)	5.632	0.975	1.400	13.147	0.116
	(8)	61.703	0.580	8.055	54.938	0.485
	(10)	0.049	0.887	2.267	28.489	0.251
	(12)	97.024	-0.275	59.730	95.801	0.847
EC=4	(6)	1349.545	0.102	360.313	693.331	0.711
	(8)	1567.275	-0.458	23.190	883.868	0.901
	(10)	935.241	0.657	5.801	428.019	0.438
	(12)	1620.714	-0.667	11.785	945.077	0.968
EC=8	(6)	239.622	0.844	2.724	99.270	0.295
	(8)	386.915	0.264	49.411	216.020	0.642
	(10)	47.649	0.999	0.977	2.883	-0.008
	(12)	457.802	-0.395	30.358	297.557	0.886

Table 7. The time required for Phytoremediation of nickel from soil at different nickel contamination levels at salinity levels EC=1,4 and 8 by *Alyssum* plant

Nickel Concentration (mg.kg ⁻¹)	50	250	500	750
Time in EC=1 (yr)	0	31	85	109
Time in EC=4 (yr)	0	64	244	1642
Time in EC=8 (yr)	0	62	124	484

The results in Table 6 and Figure 2-(c) shows that in salinity of EC=8 to a concentration of 750 mg.kg⁻¹, first-order homographic function is more effective thus, the nickel concentration in salinity levels of EC=8 of soil is the first-order homographic function. As the concentration increases, Phytoremediation rate of nickel reduces and the time required for the nickel phytoextraction will increase with increasing of concentration. The time required for the Phytoremediation of nickel at different nickel contamination levels at salinity levels of EC=1, EC=4 and EC=8 is shown at Table 7. According to Table 7, the best salinity level to manage different nickel contamination levels by *Alyssum* plant is EC=1. Because at this salinity level, the time required for Phytoremediation of contamination for 1 mg.kg⁻¹ in soil is 31 years. At salinity level of EC=4 time increases, so for Phytoremediation of contamination for 1 mg.kg⁻¹ in soil 64 years is needed and at salinity level of EC=8 for Phytoremediation of contamination for 1 mg.kg⁻¹ in soil 62 years is needed.

Figure 3- a, b, and c show the estimated time required for Phytoremediation of nickel contamination by *alyssum* shoot using equations 6, 8, 10 and 12 that have been achieved in measured values.

Tables 8 shows the quantitative assessment results of validity of relations 6, 8, 10 and 12, in the estimated time required for Phytoremediation of nickel at salinity levels by *Alyssum* shoots. The results of table 8 and figure 3-(a) indicate that in the salinity of EC=1 zero-order function to concentration of 750 mg.kg⁻¹ has a better efficiency. Thus, the concentration of nickel in the soil is zero-order function of nickel concentrations in soil in salinity level of EC=1. The assumption that with increasing nickel contamination in the soil the ability of *Alyssum* shoot in absorbing it remains constant is more compatible with the phenomenon. The results in table 8 and figure 3-(b) indicate that in salinity of EC=4 to a concentration of 250 mg.kg⁻¹, first-order homographic function is more effective thus, the nickel concentration in salinity levels of EC=4 of soil is the first-order homographic function. As the concentration increases, Phytoremediation rate of nickel reduces and the time required for the nickel phytoextraction will increase with increasing of concentration. The results in table 8 and figure 3-(c) shows that in salinity of EC=8 to a concentration of 750 mg.kg⁻¹, first-order homographic function is more effective thus, the nickel concentration in salinity levels of EC=8 of soil is the first-order homographic function. As the concentration increases, Phytoremediation rate of nickel reduces and the time required for the nickel phytoextraction will increase with increasing of concentration. The time required for the Phytoremediation of nickel at different nickel contamination levels at salinity levels of EC=1, EC=4 and EC=8 is shown at Table 9.

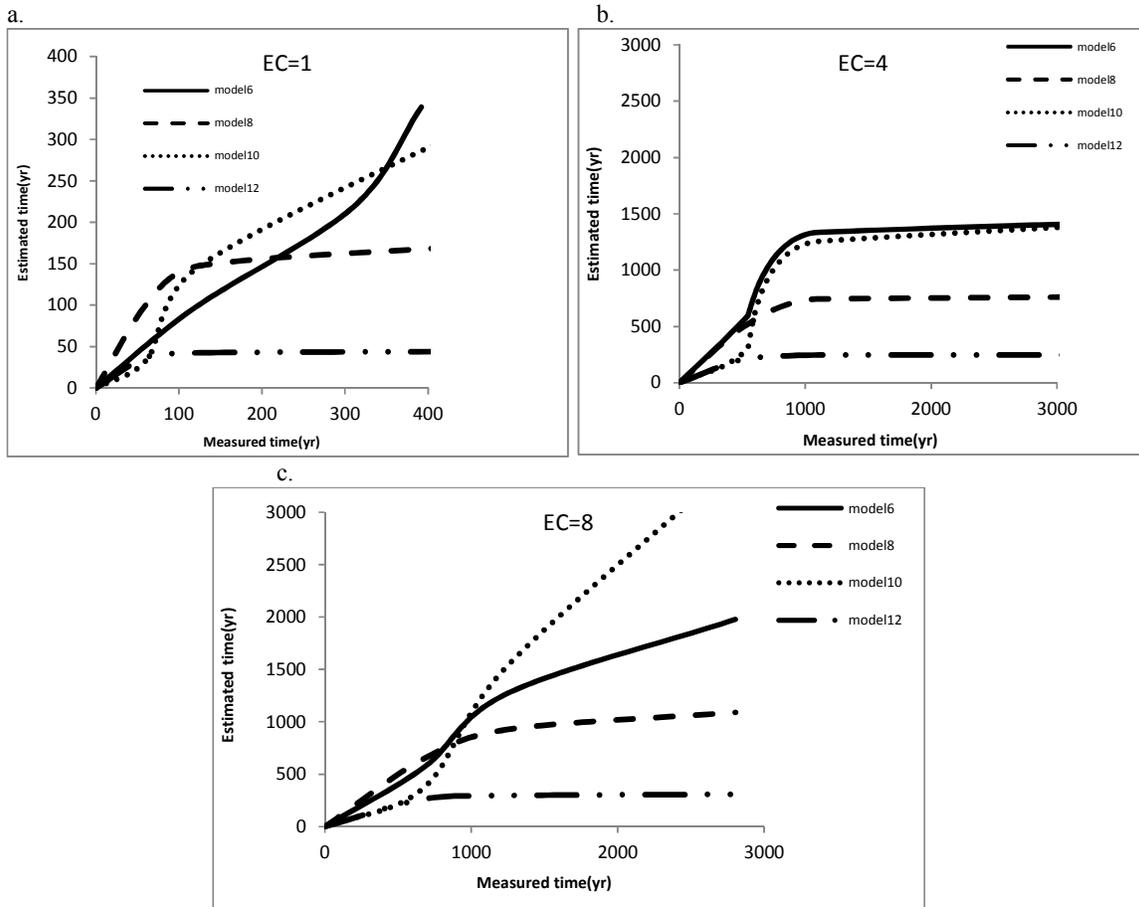


Figure 3. The estimated time required for refining nickel contamination of soil by Alyssum shoots using the measured values of their relationships in a salinity level of a) EC = 1, b) EC = 4, c) EC = 8

Table 8. quantitative assessment results of the validity of relations in the estimated time required for Phytoremediation of nickel from soil by Alyssum shoots in three salinity levels EC = 1, 4 and 8

EC	relation	ME	EF	CD	RMSE	CRM
EC=1	(6)	5.632	0.975	1.400	13.147	0.116
	(8)	61.703	0.580	8.055	54.938	0.485
	(10)	0.049	0.887	2.267	28.489	0.251
	(12)	97.024	-0.275	59.730	95.801	0.847
EC=4	(6)	1349.545	0.102	360.313	693.331	0.711
	(8)	1567.275	-0.458	23.190	883.868	0.901
	(10)	935.241	0.657	5.801	428.019	0.438
	(12)	1620.714	-0.667	11.785	945.077	0.968
EC=8	(6)	239.622	0.844	2.724	99.270	0.295
	(8)	386.915	0.264	49.411	216.020	0.642
	(10)	47.649	0.999	0.977	2.883	-0.008
	(12)	457.802	-0.395	30.358	297.557	0.886

Table 9 . The time required for Phytoremediation of nickel from soil at different nickel contamination levels at salinity levels EC=1,4 and 8 by Alyssum shoots

Nickel Concentration (mg.kg ⁻¹)	50	250	500	750
Time in EC=1 (yr)	0	119	309	391
Time in EC=4 (yr)	0	542	1113	35359
Time in EC=8 (yr)	0	676	1247	2803

According to table 9, the best salinity level to manage different nickel contamination levels by Alyssum plant is EC=1. Because at this salinity level, the time required for Phytoremediation of contamination for 1 mg.kg⁻¹ in soil is 119 years. At salinity level of EC=4 time increases, so for Phytoremediation of contamination for 1 mg.kg⁻¹ in soil 542 years is needed and at salinity level of EC=8 for Phytoremediation of contamination for 1 mg.kg⁻¹ in soil 676 years is needed. In a research, Dallaliyan and Homae (2011) studied the time required for Phytoremediation of soils contaminated to cadmium and copper by Salvia. The results showed that the Salvia has a high ability to absorb cadmium from the soil and also has a high ability to tolerate copper pollutants and is somewhat able to absorb pollution and the rate for cadmium and copper refining is zero-order function of their concentration in soil. The time required for refining cadmium of soil for concentration of 80 mg.kg⁻¹ is 12 years and for concentration of 800 mg.kg⁻¹ is 43 years. Khodaverdi Lu and Homae (2007) did a research by cress and spinach plants to estimate the time required for Phytoremediation of soils contaminated with cadmium and lead, the results indicate that the first-order function has a high efficiency at estimating the time for Phytoremediation of lead from soil by cress and spinach plants. But with cadmium the zero-order function and is more efficient than first-order function and first-order homographic function. The studies of Mahmoudi et al (2012) indicate that for estimating the time required for Phytoremediation of soils contaminated with lead and nickel by mountain Alyssum plants, the zero-order function has a better efficiency in estimating the time for Phytoremediation of lead from soil by mountain Alyssum plants but with nickel the first-order function and first-order homographic function are more efficient and mountain Alyssum plants are known to be more capable of being hyper accumulator of lead than nickel.

4. CONCLUSIONS

In simulating of nickel adsorption isotherms in the soil we can use of the linear model ($R^2=0.99$) and Freundlich model ($R^2=0.99$). But due to the simplicity of linear model to derive the mathematical models for contaminant absorption rate and the time of refining contaminants from the soil, nickel adsorption isotherms in soil was assumed linear. To estimate the time required for Phytoremediation of nickel by total Alyssum plant at salinity levels of EC=1 zero-order function and at EC=4 and EC=8 first-order homographic function is proposed and to estimate the time required for Phytoremediation of nickel by Alyssum shoots at salinity levels of EC=1 zero-order function and at EC=4 and EC=8 first-order homographic function can be used. Due to hyper accumulating feature of Alyssum plants and being tolerant at high concentrations, with increasing salinity, absorption rate by plant was reduced. The plant has the ability to grow in saline conditions, but with the increasing concentration of nickel and salinity in soil, plant growth and absorption were reduced.

Suggestions:

- 1- Native plants and weeds due to high compatibility with regional climate and low physiological need and resistance to environmental stresses are excellent options for such researches. Therefore with considering the potential of these plants, more researches are recommended to be done in this area.
- 2- In addition to the plant tolerance to high concentrations of metals, metal availability for plant absorption and sediment reduction and its stabilizing are also important issues that is suggested to be considered in future studies of the use of artificial chelation.
- 3- It is recommended that the research be carried out under field conditions.
- 4- Considering that the adsorption isotherms models were assumed to be linear models, obtain the models used in non-linear states.

REFERENCES

1. Dabiri, M. 1992. Environmental pollution (air, water, soil, noise). Martyr Beheshti, Tehran University Press. p.399.
2. Alexander M. 1994. Biodegradation and bioremediation. Academic Press, USA.
3. McGrath S. P. and F.J. Zhao 2003. Phytoextraction of metals and metalloids from contaminated soils. Current Opinion in Biotechnology 14: 1-6.
4. Afuni, M. and M. Erfanmanesh 2006. Environmental pollution, water, soil and air. Isfahan, p.318.
5. Erfanmanesh, M. and M. Afuni 2001. "Environmental pollution (air, water, soil)". Erkan Publications, Isfahan, pp. 330.
6. Vahabzadeh, A. 1994. Environmental principles. Printing one, Mashhad University Jihad
7. Alloway, B. J. 1990. Heavy metals in soils: Lead. Blackie and Glasgow. Ltd. London. pp. 177- 196.
8. Gisbert, C., R. Ros, A. de Haro, D.J. Walker, M. Pilar – Bernal, R. Serrano and J. N. Avino 2003. A plant genetically modified that accumulates Pb is especially promising for phytoremediation Biochemical and Biophysical Research Communications 303: 440 – 445.
9. Henry, J. R. 2000. An Overview of the Phytoremediation of Lead and Mercury. U. S. Environmental Protection Agency Office of Solid Waste and Emergency Response Technology Innovation office. Washington, D. C. P. 55.

10. Basic N., Salamin N., Keller C., Galland N. and Besnard G. 2006. Cadmium hyperaccumulation and genetic differentiation of *Thlaspi caerulescens* populations. *Biochemical Systematics and Ecology* 34:667-677.
11. Cataldo, D. A., Garland, T. R. and R. E. Wildung 1978. Nickel in plants: I. uptake kinetics using intact soybean seedlings, *Plants Physiol*, 62, 563- 565.
12. Smialowicz, R. J., Rogers, R. R., Riddle, M. M., and Scott, G.A. 1984. Immunologic effects of nickel: I. Suppression of cellular and humoral immunity, *Environ. Res.* 33: 413-427.
13. Zhou, L. X. and J. W. C. Wong 2001. Effect of dissolved organic matter from sludge and sludge compost on soil copper sorption. *J. Environ. Qual.* 30: 878 – 883.
14. Glick, B.R. 2003. Phytoremediation: Synergistic use of plants and bacteria to clean up the environment. *Biotechnology Advances*, 21: 383-393.
15. Chaney, R. L 1983. Plant uptake of inorganic waste constituents. In: Parr JF, Marsh PB, Kla JM, eds. *Land treatment of hazardous wastes*. Park Ridge, NJ, USA: Noyes Data Corp., 50–76.
16. Baker, A. J. M. and P. L. Walker 1990. Ecophysiology of metal uptake by tolerant plants. P. 155 – 177. In: *Heavy Metal Tolerance in Plants: Evolutionary Aspects*. A. J. Shaw (ed.).
17. Brooks, R.R. 1998. Geobotany and hyperaccumulators, In: R.R. Brooks (ed), *plants that hyperaccumulate heavy metals*, PP. 1-4. CAB International, U.S.A.
18. Abedi Koupaie, J. 2007. Phytoremediation performance evaluation method for decontamination of soils contaminated with crude oil, Congress and Exhibition of Environment, Tehran University, pp. 1-2.
19. Ouyang Y. 2002. Phytoremediation: modeling plant uptake and contaminant transport in the soil-plant-atmosphere continuum. *Journal of Hydrology*. 266(1-2): 66-82.
20. Pivetz B. E. 2001. Ground Water Issue: Phytoremediation of Contaminated Soil and Ground Water at Hazardous Waste Sites [Online]. Available from: URL: www.epa.gov/nrmrl/pubs/540s01500/epa_540_s01_500.pdf/.
21. Garbisu, C., Hernandez – Allica, O. Barrutia, I. Alkorta and J. M. Becerril 2002. Phytoremediation: A technology using green plants to remove contaminants from polluted areas. *Rev. Environ. Health* 17(3): 173 – 188.
22. Huang C.X. and Van Steveninck R.F.M. 1998. Maintenance of low Cl⁻ concentrations in mesophyll cells of leafblades of barley seedlings exposed to salt stress. *Plant physiol.*, 90: 1440-1443.
23. Mirmohammadi Meibodi, S. and B. Gharayzee 2003. Salt stress and physiological aspects of plant breeding. Martyr University of Technology Isfahan.
24. Homae, M., C. Direksen and R. A. Feddes 2002a. Simulation of root water uptake. I. Non – uniform transient salinity stress. *Agric. Water Mangt.* 57: 89 – 109.
25. Raskin, I., and B. D. Ensly, 2000. *Phytoremediation of Toxic Metal: using Plants to clean up the environmental*, John Wiley & Sons, Inc., New York.
26. McGrath S. P. and F. J. Zhao 2003. Phytoextraction of metals and metalloids from contaminated soils. *Current Opinion in Biotechnology* 14: 1-6.
27. Nash, J. E. and J. V. Sutcliffe (1970). River flow forecasting through conceptual models. Part 1: A discussion of principles. *J. Hydrol.* 10: 282 – 290.
28. Homae, M., C. Direksen and R. A. Feddes 2002. Simulation of root water uptake. III. Non – uniform transient joint salinity and water stress. *Agric. Water Mangt.* 57: 127 – 144.
29. Khodaverdi Lu, H. and M. Homae 2008. Modeling Phytoremediation of soil contaminated with cadmium and lead. *Journal of Science and Technology of Agriculture and Natural Resources*, Year eleven, number forty-two.
30. Khodaverdi Lu, H. 2007. Modeling Phytoremediation of soil contaminated with cadmium and lead. Ph.D. dissertation of Physics and Soil Conservation. University. Tehran, Iran
31. Gupta, P.K. 2000. *Soil, Plant, Water and Fertilizer Analysis*. Agrobios, New Delhi, India.
32. Levitt, J. 1980. Response of plants to environmental stress. Vol II. Water, Radiation, Salt and other stress. Academic press. New York. 2: 607. CRS Press, Florida, USA.
33. Mahmoudi, S., Dallaliyan, M. and M. Homae 2012. Simulating the Time Of Nickel And Lead Phytoextraction From Contaminated Soils Using *Thlaspi Arvense*. MS Thesis, Islamic Azad University, Tabriz. p. 106.
34. Trapp, S. and J.C., McFarlane 1995. *Plant Contamination: Modeling and simulation of Organic Chemical Processes*, Lewis Publishers, Boca Rotan, USA.
35. Tapperro, R. V., Erbe, E.F., Chaney, R. L. 2009. Interaction of nickel and manganese in accumulation and localization in leaves of the Ni hyper accumulators, *Plant Soil*, 314: 35 – 48.
36. Adhikari, T. and M. V. Singh 2003. Sorption characteristics of lead and cadmium in some soils of India. *Geoderma* 114: 81 – 92.
37. Dallaliyan, M. R., and M. Homae 2011. Simulating of Phytoremediation Time of Cadmium and Copper Spiked Soils by *Salvia Sclarea*. *Journal of Soil and Water Science*, Volume 1, Number 4.
38. Cariny, T 1995. *The Re-use of contaminated land*, John Wiley and Sons Ltd, pub, USA.