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Predictive model of heavy metals inputs to soil at Kryvyi Rih District and its use in the training for specialists in the field of Biology

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Predictive model of heavy metals inputs to soil at Kryvyi Rih District and its use in the training for specialists in the field of Biology

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Abstract. The importance of our research is due to the need to introduce into modern biological education methods of predictive modeling which are based on relevant factual material. Such an actual material may be the entry of natural and anthropic heavy metals into the soil at industrial areas. The object of this work: (i) to work out a predictive model of the total heavy metals inputs to soil at the Kryvyi Rih ore-mining & metallurgical District and (ii) to identify ways to use this model in biological education. Our study areas are located in the Kryvyi Rih District (Dnipropetrovsk region, Central Ukraine). In this work, classical scientific methods (such as analysis and synthesis, induction and deduction, analogy and formalization, abstraction and concretization, classification and modelling) were used. By summary the own research results and available scientific publications, the heavy metals total inputs to soils at Kryvyi Rih District was predicted. It is suggested that the current heavy metals content in soils of this region due to 1) natural and 2) anthropogenic flows, which are segmented into global and local levels. Predictive calculations show that heavy metals inputs to the soil of this region have the following values ($mg \cdot m^2/year$): Fe – 800-80 000, Mn – 125-520, Zn – 75-360, Ni – 20-30, Cu – 15-50, Pb – 7.5-120, Cd – 0.30-0.70. It is established that anthropogenic flows predominate in Fe and Pb inputs (60-99 %), natural flows predominate in Ni and Cd inputs (55-95 %). While, for Mn, Zn, and Cu inputs the alternate dominance of natural and anthropogenic flows are characterized. It is shown that the predictive model development for heavy metals inputs to soils of the industrial region can be used for efficient biological education (for example in bachelors of biologists training, discipline "Computer modelling in biology").

Introduction

Heavy metal (HM) pollution of atmospheric air, surface / groundwater and, especially, soil cover is an urgent problem for all industrial regions. It should also be noted that the gradual accumulation and very long finding of these pollutants occurs exclusively in the soil [1], [5], [8], [15], [18]. It is generally accepted that the accumulation in soils of a significant amount of anthropogenic HM poses a serious threat to the state of the biosphere and to human health [3], [4], [6], [41].

By now, researchers have thoroughly and in detail considered the features of HM content in soils in industrial regions. At the same time, identification of regularities of total metals inputs to soils at ore-mining and metallurgical regions remained without their proper attention [4], [5], [11], [14]. While, understanding the philosophy and details of metals inputs to soil at industrial regions can become

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a methodological basis for environment protection of these regions. It should also be noted that, measures effectiveness is determined by the successful streamlining of soil ecosystem functions as a biosphere indispensable component [11], [25], [37], [38].

Recently, biological education is increasingly using modern computer technology and a variety of computer models [23], [24]. However, in most cases, these models are created by either mathematicians or computer scientists. Therefore, such models do not reflect biological processes well enough. That is why it is so important for effective modern education that models of biological phenomena and processes are made by biologists [19], [30], [36], [40].

The object of this work: (i) to work out a predictive model of the total heavy metals inputs to soil at the Kryvyi Rih ore-mining & metallurgical District and (ii) to identify ways to use this model in biological education.

Materials and methods

Our research was performed in the Kryvyi Rih Ore-mining and Metallurgical District (named as Krivbas, Kryvorizhzhia, Kryvorizsky region). This district is located in Central Ukraine and its center is in the city of Kryvyi Rih. The geographical coordinates of its extreme points are: north – $48^0 19'$ N, south – $47^0 48'$ N, west – $32^0 58'$ E, east – $33^0 47'$ E. (Figure 1).

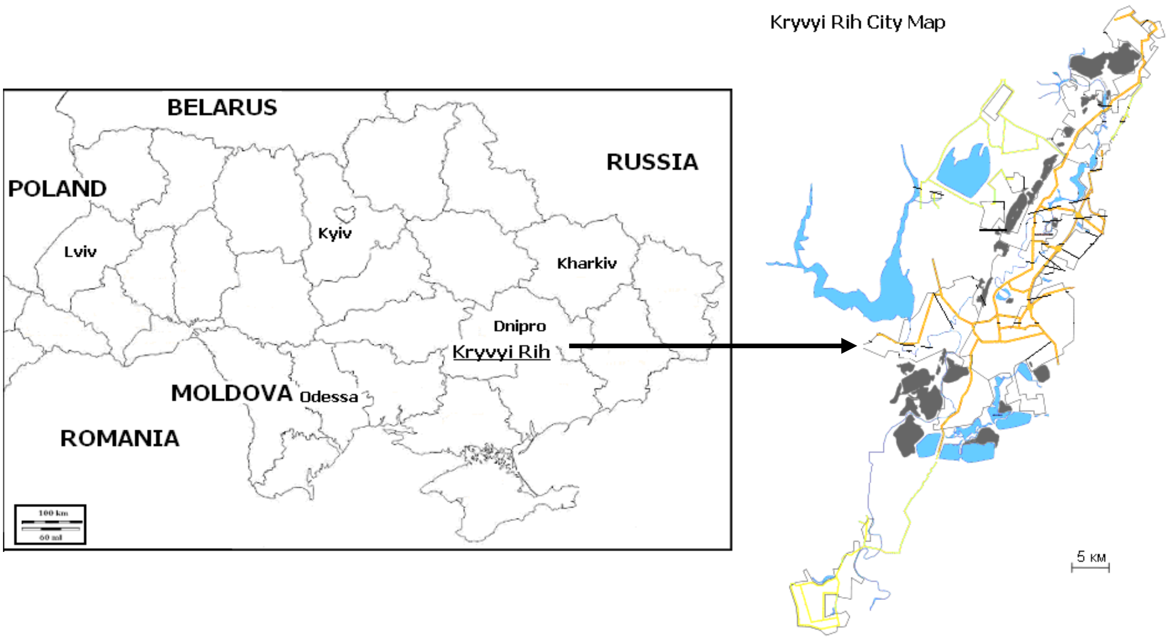


Figure 1. Location of study areas.

By the beginning of the XXI century Kryvbas – it is the largest ferrum ore and mining and metallurgical region in Europe. The full-cycle metallurgical plant, five mining and processing plants, and nine mines have been operating in this region for more than 50 years. In this region, 95-105 million tons of ore are mined annually, 60-70 million tons of enrichment products (agglomerate, pellets, concentrate) are produced, 6-7 million tons of pig ferrum and 5-6 million tons of steel are smelted [6], [32], [34].

Methods of research are analysis and synthesis, induction and deduction, analogy and formalization, abstraction and concretization, classification and modeling. Principles, methodology and formulas for forecasting of heavy metals inputs to soils are detailed in this publication [32].

Results and discussion

The concept of model of HM inputs to soil
In our opinion, the total metals' inputs to soils at Kryvyi Rih District can be represented in the coordinate axes: the x-axis is the source of inputs to and the Y-axis is the flow levels. Figure 2 manifests the concept and philosophy for our predictive model [32].

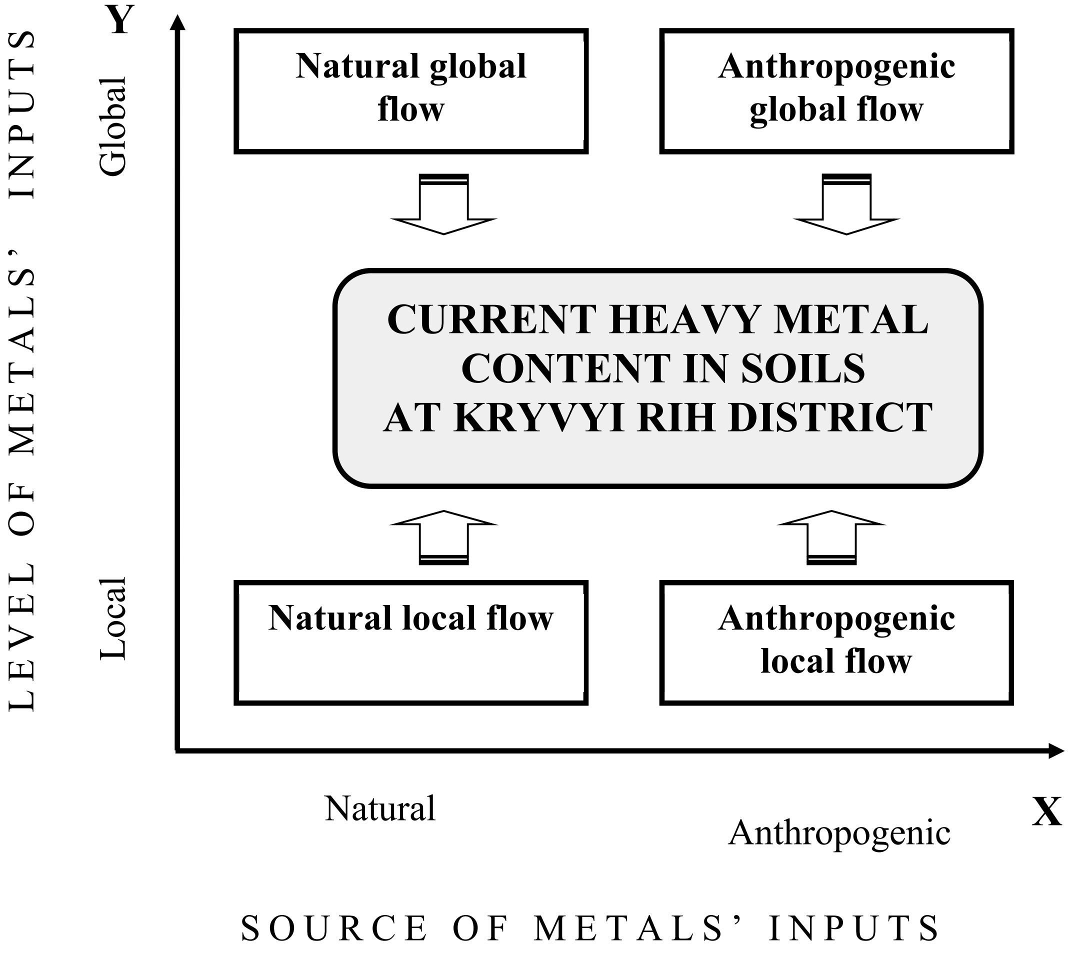


Figure 2. Concept pattern of heavy metals inputs to soil at Kryvyi Rih District.

The main sources of natural metals inputs to soils are the products of rock hypergenesis, soil formation and the products of biosphere genesis. While the main sources of natural metals inputs to soils are the arena for emissions from iron ore and mining enterprises (anthropogenic flows). In turn, these flows are segmented into two levels: global and local. Global flows of metals inputs cover all areas of the earth's surface. Therefore, these metal flows have the same values. Local flows of metals strictly timed to a specific industrial area. Therefore, these metal flows have different values for every area.

Predictive model of HM inputs to soils at Kryvyi Rih District
Published data of metals biosphere cycles [2], [7], [14], [16] we used to calculate the indicators of natural HM flow to soils at Krivbass (table 1). In this case, we a priori assumed the following prerequisites for our calculations. First, this flow of metals was formed by continental dust and oceanic precipitation.

Second, all the metals from this flow were naturally evenly distributed throughout the landmass of the planet Earth.

Table 1. Natural local flow of heavy metals to soil at Kryvyi Rih District.

Metal	Sub region	Inputs, $mg \cdot m^2/year$						
		by underground phytomass			by aboveground phytomass			Total
		Min	Max	M	Min	Max	M	
Ferrum	North	262,5	337,5	300,0	113,8	146,3	130,0	430,0
	Southern	227,5	292,5	260,0	61,3	78,8	70,0	330,0
Manganese	North	72,0	88,0	80,0	18,0	22,0	20,0	100,0
	Southern	49,5	60,5	55,0	13,5	16,5	15,0	70,0
Zinc	North	45,5	54,5	50,0	9,1	10,9	10,0	60,0
	Southern	41,0	49,1	45,0	4,6	5,5	5,0	50,0
Nickel	North	18,4	21,6	20,0	7,4	8,6	8,0	28,0
	Southern	16,6	19,4	18,0	4,6	5,4	5,0	23,0
Copper	North	5,78	6,62	6,20	2,61	2,99	2,80	9,00
	Southern	4,94	5,66	5,30	1,58	1,82	1,70	7,00
Lead	North	1,98	2,22	2,10	0,47	0,53	0,50	2,60
	Southern	1,70	1,90	1,80	0,28	0,32	0,30	2,10
Cadmium	North	0,457	0,503	0,480	0,029	0,031	0,030	0,510
	Southern	0,390	0,430	0,410	0,019	0,021	0,020	0,430

Min – minimum value, Max – maximum value, M – arithmetic mean.

According to predictive calculations, it was established that in the soils of the Kryvyi Rih mining and metallurgical region with continental dust, ferrum is introduced as much as possible – 540-550 $mg \cdot m^2/year$. An order of magnitude less manganese, two orders of magnitude less – nickel and zinc, three – less copper and lead, five – cadmium. In the soils of this area with ocean precipitation lead and zinc are the most sedimented, respectively 2,0-2.5 $mg \cdot m^2/year$ and 3,6-3,9 $mg \cdot m^2/year$. Ferrum, manganese and copper are an order of magnitude less and two orders of magnitude less – cadmium.

We found that the phytomass of herbaceous vegetation is the main source for the metal natural local flow to soils of Kryvyi Rih area. As our calculations have shown, in the soils of this area with a natural local flow, ferrum is sedimented in the largest amount 330-960 $mg \cdot m^2/year$ (table 1). The intensity of flows of manganese, zinc was one and a half time less, copper and lead – two orders of magnitude. For cadmium, the minimum values of sedimentation in the soils of this area were revealed – 0,430-0,800 $mg \cdot m^2/year$. The values of the natural local flow of HM to the soils at Kryvyi Rih area are comparable with the data of the scientific data [10], [27], [28], [44].

It should also be noted that the natural flow of ferrum, zinc and nickel to the soils of this district is by 2,5-3,0 times higher than similar indicators of their flow to the soils at steppe reserves of Ukraine [32]. Our results show that the amount of metals introduced to the soils of this region by vegetation precipitation (local level) is 3-4 orders of magnitude higher than by general biosphere input.

Our calculations indicated that according to the levels of anthropogenic global inputs to soils at Kryvbas, metals form a decreasing series ($mg \cdot m^2/year$): ferrum (180), zinc (15,0), manganese (11,0), copper (6,00), lead (5,00), nickel (2,25), cadmium (0,200). This series differs significantly from the ordering of metals flowing into the soils of the Kryvyi Rih area by natural and global fluxes. This fact manifests the dominance of anthropogenic flow of metals into the soils of this region.

Predictive calculations have determined that at Kryvyi Rih District by anthropogenic local flow annually ferrum is sedimented to the soils from 1,800 to 80,000 $mg \cdot m^2/year$ (table 2). Sedimentation rates of manganese, zinc and lead are two and a half orders of magnitude lower than ferrum. Sedimentation rates of manganese, zinc and lead are two and a half orders of magnitude lower than ferrum. The flux intensities of copper and nickel are at about the same level, which are three orders of magnitude less than ferrum. It should also be noted that the minimum flux values detected for cadmium – 0,0050-0,3000 $\mathrm{mg \cdot m^2/year}$. These values are four orders of magnitude lower than ferrum.

Table 2. Anthropogenic local flow of heavy metals to soil at Kryvyi Rih District.

Metal	Inputs, $\mathrm{mg \cdot m^2/year}$								
	Buffer area			Sub Impact area			Impact area		
	Min	Max	M	Min	Max	M	Min	Max	M
Ferrum	1 575	2 025	1 800	26 250	33 750	30 000	70 000	90 000	80 000
Manganese	9,00	11,00	10,00	180	220	200	468	572	520
Zinc	7,10	8,51	7,80	127	153	140	328	392	360
Nickel	0,37	0,43	0,40	6,35	7,45	6,90	16,4	19,2	17,8
Copper	1,02	1,18	1,10	17,7	20,3	19,0	46,6	53,4	50,0
Lead	2,35	2,65	2,50	42,3	47,7	45,0	113	127	120
Cadmium	0,0048	0,0053	0,0050	0,11	0,13	0,12	0,28	0,32	0,30

Min – minimum value, Max – maximum value, M – arithmetic mean.

A comparison of the metals anthropogenic local flow to the soils at Kryvbas with their sedimentation to the soils at industrial areas of the world showed the following. Indicators of ferrum inputs, in general, are comparable with the data from other mining and metallurgical regions, but in the impact area were by 5-15 times higher than these values [11], [26], [31], [42].

As our calculations have shown, the maximum levels of anthropogenic sedimentation of manganese, zinc, copper and lead to the soils at Kryvbas exceed their entry to the soils at other mining and metallurgical regions at the world. Lead was by 4.5 times, zinc and copper were by 2.5 times, manganese was by 2 times. While, the values of nickel and cadmium anthropogenic local fluxes to the soils of this area are comparable with the intensity of these metal flows to the soils from other industrials and agricultures areas [22], [29], [35], [39].

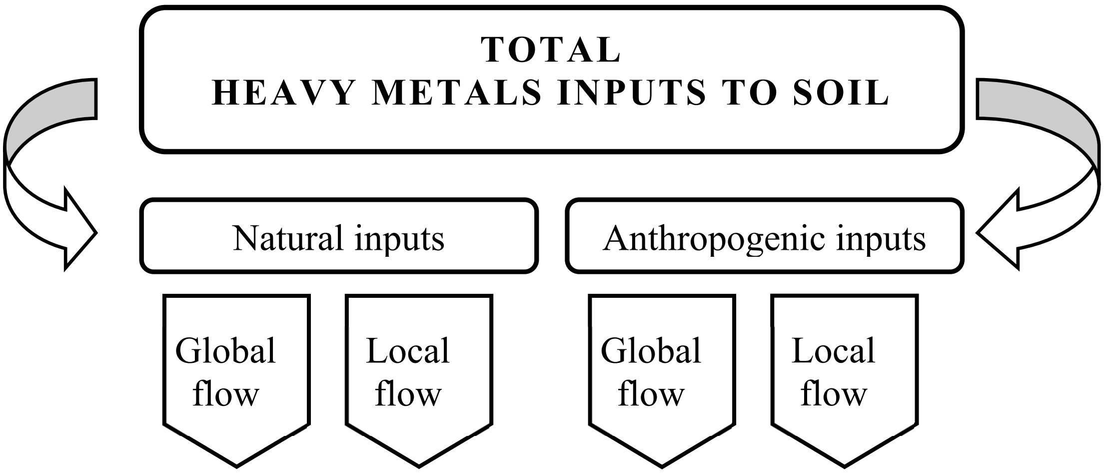
According to our predictive calculations, the metals natural global flow to the soils at Kryvyi Rih District is characterized by a negligible share. It is only 0,001-0,03% of the total amount of metals (figure 3). According to the structure of the HM total inputs to the soils at Kryvbas, metals are united into three groups: “technophilic”, “technophilic-biophilic”, “biophilic” [32], [33].

The first group of “technophile elements” includes ferrum and lead. For these metals, the atropogenic component predominates in their total soil uptake. Thus, at minimum levels of anthropogenic impact, the natural flow is: 5-35% for ferrum and 10-30% for lead. With increasing intensity of anthropogenic impact, the natural flow is reduced to zero.

The second conditional group of “technophilic-biophilic elements” includes manganese, zinc and copper. These metals are characterized by the alternating dominance of both natural and anthropogenic flows in their total entry into the area soils.

Thus, with minimal anthropogenic impact of natural substances, the flux of these metals is: manganese 50-90%, zinc 45-85%, copper 45-75%. With minimal anthropogenic impact, anthropogenic flux dominates in total intake: 55-90% for manganese, 60-90% for zinc and 55-90% for copper.

The third group of “biophilic elements” includes nickel and cadmium. The total inputs of these metals to the soil of district were exclusively due to the natural local flow. Thus, in the area of minimal anthropogenic impact, the natural flux of these metals has very high values by 85-95% for nickel inputs and by 65-80% for cadmium inputs. Despite the increase in the intensity of anthropogenic impact, the importance of natural flow in the entry of these metals into the soils of the Kryvyi Rih mining and metallurgical region remains very significant: 55-90% – nickel and 45-70% – cadmium (figure 3).



Flow Indicators

Indicator	Fe	Mn	Zn	Ni	Cu	Pb	Cd
Absolute, mg*m^2*year^{-1}	2 000 – 80 000	90-700	75-500	30-90	15-75	9,5-75	0,7-1,3
Relative, shares per unit	1	10^{-2}-10^{-3}	10^{-2}-10^{-3}	10^{-2}-10^{-4}	10^{-3}-10^{-4}	10^{-3}-10^{-4}	10^{-4}-10^{-5}

Flow structure, %

Flow		Fe	Mn	Zn	Ni	Cu	Pb	Cd
Natural	Global	<0,02	<0,03	<0,01	<0,01	<0,01	<0,04	<0,001
	Local	0,4-14	12-90	5,0-85	50-90	10-75	2,0-40	45-70
Anthropogenic	Global	0,5-6,0	1,5-2,0	3,0-20	4,5-7,5	8,0-35	4,0-50	15-30
	Local	60-99	5,0-90	10-85	1,5-40	5,0-65	25-95	0,7-35

Figure 3. Predictive pattern of heavy metals inputs to soil at Kryvyi Rih District.

The predictive model and biology education

Recently, modeling has been widely used as an effective tool for research, design and training, including in biological education. The created models, displaying the basic contours of biological phenomena and processes, help to better understand the philosophy of modern biology. That is why the created models of biological processes and phenomena are actively used also in biological education. It should also be noted that the use of computer technology significantly improves the models of biological processes and phenomena [13], [19], [20], [21], [36].

It is generally accepted that one of the effective methods of using computer technology is the use of elements of modeling phenomena and processes of the surrounding reality. At the same time, it is necessary to emphasize that models should be created by biologists to solve biological problems and problems. Since, there are currently a very large number of diverse biological models that have been developed by mathematicians and computer scientists. However, unfortunately, such models are very difficult for biologists to understand and are very far from solving biological problems and from understanding biological processes / phenomena. That is why it is so important to involve professional biologists to create a computer model of biological processes and phenomena [9], [12], [17], [30], [40], [43].

The model of heavy metals flow to soils at Kryvyi Rih Ore-mining & Metallurgical District made by us is very important and relevant. First of all, this model helps to understand the philosophy of soil contamination by heavy metals. Moreover, this model reveals the shares of natural and anthropogenic flows in soil pollution. It should also be noted that this model will allow predicting anthropogenic flows of heavy materials to soils at various mining and metallurgical activities in this district. In addition, the algorithms of the model and the model itself can be used in biological education. For example, the predictive model development for heavy metals inputs to soils of the industrial region can be used for efficient biological education (for example in bachelors of biologists training, discipline "Computer modelling in biology").

Conclusions

Modern heavy metals content in soils at the Kryvyi Rih Ore-Mining and Metallurgical District is determined by the total natural and anthropogenic sedimentation of these elements, which are formed due to their global and local flows.

In the soils of Kryvbas the natural metals' sedimentation had the following values: from 0,010 to 543,100 $\mathrm{mg \cdot m^2/year}$ by global flows and from 0,43 to 960 $\mathrm{mg \cdot m^2/year}$ by local flows. The biomass of herbaceous vegetation determined more than 99% of the HM natural flows to the soils of these areas.

In the soil of Kryvyi Rih District the anthropogenic metals' sedimentation had the following values: from 0,200 to 180,000 $\mathrm{mg \cdot m^2/year}$ by global flow and from 0,0050 to 80,000 $\mathrm{mg \cdot m^2/year}$ by local flow. Aerial emissions from ore-mining and metallurgical plants have caused anthropogenic local flows of metals to this district's soils.

Anthropogenic sedimentation dominated in the structure of iron and lead flows to Kryvyi Rih District soil. Its share ranges from 60% to 95%. Natural local sedimentation dominated in the structure of nickel and cadmium fluxes. The share of these metals ranged from 55% to 95%. Alternate dominance of natural and anthropogenic flows was revealed in the structure of manganese, zinc and copper flows in the soils of these areas.

The model of heavy metals flow to soils at Kryvyi Rih Ore-mining & Metallurgical District made by us is very relevant and can be used in biological education. In further research, it is necessary to verify our model of heavy metal flows in the soil of these areas. It will also be important to make and verify the educational technologies that will use this model.

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