The improvement of methodic principles to make technological decisions in the context of open-pit mining while land saving

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Abstract
System of the parameters, which allows to estimate techniques of open-pit mining according to their relation to the level of environmental and cost characteristics of allotment land characteristics was determined. Technological factors, which influence the land-saving level at mining enterprises are determined.
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Relevance of the problem

Today mining land use is characterized by further degradation of land resources involved in mining area [1]. In Dnipropetrovsk region activity of mining enterprises is absolutely the most important factor of land damage [2]. Each mining enterprise engaged in open-pit mineral extraction disturbs annually several thousands hectares of land (80% of total mineral mining in Ukraine fall at open-pit mining). For example, during the period of its existence Ordzhonikidze mineral processing plant has allotted almost 11.4 thousand hectares of land for its use. The land was mostly for agricultural purposes. Among them only 55% were subjected to recultivation, which caused considerable damages due to the loss and deterioration of land quality; the damages should have been compensated mostly at the expense of the enterprise disturbed the land.

Thus, high level of land disturbance in terms of open-pit mining rises the problem of determining the parameters reflecting correspondence of the techniques of deposit development as for the requirements of land saving.

Statement of Problem

It goes without saying that amounts of land allotment depend on mineral type. However, they also depend heavily on mining technique being applied [3]. Thus, to estimate the level of land degradation due to open-pit mining it is important not only to determine the amount of land properly allotted for mining but also the level of its transformation. As paper [4] emphasizes, changes in mining allotment landform depend upon the amount of residual mine workings, which in their turn are stipulated by mining technique being applied.

According to the idea by A.G. Shapar [5] and M.I. Barsukov [6] significant influence of mining on the state of land of industrial region requires accurate ecological and economic assessment of technological schemes of recultivation of land disturbed by mining operations to determine its relevance to land-saving purposes. At the same time, techniques aimed at land restoration cannot be considered independently from the techniques of mineral deposit mining. The latter are important to determine the parameters of measures to recultivate the land.

Drebot, O.I. and Shvets, O. G. [7] suppose that current requirements for both specifications and operational parameters concerning land restoration are subjected to obsolete normative and technical documentation and cannot meet up-to-date requirements as operational and organizational changes in corresponding fullscale manufacturing facilities should be involved.

Paper [8] suggests technique to mine high pit banks as it enables acceleration of disturbed land restoration. The developed scheme involves the idea that internal dump planning is carried out simultaneously with stripping and dump operations. In this context, efficiency of disturbed land restoration increases and its recultivation is simplified. At the same time, each mining technique should provide possibilities for complex mining of minerals as it implements the idea of nonrenewable natural resources conservation [9, 10].

Thus, estimation of mining techniques as well as further development of open-pit field should be the key aspect of making technological solutions as for the management of land saving at mining enterprise. Moreover, they should be grounded on such methodic tools, which allow reflecting the results of protection and restoration of mining allotment land.

Scientific and technical sources as well as design solutions concerning horizontal deposit mining consider a problem of land conservation more simply. As a rule, it is done from the viewpoint of integrated conservation of natural resources affected by mining without substantiation of approaches to mining operations optimization depending upon necessity to minimize land areas disturbed as a result of non-renewal exploitation. The problem should be solved by means of substantiation of parameters of land allocation for open-pit facilities in the field of land conservation.

Study objective is substantiation and development of evaluation criteria for land-conservation operation schedules in the process of open-pit mining, which would reflect land rehabilitation level in terms of quality and disturbance scale as well as in terms of their cost estimation. Accordingly, planning procedure for mining objects should be based upon selection of operation procedures for open-pit field opening, mining, and upgrading in relation to land conservation level. In the context of land conservation, field development technique should be aimed at disturbed land area minimization as well as at creation of favourable conditions for its further recultivation.

Key Outputs. No mining enterprise is interested in the increase of level of its financial and legislative liability for the deterioration of quality of the land disturbed as a result of mineral mining. That is why it is rather topical to implement such mining techniques characterized by minimum land intensity. In this context reserves of land area decrease should be first determined by means of optimization of the parameters of land allotment for technological objects of open pit. The parameters should be identified involving each technological stage of the deposit mining.

Consequently, factors of land intensity and recultivation should be those initial indicators of the level of mining effect on the land state. They are determined as follows:

$$З_e = \sum_1^n \frac{S_{г.оi}\left(1-K_p\right)}{Q_м}, \text{ ha/t;} \quad (1)$$

$$K_p = \sum_1^n \frac{S_{pi}}{S_{г.о}}, \text{ unit fraction,} \quad (2)$$

where $S_{г.оi}$, S_{pi}, are areas of allotted (disturbed) and recultivated (returned) lands respectively on the i^{th} open-pit object , ha; n is the number of technological facilities; $S_{г.о}$ is the total area of mining allocation for the deposit development, ha; $Q_м$ is the operating mineral reserves of the deposit, t.

The importance of the problem solutions is emphasized by the results of author's calculations for land area to be allocated for the facilities of manganese ore deposit development in the context of open-pits of Ordzhonikidze Mining and Preparation Integrated Works. Thus, 163…228 ha of natural lands (Table 1) should be allocated for main openings and dump depending on the depth of ore bed occurrence. Permanent trench takes 3.5…4.5%; transport incline takes 8.6…8.4%; working trench takes 57.0…56.1%; and construction dump takes 31.0%. Hence, working trench and construction dump cover the major share of residual mine workings (almost 90%). Internal dumps are being recultivated and transferred for further use while ore bed mining.

Taking into consideration current economic problems of mining enterprises it is possible to reduce allotted land areas, increase areas and quality of restored lands by developing comprehensive rational technological facilities within open-pit field basing upon the criteria of land conservation.

Technical and technological solutions as for deposit operation taken on the basis of land size $З_e$ and recultivation coefficient K_p, may provide the following results:

- Decrease in the area of natural lands allotted for ore bed open-cast mining;
- Increase in the area of recultivated lands returned to the national economy;
- Improvement of the quality of lands restored for their original use;
- Improvement of the conditions for mining recultivation (decrease in the number of recultivation operations concerning dump crest cutting and filling openings, dump surface leveling, formation of its slope allowable for the use of agriculture machinery, to generate black soil and potentially fertile soil layer in accordance with the requirements of further land use to prevent pollution and erosion of land resources etc.).

Recovered land should be considered as a combination of several positive qualities and effects that human can use in practice independently; moreover they define rate of potential consumer value of recovered land. It is clear that the range of technogenic soil use is narrower than use of wild lands: purposeful restoration of certain chemical and physical and mechanical soil characteristics is planned. It reduces economic potential of the former as integrity of independent productive possibilities or unused reserves. Thus, the coefficient of changes in cost potential of land is determined as follows [11]:

$$K_{з.п} = \frac{\sum_{i=1}^{к} Ц_{p_I}}{\sum_{i=1}^{n} Ц_{нi}}, \quad (3)$$

where $Ц_{p_I}$, $Ц_{нi}$ is market evaluation of recultivated and undisturbed plot of land in accordance with the i^{th} economic field, respectively; $к$ and n are the numbers of useful properties of restored and wild lands respectively.

If recultivation results in complete changes in disturbed land nature, then its efficiency should involve environmental component of land restoration; in particular it concerns changes in ability of newly formed soil layer to maintain useful properties due to unfavorable natural and technogenic factors of its further exploitation. Agriculture applies coefficients of environmental stability of different types of lands being numerical expression of ecological sustainability of land plot used purposefully in the context of natural ecosystem. The higher level of changes in soil condition after anthropogenic intervention is (being maximum while forming arable land), the lower its ecological sustainability level is. Thus, ecological efficiency of changes in targeted use of technogenic soil may be estimated according to coefficient of soil ecological recovery $K_{e.в}$, which is proposed to be determine by the following formula [12]:

$$K_{e.в} = \frac{\sum_{i=1}^{m} S_{p_i} E_{p_i}}{\sum_{i=1}^{n} S_{в_i} E_{в_i}}, \quad (4)$$

where S_{p_i}, $S_{в_i}$ are areas of i^{th} type of land of recultivated and allotted land respectively; E_{P_I}, $E_{в_i}$ are the coefficients of ecological sustainability of i^{th} type of a land plot after recultivation and before allocation respectively; *n, m* are the numbers of different land types located within undisturbed and restored area respectively.

On the whole, land recultivation and measures for their protection should involve the following criteria: 1) previous purpose of the disturbed land (the criterion is oriented to the land owner); 2) structural changes in production aims of the area use (the criterion is oriented both to land owner and society in general); 3) the required level of costs to recultivate land according to the certain business aim (the criterion is oriented to recultivation subject); 4) soil state, changes in landform and climate after the period of mining operations (the criterion is generally oriented); 5) forecast cost of soil after its restoration (the criterion is generally oriented).

In practice one of above mentioned aspects concerning future land use is of crucial importance; however, other criteria of recultivation purposes will effect on its implementation.

Taking into account specificity of land restoration, planning of its results is a long-term process. The planed positive recultivation effects will be rather timely distanced from capital expenses stipulating them. That involves implementation of dynamic estimation of qualitative expression of economic result of land restoration according to which recultivation variant may be chosen as follows:

$$E_R = \frac{\sum_{i=1}^{n}\left(\mathrm{Re}_i - K_{R_i}\right)\cdot\frac{\mathrm{Re}_i}{\overline{\mathrm{Re}_\nu}}\cdot\left(1+E_н\right)^{-i} - K_в}{K_{an}} \to \max, \quad (5)$$

where E_R – is economic efficiency of recultivation variant, coefficient; Re_i – is land rent in i[th] year, UAH/ha; K_{R_i} – are the expenses connected with land improvement being implemented in i^{th} year after industrial land use, UAH/ha; $\overline{\mathrm{Re}_\nu}$ – average level of land rent of zonal soils, UAH/ha; $E_н$ – is the norm of annual deposit interest, coefficient; $K_в$ – is compensation for land state deterioration, UAH/ha; K_{an} – is expenses of initial recultivation stage, UAH/ha; n – is period of capitalization of rent concerning restored land, years.

Consideration of land resources in terms of labour conditions of mining enterprise economy to estimate selected land preservation mode should also involve the criteria containing cost changes in land resources as well as expediency of expenses connected with their restoration. They are:

1) economic efficiency of land preservation characterizing level of value (monetary evaluation) conservation of nature lands:

$$E_{зс} = 100\, Ц_р\, (1 - П_{з.р})/Ц_{пр}, \%, \quad (6)$$

where $Ц_р$, $Ц_{пр}$ are the monetary values of recultivated and undisturbed lands respectively, UAH/ha; $П_{з.р}$ is loss of land resources according to area, unit fraction.

$$П_{з.р} = (1 - К_р)\, Б_{пр} / Б_р, \text{ unit fraction.}; \quad (7)$$

where $Б_{пр}$, $Б_р$ are the bonitet (quality) of wild and recultivated lands respectively, %; $К_р$ is recultivation coefficient (unit fraction);

2) economic efficiency of recultivated lands as payback index per recultivation operation:

$$E_р = 100\, Ц_р\, (Б_р)\, К_р / В_р, \%, \quad (8)$$

where $Ц_р\,(Б_р)$ is monetary value of recultivated lands according to their bonitet, UAH/ha; $В_р$ is cost value of disturbed land recultivation, UAH/ha.

Land allocation for open-cast deposit mining contains mine workings, internal and external dumps, technological facilities of open-pit, and recultivated and disturbed lands.

To perform more accurate estimation of land conservation economic efficiency involving various types of soils within certain areas of land allocation, various soil costs and expenditures connected with land reclamation in the context of further use, the authors propose to apply integral coefficient calculated as following:

$$E_{e.з} = \frac{(Г_{з.р} - В_{з.р})\mathrm{S}_{з.р} + (Г_{з.т} - В_{з.т})\mathrm{S}_{з.т} + \ldots + (Г_{з.в} - В_{з.в})\mathrm{S}_{в.в}}{Г_{з.п}\cdot \mathrm{S}_{з.г}} \quad (9)$$

where $Г_{з.р}$, $Г_{з.в}$, $Г_{з.т}$, $Г_{з.п}$ are the monetary estimations of recultivated (to be returned) lands; those under residual mine workings, technological and subsidiary facilities (e.g. external dumps, other objects not subject to reclamation but being improved in accordance with their further use) as well as wild (undisturbed) lands, UAH/ha; $В_{з.р}$, $В_{з.т}$, $В_{з.в}$ are expenditures connected with disturbed land improvement for its further use; $S_{з.р}$, $S_{в.т}$, $\mathrm{S}_{з.в}$ are land areas according to their use (recultivated for agriculture; that after liquidation of technological and subsidiary facilities; improvement of external dumps after residual mine working has been closed), ha; $S_{з.г}$ is area of wild lands aimed for mining allocation, ha.

In the context of rational land use both location and dimensions of technological facilities of open-pit should provide maximum value of $E_{e.з}$ coefficient. The coefficient involves dimensions, level, and nature of wild land disturbance, its further recovery and use in terms of all the technological facilities. In general form with consideration of land area, allotted for i^{th} technological facility and restored in j^{th} filed of use within total area of land allocation $S_{з.г}$, the coefficient of economic efficiency of land preservation is described by the ratio:

$$E_{e.з} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}(Г_{pij} - В_{pij})К_{pij}}{\sum_{j=1}^{m}Г_{nj}}, \text{ where } К_{pij} = \frac{\mathrm{S}_{pij}}{S_{pj}}, \text{ unit fraction,} \quad (10)$$

where n, m are the numbers of technological facilities of open-pit for which wild lands have been allotted (i = 1,2,…, n) and fields of restored land use (j= 1,2, ... m).

K_{pij} is share of S_{pij} land area of i^{th} technological facility within the total area S_{pj} of lands, restored in accordance with j^{th} use field in total, unit fraction.

Expressions (9) and (10) help to select efficient for land conservation technological schedule of open-cast mining as the expressions involve expenses of a mining enterprise connected with recultivation as well as volume and quality of restored land resources. The indices depend on the conditions of recultivation being mainly determined by the standard schedule of mineral mining. Application of the above evaluation criteria of land conservation mode helps to estimate economic efficiency of sheet ground mining technique. If the developed technique provides more favourable conditions of mining recultivation to compare with standard one, then values of the criteria should grow. Accordingly, such a technique for deposit mining is considered as economically expedient from the viewpoint of improved land conservation.

Monetary evaluation $Г_{з.п}$ is set as a weighted mean value for all types of soils (arable, pasture, economic area etc.) allotted for technological facilities of open-pit. Wild land allotted in 2012 for manganese deposit of Ordzhonikidze Mining and Preparation Integrated Works had the following structure (Fig. 1):

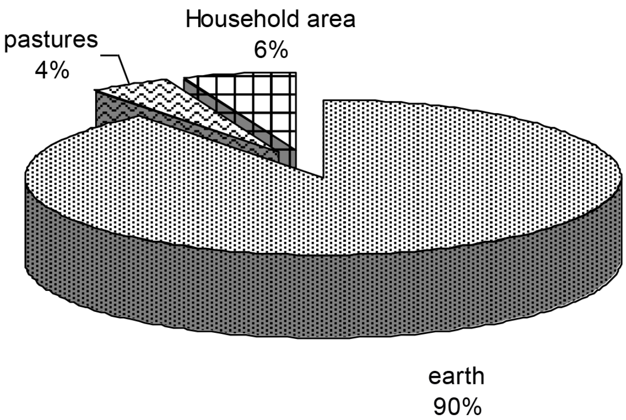

Figure 1. Structure of land allotted for deposit mining (Ordzhonikidze MPIW, 2012)

Weighted average monetary value of the land was 42.7 thousands UAH/ha. Total amount of land allotted for the expansion of 4 open pits of the integrated works (Pivnichny, Chkalovsky, Shevchenkivsky, Oleksandrivsky) was 193.15 ha. Total area of land restoration in 2012 shown in Fig.2 was 34 ha.

In 2012, the recultivation took 69.9, 24.7, 45.5, 20.0 and 30.2 thousands UAN per ha, cadastral valuation of lands - 35.3, 12.0, 25.2, 10.8, 15.0 thousands UAN per ha respectively. Integral coefficient of economic efficiency of land conservation calculated according to formula (9) based on the mentioned data, is -0.57. Thus, restoration of disturbed lands is an unprofitable process for the integrated works, which is confirmed by negative value of the determined efficiency. Restored lands are mainly used for water bodies, forest cover, construction and other facilities; return of initially fertile lands with higher monetary evaluation to the agricultural use is not complete. This confirms the necessity of more rational planning of mining objects to minimize the amount of disturbed land and decrease of financial and legislative liability of mining enterprise for its quality deterioration.

Conclusion

1. Development of the system of efficiency level indices for recultivation operations is significant tool to control a mode of mine allocation land use which gives real idea of the scope and outcomes of land allocation.

2. Post-industrial economic land use should be determined taking into consideration the assessment of economic efficiency of the use in the context of various land capability soil groups, expediency of expenses according to recultivation aims. It is required to determine the priorities while implementing possible consequences of restoration operations and maximize positive effects from future use of recultivated land.

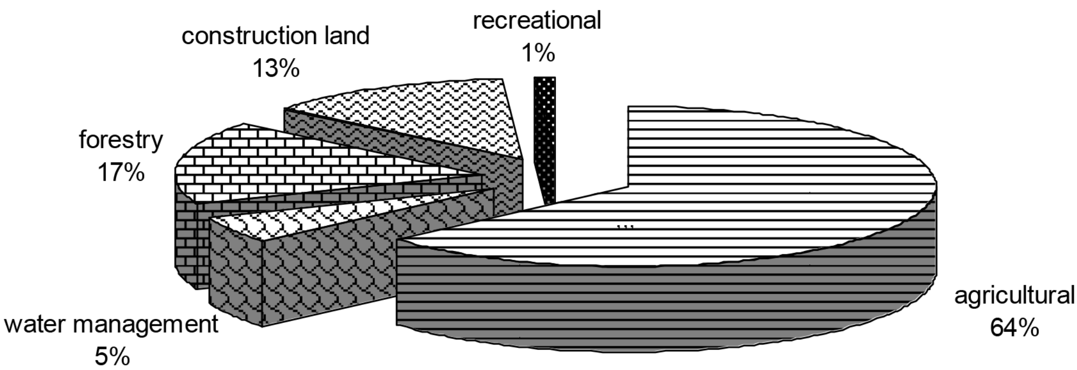

Figure 2. Structure of recultivated land in the context of Ordzhonikidze MPIW in 2012

3. It is required to select such an operation schedule for deposit mining, which will provide preservation of both monetary and environmental value of technogenic lands at the background of their maximum restoration in terms of quality and disturbance volume. Prevention of value losses of recultivated land results in positive effects and prerequisite for minimization of unprofitability level of mining enterprise environmental programs.

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