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Design strategies of soil and water conservation measures for Ereen gold deposit in Mandal Soum, Selenge province, Mongolia – a case study

The objective of this environmental due diligence review is to identify and or verify the existing and potential environmental liabilities and risks, and assess any associated proposed remediation measures for the Ereen gold mine. The results show that area of soil and water conservation measure was produced prior to 5 measures mentioned above, belong to a positive design process, closing hillside of which has been decided lately, other 4 measures were produced between these two factors. The four measures were not been decided simultaneously, have the trend of building soil and water conservation forest and building economic forest prior to terracing and conservation tillage, but they are independent to each other, belong to parallel coupled design. Conservation tillage, terracing, building economic forest, building soil and water conservation forest account for 31%,12%,21%,24% of area of soil and water conservation measure, which has some change extent.

Keywords: *Ereen deposit, digitization, three-dimensional model.*

1. Introduction

The Ereen property is located in north-central Mongolia approximately 42 km to SW from the centre of Mandal soum, Selenge province and 140 km to NNW of Ulaanbaatar, capital of Mongolia (Fig.1). The Dzüünharaa, one of the largest stations on the Trans-Mongolian Railway is located 35km to the north. The main towns in the area are served by good infrastructure including power, water and communications; it is the detailed location in north-central Mongolia. There are two main access rates to the Ereen site; by paved road from Ulaanbaatar to Bornüür (110km) and then approximately 50km on dirt road to the site, or 136km to the north of Ulaanbaatar to Boroo gold mine's improved earth road, and then approximately 30km by unpaved road to the site.

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Design strategies of soil and water conservation measures showed a diversity of practice. African farmers can even more clearly understand the dangers of soil erosion and can configure a series of soil and water conservation measures according to the specific circumstances, some study have evaluated local farmers willingness to participate in water and soil conservation planning, which indicates that the design of water and soil conservation measures is concerned about not only the government, but the whole society. Scientists use advanced technology to plan water and soil conservation measures, proposed method of measures on the whole and conduct scenario simulation. Some control measures and water and soil loss control model was presented from research angle, some from selection control object, control measures layout, administration measures and so on. But the planning of SWC from natural condition is not fit to the social needs.

Therefore, a lot of control models cannot be applied. If grasping and summarizing the control projects finished and their management models, it will help to improve the basis for the development of scientific and practical models. But the research of management model for eco-environmental engineering is mainly qualitative summary, while lacks quantitative analysis, and does not describe the relationship between area of measures and influence factors. In addition, most of the present research is about typical small watershed whose representative is still incomplete. However, the relation of the whole project was rarely studied. The aim of this study was to establish a pragmatic approach to model water and soil conservation measures, which describes the design direction, the relationship among measures and the relationship between individual measures and related factors.

2. Geology of the region and deposit

Ereen deposit is located near to the principal gold deposit in the district, Gatsuurt mine, developed by Centerra Gold Corporation. The Sujigtei fault separates Devonian rhyolites (which host Ereen) in the west from Palaeozoic granites in the east. Therefore, certain Gatsuurt ore controlling features

Fig.1 Project location in North-Central Mongolia

could be similar to Ereen ore-controlling factors. Stratigraphic section of the Ereen area is consecutively represented by Cambrian-Ordovician Kharaa group formation, Ordovician-Silurian Undur formation, Silurian Mandal group formation, Devonian Uaan Undur formation, Jurassic-Cretacious Ajnai white fracture formation, lower Cretacious Shariin Gol formation, Quaternary Holocene sedimentary formation. Plutonic rocks are spread moderately in the project area. From the previous research the following groups of plutonic rocks were identified on the basis of the geologic-structural location, stratigraphy deposition and border relation towards each other, petrography, and petrochemical characteristics.

1. Medium late Ordovician Boroo river formation
2. Late Ordovician Ikh Tashir formation
3. Medium Devonian rock formation
4. Permian Guadeloupian small Khentii formation
5. Early Triassic Tukhum formation

3. Mine geology

Gold grades vary from trace to 409g/t along the strike and depth extension of the vein. Better grades (from 14g/t to 363.4g/t) of Au were distributed in the middle and deeper parts of the vein, with near-surface grades (down to 40m) considered uneconomic. The average gold grades were 18-23g/t in different blocks.

Ore minerals are pyrite, arsenopyrite, tetrahedrite, chalcopyrite, sphalerite, galena, scheelite, malachite, azurite, limonite and free gold. Free native gold is associated with quartz, galena and arsenopyrite. The average size of visible Au was reported to be of 1mm. Vein 2 is located in the north-east part of the deposit, strikes north-east and dips gently (12^o) to the north-west. It has a strike length of 200m and an average thickness of 0.4m. Trenching undertaken between 1959 and 1960 showed the average thickness of the vein to be of 1m on surface and to be surrounded by a 7m wide silicified halo. Gold grade varied from 0.5g/t to 2.7g/t on the surface.

4. Methods

4.1 Theoretical framework

The design strategies of soil and water conservation measures include design direction, relationship among measures and relationship between individual measures and influence factors. The design direction means the precedence relationship between total area and area of individual measure, this study assumes that there are positive designs, reverse design, uncertainty direction design, which is verified through model simulation results. Positive design firstly determines total area, and then determines the area of individual measure which is obtained through the total area that is subtracted by the area of other measures, the influence of other factors is small. In other words, positive design is not specifically designed about an area of individual measure. On the contrary, if each individual measure is decided by the respective influences factors but are not affected by the total area, and the total area is not individually designed in the design process, this design is described as reverse design. So, reverse design is the total area of control measure without individually designed. Suppose the model results support neither positive design nor reverse design, it is classified as uncertainty direction design. The relationship among measures means the precedential order of area of the relatively independent design, and the correlation among the area of measures. Design strategy of soil and water conservation measures are often neglected in previous research, in some related study, it is mainly based on qualitative analysis, the relationship among measures and relationship between measure and influence factors are not clear. In order to resolve the problem, the study must be based on professional analysis, put forward possible relationship between measure and influencing factors from theoretical perspective and construct a hypothetical model. The correctness of proposed theory is verified by model accuracy. If the accuracy of the model is high, the constructed model and the proposed theory can be accepted; on the contrary, the proposed theory cannot accept. Compared to the common modelling methods, this method contains theoretical analysis. The reasons are that, in many scientific problems, preliminary research has raised the relationship framework among elements, influence factors (independent variables) of an element and relationship types have been determined; the study is to explore a particular solution of the problem under the conditions of fixed independent variable and fixed model type. However, this study explores the relationship between measures and influence factors with uncertain independent variable and uncertain mode type. In the process of modelling, there may be many factors which can affect soil and water conservation area of individual measures; if the model involves too many factors, it will be complex and its practical operation will be very poor. There may be a relatively simple design method of soil and water conservation plan in small watershed. The study should try to build minimalist model to describe the design of measures and to reflect the actual design idea as much as possible.

4.1.1 Correlation validation among measures

As mentioned before, the area of 5 single-item measures equals to soil and water erosion management area, the equation is:

$$Z = \sum Y_i \qquad \ldots \quad (1)$$

Z is water and soil erosion area, Y_i is respectively the area of each measure, which includes the area of terracing (Y_1), soil and water conservation forest (Y_2), cash forest (Y_3), closing hillside (Y_4), conservation tillage (Y_5). In order to analyze the relationship between the 5 soil and water conservation measures and influence factors, we need to establish the model of area and influence factors. The model can be 5 independent relationship models or coupling model that contains 5 independent variables, which depends on whether there is collinear relationship among the 5 measures (dependent variables). The correlation analysis showed that (Table 1), there are 5 significant correlations among the 5 types of measures; therefore, it is not consistent with the relationship nature to respectively study the measures. We should establish coupling model which contains 5 dependent variables. The equations are (equation 2):

$$\begin{cases} Y_1 = f(X_i) \\ Y_2 = f(X_i) \\ Y_3 = f(X_i) \\ Y_4 = f(X_i) \\ Y_5 = f(X_i) \end{cases} \qquad \ldots \quad (2)$$

Here X_i refers to all the influence factors of measure area.

4.1.2 Research method of design direction

The meaning of equation (2) is the previous reverse design strategy. The condition of model establishment is that the decision coefficient of 5 sub-models reaches the requirement; the study selects 0.36 as the evaluation criteria. If one sub-model in equation (2) (here select Y_5 model as an example) is not up to the accuracy requirement, the model needs to be improved. The methods are: turn equation (1) into equation (3), and model (2) is expressed by model (4). The meaning of model (4) is positive design, which firstly decides total area, and then determines the area of each measure that is restricted by total area. If more than two sub-models are not up to the accuracy requirements, model (3) and model (4) are not up to the accuracy requirements, we need to take other ways to improve modelling. In this case, design direction is not discussed.

$$Y_5 = Z - Y_1 - Y_2 - Y_3 - Y_4 \quad \ldots \quad (3)$$

$$\begin{cases} Y_1 = f(X_i) \\ Y_2 = f(X_i) \\ Y_3 = f(X_i) \\ Y_4 = f(X_i) \\ Y_5 = Z - Y_1 - Y_2 - Y_3 - Y_4 \end{cases} \quad \ldots \quad (4)$$

4.1.3. Assumption of model types

The model illustrates the relationship between area and influence factors. For statistical model, it also contains linear and non-linear forms. Model form depends on objective, if the study wants to accurately express a target, it often requires relatively complex model, while if the study aims for a practical and easy target, it needs a simple model. This study belongs to the latter, therefore the study aims to establish a linear model and simplify the model as much as possible.

4.1.4. Independent variables selection of minimalist model

There may be numerous factors in affecting soil and water measure area, from professional knowledge perspective; present land use, socio-economic status, investment, water and soil erosion management area and area of other measures are likely to be the influence factors of each measure area. The model includes many independent variables, which has become a coupling relationship model. The equations are (equation 5):

... (5)

X_1 is present land use variable, X_2 is socio-economic variable, X_3 is investment variable, X_4 is water and soil erosion management area, X_5 are other variables.

From the demand of simplified model, the ideal model should be composed of 5 linear equations, and the variables of different sub-models are the same. To achieve this goal, we need to analyze the previous 5 categories of factors, and screen the most likely independent variable. If we select the area of other measures as independent variable, an equation that a dependent variable is equal to independent variable must appear, such as equation (6), and the equation loses the meaning.

$$Y_2 = Y_2 \quad \ldots \quad (6)$$

If we choose land area with a certain type as independent variables, it is difficult to select the appropriate independent variable due to various land types; socio-economic and investment also have the same situation. Therefore, this research attempts to choose water and soil erosion control area as independent variables to establish model. If the design is a reverse process, the model form looks like equation (7); If the design is a positive process, then the model forms looks like equation (8). The study accepts the model with relatively high precision.

$$\begin{cases} Y_1 = a_1 + b_1 \times Z \\ Y_2 = a_2 + b_2 \times Z \\ Y_3 = a_3 + b_3 \times Z \\ Y_4 = a_4 + b_4 \times Z \\ Y_5 = a_5 + b_5 \times Z \end{cases} \quad \ldots \quad (7)$$

$$\begin{cases} Y_1 = a_1 + b_1 \times Z \\ Y_2 = a_2 + b_2 \times Z \\ Y_3 = a_3 + b_3 \times Z \\ Y_4 = a_4 + b_4 \times Z \\ Y_5 = Z - Y_1 - Y_2 - Y_3 - Y_4 \end{cases} \quad \ldots \quad (8)$$

Y_1-Y_5 are respectively the area of 5 types of soil and water conservation measures, Z is water and soil erosion management area.

In order to construct model (7) and model (8), the study uses path analysis method and MATLAB software programming.

5. Results

5.1 Design direction analysis

The study obtains equation(9) according to above modelling, the accuracy precision of sub-model 2 in 5 sub-models is low, which affects the whole accuracy of the coupled model, so that the model cannot be used, we must try to improve the model's precision to obtain acceptable results. The improved method selects area of the remaining 4 measures as the research object to establish model, and the area of closing hillside measure is the difference between water and soil erosion area and the area of other measures, the improved model(equation 10) has reached the modelling accuracy.

From equation (10), 5 kinds of measures are not parallel design, but positive design process which firstly determines water and soil erosion management area, and then designs other measures, the final difference value is for closing hillside area, in other words, closing hillside measure is the last to be designed.

... (9)

$$
\begin{cases}
Y_1 = -1.3331 + 0.3080 \times Z & R^2 = 0.4436 \\
Y_3 = -0.0148 + 0.1183 \times Z & R^2 = 0.3932 \\
Y_4 = -0.0278 + 0.2135 \times Z & R^2 = 0.5978 \\
Y_5 = 0.0539 + 0.2390 \times Z & R^2 = 0.5742 \\
Y_2 = Z - Y_1 - Y_2 - Y_3 - Y_4 & R^2 = 1
\end{cases} \quad \ldots \quad (10)
$$

Y_1 is conservation tillage area, Y_2 is closing hillside area, Y_3 is terracing area, Y_4 is cash forest area, Y_5 is soil and water conservation forest area, Z is water and soil conservation area

Ecological environment construction project is a global engineering, the design strategy of measure is policy and technical issue, but the related theoretical research of design strategy has not been reported. From the policy implementation, positive process is more easier. Water and soil erosion management area is closely related to investment, positive design determines the amount of investment more easily, and then determines the management area, so that the government can wholly seize the funding and management effect. On the contrary, in reverse design process, government is difficult to clearly understand investment and management effect before the project is finally determined, this will influence decision-making to a large extent. Therefore, positive design has greater possibility in practical implementation. From the theoretical support of implementation, positive design process is more fitted to related theories. It firstly decides water and soil loss management area, and then decomposes it into area of each measure, this approach is possible. The previous research showed: control degree has a significant influence on benefits of sediment reduction, soil and water loss can be better controlled by determining control degree. Secondly, control area is more easily to grasp than area of each measure, the maneuverability is stronger, and the effect is relatively more measurable. Although the benefits of sediment reduction of each measure has been studied a lot, but their effect in actual engineering remains to be validated, and the coupling effects of different measures combination are difficult to measure. Relatively speaking, to forecast water and sediment benefit through management degree is more testable. From the importance perspective, positive design process conforms to efficiency characteristic and implementation difficulty of different measures. In the two models, the difference exists in the sub-model of closing hillside measure. The relevance between area of closing hillside and water and soil erosion control area is far lower than other measures (Table 1), which may be caused by two reasons. First, the land with high erosion degree has control priority in water and soil loss control, such as wasteland and steep slope cropland, so they may have significant correlation with control measures of this two kinds of land, such as soil and water conservation forest and cash forest. Since the control of weak erosion land is relatively in less important position, the correlation between land and land management is not high, such as closing hillside measure of grassland and open forest land. Second, from the measures' implementation difficulty, closing hillside can take protection measures, which is relatively simple compared to other measures. From investment amount, other measures need to invest a large number of materials and labour costs; the investment is large per unit area, while the investment of closing hillside is small. The previous reasons may cause the production of other measures in preference to closing hillside measure.

According to "regulation of acceptance for comprehensive control of soil erosion", the small watershed which belongs to national key and all level key management district should achieve first grade level, sediment must reduce by more than 70% after the treatment, in order to ensure this goal, comprehensive control of small watershed should firstly target the land with high erosion degree, and then consider weak erosion land, such as open and young forest land.

From control requirements, positive design process conforms to the related standards on comprehensive control

TABLE 1: CORRELATION ANALYSIS OF SOIL AND WATER CONSERVATION MEASURES

	Conservation tillage	Closing hillside	Terracing	Cash forest	Soil and water conservation forest	Management area
Conservation tillage	1	-0.252	0.343 (*)	0.645 (**)	0.151	0.666 (**)
Closing hillside	-0.252	1	-0.142	-0.068	0.528 (**)	0.35 (*)
Terracing	0.343 (*)	-0.142	1	0.608 (*)	0.51 (**)	0.627 (**)
Cash forest	0.645 (**)	-0.068	0.608 (**)	1	0.340 (*)	0.773 (**)
Soil and water conservation forest	0.151	0.528 (**)	0.510 (**)	0.340 (*)	1	0.758 (*)
Management area	0.666 (**)	0.35 (*)	0.627 (**)	0.773 (**)	0.758 (**)	1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed)

of soil and water loss in small watershed. Other measures area mainly depends on water and soil erosion control area, but closing hillside is different which may have relationship with determination method of water and soil erosion control area. In studying small watershed, the average percentage between water and soil erosion control area and water and soil erosion area is 94%, which shows that not all erosion land is being in control. In this case, there are two ways to determine the area of each measure, the first is that the area of different erosion land types is reduced, that is to say the area of all kinds of measures is reduced. In this case, the land with high erosion degree such as steep slope cropland, cannot completely be governed, this is at odds with the state promulgated laws that steep slope cropland must be returned to forest, which is basically impossible. The second is to ensure the control area of some certain land types and reduce management area of one certain land type. In this case, the land with high erosion degree such as wasteland and steep slope cropland, can be completely controlled, which can ensure the indicator that sediment can reduce by more than 70%. The closing hillside measure of open and young forest land does not have decisive influence on management target due to the relatively small erosion reduction effect. Since control degree of each small watershed is different and each measure have some fluctuation, it is difficult to have significant correlation between closing hillside measure and water and soil erosion management area.

5.2 Relationship among measures

The result of positive design is that one measure area is generated after the area of other measures. Therefore, measure area is not generated simultaneously, but successively. In addition to closing hillside, the other 4 measures also have generation order. The analysis of design order can also be obtained from the correlation level between single measure area and total area in addition to from positive design perspective. The correlation level between conservation tillage area and water and soil erosion control area is poor, so, conservation tillage is identified as the last generation. In other 4 measures, terracing model has the smallest decision coefficient and the lowest relationship with water and soil erosion management area, it can be explained as the last design. The conclusion is not contradictory with parallel design, because in small watershed conservation planning process, the 4 measures area is not necessarily determined at the same time, but one by one according to the sequence. According to the determination coefficient, the design order of 4 measures is cash forest > soil and water conservation forest > conservation tillage > terracing. Although there is design order, there is no decisive relationship among each other, and they are all determined by water and soil erosion management area, which can be accepted as parallel design assumption. There is correlation relationship among the various measures area, the area is not an independent design, but influences each other, so, it can be defined as parallel coupling design. From the implementation object of measures, the parallel coupling relationship conforms to the actual situation of design. In the actual planning design and decision-making process, the four measures have different objects, soil and water conservation forest and cash forest aim at wasteland and steep slope farmland; terracing and conservation tillage aim at gentle slope land, so, the measures do not affect each other in principle, which belongs to parallel design. For the above land types which are affected by population density, soil and other factors, each small watershed has certain flexibility in the implementation process, rather than conforms to certain slope. For example, some small watershed still exist steep slope farmland after management, and do not secede farmland according to unified slope. So the control measures of different slope land such as tillage, terracing, cash forest and soil and water conservation forest exist cross and correlation, therefore, this can be called parallel coupling design.

5.3 Analysis of design strategy

According to formula (10), the area of conservation tillage, terracing, cash forest, soil and water conservation forest respectively accounts for 31%, 12%, 21%, 24% of the water and soil erosion control area, and there is certain fluctuation. The area of closing hillside is the area difference between water and soil erosion management area and the area of other four measures. Cash forest and soil and water conservation forest are conducted in wasteland or steep slope farmland, so, the area belongs to afforestation and reforestation area and accounts for 45% of the total area, this has gone beyond the occupation rate of wasteland and steep slope cropland, because wasteland accounts for only 5%, the afforestation is not only limited to steep slope farmland but also slope afforestation; but there may not be a unified slope of each small watershed. Therefore, conservation tillage and terracing also do not exist a uniform slope that consistent with the previous analysis.

The farmland area after treatment is still more than 50%, which is far higher than the percentage of farmland covers in Mandal Soum, Selenge province, and is also higher than the percentage of farmland covers around the Ereen. In the adjustment process of land use structure, farmland area in most of the small watershed inevitably declines, only some can still maintain its farmland area. Farmland includes basic farmland and other farmland, paddy field and trace belong to basic farmland, which are state protection and no development of farmland. While slope farmland is at a lower level, it is the main type of returning farmland to forest, so, slope farmland that adopts conservation tillage measure after water and soil erosion management is the main land type of future returning farmland to forest. After the treatment, the occupation percentage of slope farmland area is 21%, which is far higher than the average level of Mandal Soum, Selenge province. It also is the focus of the adjustment of land use structure, and its main approach is to return farmland to forest.

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