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Practical Exploration of Eco-Geological Survey Mapping in Qinghai–Tibet Plateau: Framework, Standard and Preliminary Cost Estimation

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Abstract: It is a common responsibility of all countries to protect the ecological environment and promote sustainable development. Eco-geology, which provides a basic guarantee for the rational utilization of natural resources, ecological protection and restoration, has gradually become a new hot spot of geological survey institutions in various countries. Eco-geological survey in the Qinghai–Tibet Plateau plays an important role in regional ecological protection and global change research. Setting up workable budgets symbolizes the competence of geological survey organizations in fulfilling their responsibilities, and unreliable cost estimates can cause economic and political complications. The unclear scope definition and scarcity of project information available at early stages make it hard to generate reliable preliminary cost estimates. Hence, based on historical data and the practical experience of scientists who have been engaged in eco-geological survey in the Qinghai–Tibet Plateau for a long time, this research aimed to develop a cost estimation model using statistical learning methods for geological survey organizations to forecast preliminary costs during the early stages of an eco-geological survey project to fulfill different cost control and managerial functions. This research makes full use of modern remote sensing technology and reasonably arranges the input of ground survey, drilling, geophysical exploration and other workloads, supplemented by the existing ecological monitoring station data. It comprehensively sorts out the work means and workload of field and office work needed to complete the map work, and it puts forward a consistent index system and preliminary cost calculation framework. On this basis, based on the principle of matching quantity and price, a reasonable budget standard or market price is selected to calculate the budget estimate of a single map sheet, and then, through the regional adjustment coefficient, the budget estimate of a map sheet covering the whole Qinghai–Tibet Plateau is extended and calculated. The budget estimate will provide effective support for the declaration of eco-geological survey projects in the Qinghai–Tibet Plateau and the calculation of the scale of project funds so as to ensure the smooth development of eco-geological surveying in the region.

Keywords: preliminary cost estimation; eco-geological survey; Qinghai–Tibet Plateau

1. Introduction

Climate warming, environmental degradation, frequent disasters and other ecological degradation phenomena are global problems, which pose a serious threat to human survival and sustainable economic development [1,2]. The United Nations attaches great importance to the protection of the ecological environment and has issued "Transforming our world: the 2030 Agenda for Sustainable Development" [3]. The eco-geological survey is based on the regional geological survey, focusing on identifying the eco-geological status, main eco-geological problems and the control relationship with the basic geological background

and realizing the dynamic evaluation of eco-geology so as to regulate human activities and reduce the threat of ecological destruction to human beings [4]. The Qinghai–Tibet Plateau has a special location, complex landform and abundant resources, possessing important climate regulation, ecological security and unique geographical significance for China and even the whole world. Carrying out the eco-geological survey of the Qinghai–Tibet Plateau and evaluating the changes in the eco-environmental quality of the Qinghai–Tibet Plateau play an important role in regional ecological protection and global change research. Since 2019, China has deployed 1:50,000 ecological geological surveys and maps in the Qinghai–Tibet Plateau. Three maps of the source region of the Yellow River and the source region of the Yangtze River have been completed, and the ecological pattern of the 132,000 square kilometers of the source region of the Yellow River has been preliminarily mastered, and the spatial characteristics and distribution of water and vegetation resources in the region have been explored [5]. The model and measures of ecological protection and restoration were put forward, and remarkable results were achieved.

Preliminarily estimating the project cost is an important process in the early stage of the geological mapping project. Accurate cost estimation prevents major issues like cost deficiency and disputes in the project. Identifying the affected parameters to project cost leads to accurate results and enhances cost estimation accuracy. Due to the high degree of freedom in eco-geological surveying and the uncontrollable cost, the risk of the project is greatly increased. Therefore, based on the relevant technical standards and specifications, this paper systematically sorted out the theoretical and practical exploration of the 1:50,000 eco-geological mapping in the Qinghai–Tibet Plateau, with commonly used work means and workload, making full use of modern remote sensing technology, rationally arranging the input of ground survey, drilling, geophysical exploration and other workloads and supplementing the existing ecological monitoring station data, comprehensively sorting out the field and internal work means and workload that need to be addressed to complete the map work. A consistent index system and preliminary cost estimate framework are put forward to provide a reference and standard for the budget of the eco-geological survey in this area and ensure the smooth development of the eco-geological survey in this area.

2. Literature Review

In recent years, geological survey institutions in some countries such as the United States, Britain, Russia and Japan have adjusted their tasks and directions, gradually breaking the traditional orientation and development model and focusing on resource exploration and development, disaster prevention and mitigation. They began to explore the role of human beings in the ecological environment and the coupling relationship between them from the perspective of Earth System Science [6–9], not only listing eco-geological surveying as an integral part of the national medium- and large-scale geological maps but also carrying out special geological surveys, such as agricultural eco-geology, urban eco-geology, eco-geology of large rivers and lakes and eco-geology of large projects [10–12]. The regional eco-geological mapping work in China started relatively late. Since the deployment and implementation of the "1:250,000 Tieling City Sheet Eco-Geological Survey" project in 2003, the technical and methodological system of eco-geological survey has been initially established through continuous exploration and practice and is currently being promoted and practiced throughout the country [13–16].

Global warming and glacier retreat have significant impacts on the structure and function of natural ecosystems in the Qinghai–Tibet Plateau [17–19]. On the one hand, the Qinghai–Tibet Plateau itself contains major ecological assets, which are transferred to the areas outside the plateau through various biogeochemical cycles, providing material and energy input for the sustainable development of the population, resources and environment in the lowland areas of Asia. On the other hand, in the past 30 years, the trend of global warming has become more and more obvious; combined with the impact of human activities, various ecological, geological and environmental factors on the

plateau have undergone rapid adaptive changes, such as the sharp retreat of the modern glacier snow line, the reduction in water wetland area, the expansion of desertification, the degradation of grassland, the melting of the permafrost layer and the occurrence of geological disasters such as collapse, landslide and debris flow. These changes not only deteriorate the ecological environment quality of the Qinghai–Tibet Plateau itself but also adversely affect the ecological environment quality of eastern China and the sustainable development of the social economy in China [20–22]. Therefore, an eco-geological survey should be carried out in the Qinghai–Tibet Plateau, and the spatial distribution pattern, change law and geological process should be studied as a whole so as to obtain the integrated ecology–soil–water–weathering crust-rock information above and below the ground, scientifically assess the ecological situation and evaluate the quality of the ecological environment of the Qinghai–Tibet Plateau. It plays an important role in regional ecological protection and global change research [23,24].

Carrying out the eco-geological survey of the Qinghai–Tibet Plateau and evaluating the changes in the eco-environmental quality of the Qinghai–Tibet Plateau play an important role in regional ecological protection and global change research. Much progress has been achieved in the eco-geological survey of the Qinghai–Tibet Plateau [25–27]. After years of field mapping practice, the current situation of grassland and vegetation, the distribution law and type of "three modernizations" (grassland degradation, desertification and salinization) and the identification of geological, geomorphological, hydrogeological and environmental geological units have been realized, as well as the regional and watershed scale (1:250,000). The impact of the Yellow River drying up and regional groundwater drawdown on the water resources and geological environment in the middle and lower reaches of the Yellow River source region, as well as the evolution characteristics and development trend of glaciers, frozen soil, water environment and marshes and wetlands in the source region of the Yangtze River, provide a scientific basis for the ecological environment protection of the Yellow River and the source region of the Yangtze River. It provides a decisionmaking basis for the layout of local agriculture and animal husbandry and sustainable economic development [28,29]. However, due to the dual effects of climate change and human action, the natural resources such as forest, grass and wetland in the ecological barrier area of the Qinghai–Tibet Plateau tend to be degraded to a certain extent, and the trend of the future evolution of the ecological environment is not clear, so the leading factors and related control mechanisms of these changes need to be investigated and studied more deeply. In response to these problems, China began to deploy the eco-geological survey of the Qinghai–Tibet Plateau at the ecosystem scale (1:50,000) in 2019. At present, three maps of the source areas of the Yellow River and the Yangtze River have been completed, and the eco-geological survey technology of the alpine ecological process and the alpine region guided by remote sensing has been preliminarily established. By investigating the ecological pattern in the source region of the Yellow River within 13.2 of ten thousand kilometers, the spatial characteristics and distribution laws of water resources and vegetation resources in the region were explored, and the types, degrees and evolutions of ecological problems such as grassland desertification, wetland shrinkage and ecological service function degradation were investigated; moreover, the controlling and influencing factors were analyzed and the formation mechanism was studied. The mode and measures of ecological protection and restoration were put forward [14].

However, the current basic geological survey of the Qinghai–Tibet Plateau is still far from sufficient, and the ecological geological survey is still in its infancy, which has difficulty meeting the urgent needs of the ecological protection practice of the Qinghai–Tibet Plateau. The main deficiencies are reflected in the following three aspects: first, due to the division of ecological management responsibilities in different institutions in the past, there is a lack of systematicness and integrity. Neglecting or despising the investigation of natural endowment conditions such as water resources, soil, light and heat, DD 2019-09 Technical Requirements for Eco-geological Survey [30] stipulates the requirements for the purpose, task, basic requirements, work quota (minimum workload requirement), design

compilation, survey content, technical methods, comprehensive evaluation, database construction, results compilation, field acceptance and review of ecological geological survey and comprehensively standardizes and guides the work of ecological geological survey. Secondly, the eco-geological problems in the Qinghai–Tibet Plateau are complex and diverse, and the mechanisms of many important eco-geological problems are not yet clear. Up to now, only three maps have been completed in the 1:50,000 eco-geological survey and mapping. It is necessary to further carry out the 1:50,000 eco-geological survey in the Qinghai–Tibet Plateau to clarify the eco-geological background in the region and provide technical support for the ecological protection and restoration in the region. Third, the cost of eco-geological survey is not clear; 1:200,000 and 1:50,000 eco-geological mapping, respectively, reach 180,000–190,000 and 65,000–70,000/km^2 per year in Russia [31]. The costs of a 1:500,000 eco-geological survey in the forest, grass and wetland distribution areas in northern China and 1:50,000 eco-geological survey in key ecological function areas such as the source area of the Yellow River and the Daliangshan area range from 20,000 to 6000 CNY/km^2, with a very large gap.

Budget estimate plays a vital role in the management of geological mapping projects, which is not only the basis of investment allocation but also directly affects the quality, schedule and cost of the project [32–35]. However, in order to save time, some project-undertaking units only pay attention to the surface in the design stage without taking other factors into account, resulting in a lack of a basis for the preparation of budget estimates and unreasonable investment, which results in inconvenience regarding the geological mapping work [36–39]. Due to the high degree of freedom of eco-geological surveying and the uncontrollable cost, the risk of the project is greatly increased. Therefore, this paper will focus on how to quickly and accurately estimate the budget in the design stage.

3. Methodology

Due to the lack of previous research on the 1:50,000 eco-geological survey cost in the Qinghai Tibet Plateau, this study builds a framework of work means based on the settlement data of completed ecological geological survey projects according to statistical analysis, analogical comparison and expert opinion methods. In accordance with the "quantity, price, and cost" model, we calculate the cost of the map. Finally, based on the regional adjustment coefficient, we calculate the map cost for other regions. Specifically, as follows:

Firstly, we collect the data of eco-geological survey projects over the years. Through statistical analysis, the settlement data of a large number of completed projects were systematically counted, sorted out and analyzed, and outdated working means were removed and common working methods were selected to build a frame of 1:50,000 eco-geological survey mapping means, as shown in Figure 1.

Then, through the completed project data, using statistical analysis [40,41] and expert opinion method [42,43], we choose the corresponding terrain grade and geological complexity to adapt to the characteristics of the area. Combined with the requirements of technical specifications, we determine the workload and accuracy requirements of the 1:50,000 map and sort out the common technical conditions in the Qinghai–Tibet Plateau region.

Next, for the work means regarding workload that can be counted, we calculate these costs according to the principle of volume price, combined with the current budget standard or market price. For the work means regarding workload that cannot be counted, such as rock and mine testing and equipment purchase, we control these costs according to the statistical data of the project implementation in previous years [44,45]. Afterwards, we summarize the estimate of map and unit area.

Finally, according to the regional adjustment coefficient, we calculate the map estimate and unit area estimate suitable for other regions of the Qinghai–Tibet Plateau.
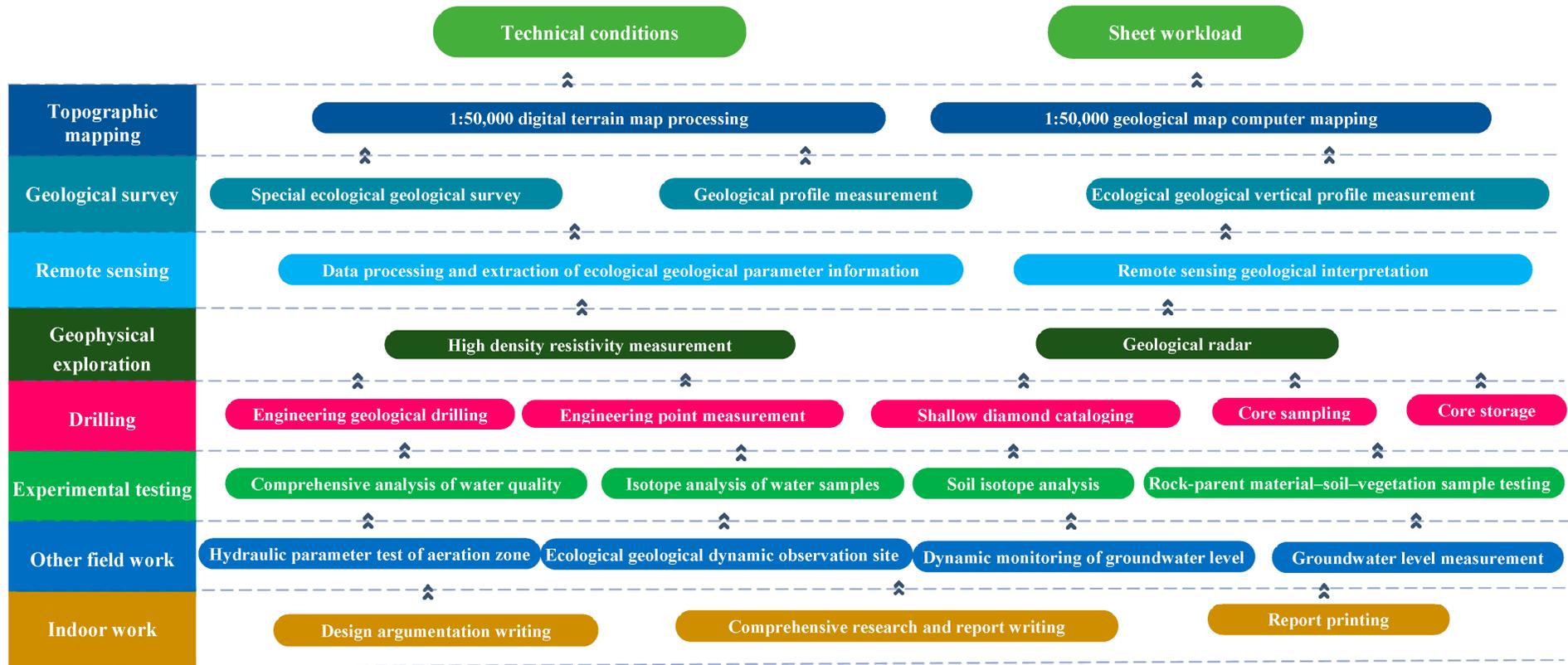
Figure 1. Frame diagram of working means required for 1:50,000 eco-geological survey mapping.

4. Results: Modeling of 1:50,000 Eco-Geological Survey Budget in the Qinghai–Tibet Plateau

(1)   Build the basic framework

The basic framework is based on the usual workload of the areas where geological survey work is often carried out in the Qinghai–Tibet Plateau (except the northern Tibet region). The basic structure is the combination of various working means vertically and the combination of volume and price horizontally, which can be called the volume-price structure model of working means in general.

(2)   Sorting out work means and workload

The work means to complete the 1:50,000 eco-geological survey on the Qinghai–Tibet Plateau mainly include topographic mapping, geological survey, remote sensing, geophysical prospecting, drilling, experimental testing and other geological work. By sorting out the relevant requirements of DD 2019-09 Technical Requirements for Eco-geological Survey (1:50,000) and other relevant technical standards (specifications), consulting scientists who have been engaged in eco-geological survey in the Qinghai–Tibet Plateau for a long time and checking the fund settlement of existing projects, the specific work means and workload can be refined as follows:

①   Topographic mapping. Before the project team conducts field work, it is generally necessary to carry out a 1:50,000 digital terrain map processing work and a 1:50,000 geological map computer mapping work for the entire area. The purpose is to carry out targeted ecological geological survey work based on previous work.

②   Geological survey. First, according to the eco-geological conditions and the main eco-geological problems in the survey area, the survey is carried out by means of actual measurement, revision or compilation. The layout of the observation route is mainly based on the crossing method. The route crossing should be perpendicular to the maximum change direction of vegetation type or geomorphologic type, covering different eco-geological types as far as possible. The workload of 1:50,000 special eco-geological survey is required. The second is to select representative sections to carry out profile survey. Important eco-geological types should be controlled by 1–2 survey profiles, and the surveying and mapping accuracy should be 1:500–1:2000. According to the actual work experience of the project, a map is generally deployed for 2 km of 1:5000 geological profile survey and 1 km of 1:2000 geological profile survey. The third is to select representative ecology–soil–water–soil–parent material–rock profiles in the survey area or adjacent area, establish typical marks and unify working methods. According to the actual working experience of the project, a map should generally be deployed with a 1:10 ecological geological vertical profile measurement at 19 locations.

③   Remote sensing. Remote sensing data with spatial resolution better than 16 m are generally used in regional eco-geological survey, and remote sensing data with spatial resolution better than 2 m are used in eco-geological survey in key areas. Under the condition of meeting the accuracy of remote sensing survey, qualified remote sensing data sources with rich image levels, clear images, uniform tones and moderate contrast should be selected. Priority should be afforded to the use of satellite image data such as domestic Resource 3, Gaofen 1 and Gaofen 2. The data source of an eco-geological survey should have a strong current situation, and the vigorous growth period of vegetation should be generally selected. The extraction of ecological information mainly includes plant coverage, net primary productivity, leaf area index and distribution of vegetation types. The content of remote sensing interpretation should generally include the spatial distribution, types and dynamic changes of forests, grasslands and wetlands, as well as eco-geological problems and their influencing factors. Remote sensing interpretation should run through the whole process of field survey, design and compilation and ground survey and report compilation. Therefore, data processing of all elements and information extraction of eco-geological parameters

should be deployed for a map, and the workload of 1:50,000 remote sensing geological interpretation should be set for the whole map.

④ Geophysical prospecting. For areas with unknown physical properties and disputed geological effects, the applicable test work shall be carried out before the arrangement of geophysical prospecting; the geophysical prospecting profile shall be arranged along the direction with the greatest change in ecological and geological conditions; in the case of a difficult solution, multiple solutions or disputed interpretation results, a variety of methods or other exploration means shall be used for comprehensive judgment. Geophysical prospecting with high precision can be carried out in key sections. The eco-geological survey is mainly focused on the shallow layer to the surface, and 600 points of high-density resistivity survey and 5 km of geological radar are generally deployed in one map.

⑤ Drilling. The drilling work is mainly arranged in the karst mountain area and wetland distribution area. At the end of drilling, the exposed strata shall be accurately stratified, and backfilling or isolation and hole sealing shall be carried out according to the water head and water quality of the aquifer. Boreholes requiring final completion shall be adequately flushed, and infiltration and pumping tests shall be properly conducted to determine the permeability parameters of the aquifer and vadose zone. According to the project experience, 150 m of engineering geological drilling is generally deployed for a map in the Qinghai–Tibet Plateau. The workload of engineering point survey and shallow drilling logging corresponds to the number of drilling holes of 15 points and shallow drilling logging of 150 m. Set 120 m core sample (recovery rate 80%) and 150 m core storage according to the footage.

⑥ Experimental test. Rock and mineral analysis, soil analysis, water analysis, weathering crust, aeration zone, soil parent material analysis, vegetation test and analysis are carried out according to the eco-geological conditions, the needs of eco-geological investigation and the characteristics of sample composition. According to the actual experience of the project, experimental testing methods such as water quality comprehensive analysis, water sample isotope analysis, soil isotope analysis and rock-parent material–soil–vegetation sample testing are deployed.

⑦ Other geological work. According to the actual experience of the project, each map of the Qinghai–Tibet Plateau generally needs to set up six eco-geological dynamic observation sites, three-hundred-twenty groundwater level dynamic monitoring points and one-hundred-twenty groundwater level unified measurement points.

⑧ Indoor work. The preparation of design demonstration at the initial stage of project implementation and the preparation of comprehensive research and report at the end of the project and the printing of the report should also reflect the workload.

(3) Unit price selection for preliminary cost estimate

The unit price selection of work means should focus on matching the minimum accounting unit of workload. At present, the most authoritative price standard in China's geological industry is the Budget Standard for Geological Survey Projects (2021) [46] issued by the China Geological Survey, which is filed with the Ministry of Finance and widely used in the budget and accounting of project funds of geological prospecting units. Therefore, the work means included in the Budget Standard for Geological Survey Projects (2021), such as topographic mapping, geological survey, geophysical and geochemical exploration, drilling, mountain engineering (pit exploration, shallow well exploration and trenching), experimental testing, other geological work, site construction, regional adjustment coefficient, etc., involved in this paper shall be priced with reference to the budget standard. Two points should be heeded: one is site construction, which refers to the construction of simple houses, simple roads, bridges and water towers, the erection of transmission and communication lines, the purchase of mobile houses, tents and Mongolian yurts and the maintenance of the above-mentioned site buildings in or near the operation area. The site construction cost of the eco-geological survey shall be 8% of the field work means according to the Budget Standard for Geological Survey Projects (2021). Second,

regarding the regional adjustment coefficient, because the budget standard is based on the national basic level as the main basis, the price difference caused by objective factors in different regions is corrected by the regional adjustment coefficient; there are many factors affecting the regional adjustment coefficient, mainly considering the field construction period, wage level, transportation conditions and other major factors. The Budget Standard for Geological Survey Projects (2021) divides the country into 11 regions, as shown in Appendix A.

For the temporary shortage work means in the "Budget Standards for Geological Survey Projects (2021)", such as 1:10 eco-geological vertical profile measurement, geological radar, rock-parent material soil vegetation sample testing, aeration zone hydraulic parameter testing, eco-geological dynamic observation sites, groundwater level dynamic monitoring, etc., reference should be made to relevant industry budget (cost) standards or the average pricing should be taken based on the settlement situation of existing projects.

(4)　Cost estimate for image frames

The above workload is based on the areas where eco-geological surveys are frequently conducted on the Qinghai–Tibet Plateau (except for the northern Tibet region, with a regional adjustment coefficient of 1.9). According to the volume-price structure model (Table 1), the field and office unit estimates for 1:50,000 eco-geological surveys (in the Qinghai–Tibet Plateau) with a regional adjustment coefficient of 1.9 can be calculated, providing basic data for cost estimation under other regional adjustment coefficients in the next step.

Table 1. Cost estimate for 1:50,000 eco-geological survey (Qinghai–Tibet Plateau).

Means	Workload			Unit Budget Standard (CNY)	Cost (Ten Thousand CNY)
	Technical Conditions	Unit of Measurement	Sheet Workload		
a	b	c	d	e	f = d × e/10,000
1. Topographic mapping					**2.26**
1:50,000 digital terrain map processing	total factor	sheet	1	12,000	1.20
1:50,000 geological map computer mapping	difficulty category level II	sheet	1	10,600	1.06
2. Geological survey					**116.82**
1:50,000 special ecological geological survey	moderately complex area class II	km^2	420	1140	90.97
1:5000 geological profile measurement	moderately complex area class II	km	2	4428	1.68
1:2000 geological profile measurement	moderately complex area class II	km	1	8788	1.67
1:10 ecological geological vertical profile measurement	moderately complex area class II	point	15	15,000	22.5
3. Remote sensing					**30.53**
Data processing and extraction of ecological geological parameter information	total factor	km^2	420	513	21.55
1:50,000 remote sensing geological interpretation	Solvability level II	km^2	420	214	8.99
4. Geophysical exploration					**31.95**
High density resistivity measurement	level III, point spacing of 1–5 m	point	600	134	15.28
Geological radar		km	5	17,550	16.67

Table 1. *Cont.*

Means	Workload			Unit Budget Standard (CNY)	Cost (Ten Thousand CNY)
	Technical Conditions	Unit of Measurement	Sheet Workload		
5. Drilling					**20.29**
Engineering geological drilling	rock grade V, 0–10 m	m	150	383	10.92
Engineering point measurement		point	15	2488	7.09
Shallow diamond cataloging		m	150	32	0.91
Core sampling	80% coring rate	m	120	31	0.71
Core storage		m	150	23	0.66
6. Experimental testing					**27.66**
Comprehensive analysis of water quality	full analysis	sample	60	810	4.86
Isotope analysis of water samples	Isotopes of carbon, hydrogen, oxygen, etc.	sample	60	1200	7.20
Soil isotope analysis	Isotopes of carbon, hydrogen, calcium, gallium, etc.	sample	30	1200	3.60
Rock-parent material–soil–vegetation sample testing	Indicators such as total amount and effective state of elements	sample	120	1000	12.00
7. Other geological work					**43.84**
Hydraulic parameter test of aeration zone		group	4	5000	2.00
Ecological geological dynamic observation site		point	6	30,000	18.00
Dynamic monitoring of groundwater level	monitoring	point	320	60	1.92
Groundwater level measurement		point	120	700	8.40
Construction site construction	8% of field work costs				13.52
8. Indoor work					54.00
Design argumentation writing		copy	1	135,000	13.50
Comprehensive research and report writing		copy	1	325,000	32.50
Report printing		copy	1	80,000	8.00
9. Special instruments and equipment					**27.53**
Sheet estimation		ten thousand CNY/sheet			**354.87**
Per unit area estimation		CNY/km²			**8449**

The above work means and workload are based on the areas (except northern Tibet) where eco-geological surveys are frequently carried out on the Qinghai–Tibet Plateau (regional adjustment coefficient is 1.9). According to the volume-price structure model (cost = effort × price), the field and domestic unit budget estimates of 1:50,000 eco-geological survey (Qinghai–Tibet Plateau) can be calculated when the regional adjustment coefficient is "1.9" (Appendix A). In addition to the cost of the work means, the cost of completing a map should also include the cost of equipment and instruments, such as GPS, RTK, laptop and other necessary equipment for mapping. According to the historical project financial data, the average equipment purchases cost of the project team with a regional adjustment coefficient of 1.9 is CNY 275,300. This paper takes this average value as the benchmark to provide basic data for the next cost calculation under the adjustment coefficient of other regions.

After calculation, under the condition of a regional adjustment coefficient of 1.9, the estimated cost of a 1:50,000 eco-geological survey (in the Qinghai–Tibet Plateau) map is CNY 3.55 million per map, and the average area of the map is 420 km². The equivalent estimated cost per unit area of the map is CNY 8449/km².

(5)   Cost estimation models applicable to different regions

In order to make it convenient for users to calculate the total amount of funds quickly and directly by using the budgetary estimate when applying for funds, this paper incorporates the regional adjustment coefficient into the budgetary estimate model. According to the regional adjustment coefficient (Appendix A) in the Geological Survey Project Budget Standard (2021), the coefficient involved in the Qinghai–Tibet Plateau is 1.6–2.0, so the vertical structure of the calculation model is the combination of regional adjustment coefficients. Because the regional adjustment coefficient is only the adjustment of the cost of field work (geological survey, geophysical prospecting, drilling and field work in other geological work), the cost of office work (topographic mapping, remote sensing, experimental testing, indoor work in other geological work and purchase of special instruments and equipment) is basically similar through historical statistical analysis. Therefore, the horizontal structure of the calculation model is the combination of field costs and office costs.

After calculation, the field work cost with a regional adjustment coefficient of 1.9 is calculated as the field work cost with a regional adjustment coefficient of 1.6–2.0, and the office work cost is added to calculate the estimated cost of the 1:50,000 eco-geological survey (in the Qinghai–Tibet Plateau) map and unit area (Table 2). The estimated cost of the 1:50,000 eco-geological survey (Qinghai–Tibet Plateau) map is CNY 3,281,800 to CNY 3,637,700, and the estimated cost per unit area is CNY 7814/km² to CNY 8611/km².

Table 2. Cost estimate for 1:50,000 eco-geological survey (Qinghai–Tibet Plateau) under different regional adjustment factors.

Regional Adjustment Coefficient	Field Cost (Ten Thousand CNY)		Office Cost (Ten Thousand CNY)	Sheet Estimation (Ten Thousand CNY)	Per Unit Area Estimation (CNY/km²)
	Base Cost	Adjusted Cost			
a	b	$c = b/1.9 \times a$	d	$e = c + d$	$f = e/420 \times 10{,}000$
1.6	169.05	142.36	185.82	328.18	7814
1.7	169.05	151.26	185.82	337.08	8026
1.8	169.05	160.15	185.82	345.97	8237
1.9	169.05	169.05	185.82	354.87	8449
2.0	169.05	177.95	185.82	363.77	8661

5. Discussion

In the demonstration stage of eco-geological work, it is necessary to clarify the necessity and amount of each expenditure, incurred by the state and taxpayers. The core of project demonstration is to elaborate the necessity of project development from a technical point of view, and to explore the main engineering and technical means to achieve the preset objectives. Every work means is very clear, and many specific work details need to be implemented in the project design stage. A large number of practical experiences show that the scientific and simple method of budget estimation in advance should be adopted in the stage of project demonstration.

However, the budget estimate in advance is not a rough estimate based only on experience, which will lead to the phenomenon that the funds issued do not match the project tasks, resulting in difficulties in project construction and waste of funds. The establishment and improvement of a scientific and reasonable calculation standard is the monetary form of labor and material consumption of all engineering (work) means invested in completing a geological survey task of a certain measurement unit (map sheet, unit area, and resource quantity) of a geological survey project in a certain region and under certain

geological and technical conditions and natural conditions [47]. The calculation standard can basically determine the total project funds accurately and quickly, which is conducive to the preparation of a project design budget, the operation of the project, the use of funds and the rational allocation of funds.

The preliminary cost estimation model of eco-geological mapping in the Qinghai–Tibet Plateau constructed in this study mainly considers three factors: first, external conditions, including physical and geographical conditions, as well as geological complexity. Because the cost of completing geological projects with the same technical conditions varies greatly in different topographic grades and different geological complexities, these factors are fully considered in this study. Second, regarding the geographical factors, the complex terrain of the Qinghai–Tibet Plateau, for the whole region, it is obviously unreasonable to calculate only one cost. Combined with the regional adjustment coefficient in the Geological Survey Project Budget Standard (2021), the areas involved in the Qinghai–Tibet Plateau are adjusted according to the coefficient, which is simple and easy to use and easy to operate. Third is the workload factor; the formulation of the budget estimate is a very complex process, and this paper uses the project budget method, the proportional method and the expert opinion method. The project budget method is based on the settlement data of a large number of completed projects, through systematic statistics, collation and analysis, to remove unreasonable factors and obtain the universal workload according to the average value; the proportional method is to determine the workload according to the requirements in combination with the technical specifications. The expert opinion method is aimed at the workload of new technologies and methods that are not explicitly required in the technical standards and are not involved in the completed projects, and the workload is judged by experienced scientists through consultation.

This paper collected the actual expenditures of three completed 1:50,000 eco-geological survey projects in the Qinghai–Tibet Plateau and compared and verified the research results of this paper. The total workload is 1300 km^2, and the total funding is CNY 10.4 million. The average unit price of 1:50,000 eco-geological survey is about CNY 8000/km^2 through statistical calculation. According to the estimated average unit price of this paper, CNY 8237/km^2, the error with the actual unit price of the project is less than 3%.

The preliminary cost estimation model for the 1:50,000 eco-geological survey (Qinghai–Tibet Plateau) constructed in this study has been incorporated into the Geological Survey Estimation Standard (2022) [48], which has been officially published in 2023. The calculation model will effectively guide the demonstration work of the Qinghai–Tibet Plateau Eco-Geological Survey Project, improve the quality of the project demonstration, realize the scientific, fair and reasonable investment in the project and ensure the smooth implementation of the project.

6. Conclusions

This study is based on the technical specifications of a 1:50,000 eco-geological survey, combined with the practical experience of scientists who have been engaged in eco-geological survey work in the Qinghai–Tibet Plateau for a long time and previous project settlement data, comprehensively sorting out the work means and quantities of field and office work required to complete the map work and proposing an indicator system and pre-calculation framework, supplemented by appropriate budget standards and market prices. The estimated map size for the 1:50,000 eco-geological survey in the Qinghai–Tibet Plateau region is between CNY 3.28 and CNY 3.64 million, and the estimated unit area is between CNY 7814 and CNY 8661/km^2 (regional adjustment coefficient 1.6–2.0).

The innovation of the research results lies in changing the previous extensive cost estimation method at the project initiation stage, providing effective support for the project initiation and application of the eco-geological survey project in the Qinghai–Tibet Plateau, scientifically and quickly calculating the scale of project funds and ensuring the smooth development of the eco-geological survey work in the region. This method will also provide a reference for other professional geological surveys in other areas of the estimate.

However, with the progress in eco-geological surveying in China, more and more project settlement data will provide a broader sample for revising the work means, efforts and prices in the calculation model.

Appendix A

Table A1. Regional Adjustment Coefficient for the Budget Standards for Geological Survey Projects (2021).

Coefficient	Adaptation Region
2.0	Northern Tibet region
1.9	Other regions in Tibet, Qinghai Kunlun Mountains, Xinjiang Kunlun Mountains, Tanggula Mountains
1.8	Bayan Kara Mountains, Animaqing Mountains, Hengduan Mountains, southwestern region of Alkin
1.7	Yilehuli Mountain and Primitive Forest Area in the Greater Khingan Mountains
1.6	Qilian Mountains in Gansu and Qinghai, Western Tianshan Mountains in Xinjiang, Northeast Altyn Tagh, Altyn Mount Taishan
1.5	Aba region in Sichuan, Beishan Mountain range in Gansu and Xinjiang, East Tianshan mountain range in Xinjiang, Altay region in Xinjiang and other regions of the Greater Xing'an Mountains
1.4	Alxa region, Panxi region in Sichuan, Gannan region in Gansu, central and southern section of the Southwest Three Rivers, Qaidam region, Tarim desert region
1.3	Eastern Inner Mongolia (north of Zhalantun and Manzhouli), Xiaoxing'an Mountains, Changbai Mountains, Daba Mountains (adjacent to Sichuan, Shaanxi and Hubei), Qinling Mountains (adjacent to Shaanxi, Gansu, Sichuan and Henan), other regions of Qinghai, Helan Mountains in Ningxia
1.2	Other regions in Inner Mongolia, other regions in Heilongjiang, northern Shaanxi, other regions in Gansu, other regions in Ningxia, other regions in Xinjiang, the Nanling Mountain Mountains, Mount Wuyi, eastern the Yunnan-Guizhou Plateau, Dabie Mountains, Luliang Mountains, Wuzhi Mountains
1.1	Zhangjiakou and the northern part of Chengde, other regions of Liaoning, other regions of Jilin, Taihang Mountains, Mount Taishan Mountains, adjacent regions of Hunan, Hubei and Jiangxi (Mufu Mountain, Jiuling Mountain, Lushan Mountain), Yunkai Region, Northwest Guangxi, Northwest Hunan, other regions of Guangdong, other regions of Hainan, other regions of Guizhou and other regions of Yunnan
1.0	Other regions except for the aforementioned ones

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