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Review and Future Research Directions about Major Monitoring Method of Soil Erosion

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Abstract. Soil erosion is a highly serious ecological problem that occurs worldwide. Hence, scientific methods for accurate monitoring are needed to obtain soil erosion data. At present, numerous methods on soil erosion monitoring are being used internationally. In this paper, we present a systematic classification of these methods based on the date of establishment and type of approach. This classification comprises five categories: runoff plot method, erosion pin method, radionuclide tracer method, model estimation, and 3S technology combined method. The backgrounds of their establishment are briefly introduced, the history of their development is reviewed, and the conditions for their application are enumerated. Their respective advantages and disadvantages are compared and analysed, and future prospects regarding their development are discussed. We conclude that the methods of soil erosion monitoring in the past 100 years of their development constantly considered the needs of the time. According to the progress of soil erosion monitoring technology throughout its history, we predict that the future trend in this field would move toward the development of quantitative, precise, and composite methods. This report serves as a valuable reference for scientific and technological workers globally, especially those engaged in soil erosion research.

1. Introduction

Soil erosion monitoring is important in determining the soil erosion rate and upholding soil and water conservation [1]. Along with the gradual progress of soil erosion research, international studies have shown considerable attention on the proper choice of soil erosion monitoring method to be used in particular aspects of investigation [2] .To date, several works are focusing on soil erosion [3]. Yoo, Kyungsoo [4] studied soil formation and soil erosion by using the method of geochemical mass balance. Kairis, Orestis [5] emphasized the importance of using an efficient land management model to prevent soil erosion in the desert portions of rural areas in Crete. Research on soil erosion provides a scientific basis and theoretical guidance for soil erosion monitoring and aids in developing new technology and methods for this purpose [6].

Several soil monitoring methods have been established, each having its own advantages and disadvantages as well as specific conditions for use. Soil erosion monitoring has been performed for over 100 years, but a deep understanding of the involved theories, methods, and applications has been difficult to achieve. The history of the development of international mainstream technology and methods of soil erosion monitoring has been seldom discussed. Furthermore, a comprehensive

comparison of these approaches, including the enumeration of their advantages and disadvantages, has been rarely reported. Current research statuses and future trends in the development of these methods have been highlighted infrequently. In this regard, this article examines the runoff plot method and erosion pin technique, two methods used in the quantitative observation of soil erosion. Furthermore, this report discusses and summarizes the development of soil erosion monitoring, including the gradual improvement of the radionuclide tracer method, model estimation, and "3S" technology. It also touches on the soil erosion monitoring techniques common in the international mainstream and reviews the development history, research status, main advantages and disadvantages, and future development trend and direction of each method. This paper aims to provide a valuable reference for research on soil erosion and its related surface processes. It also seeks to formulate plans and measures for preventing and controlling water and soil erosion.

Throughout its history, soil erosion monitoring has involved techniques that developed gradually from crude to precise and semi-quantitative to quantitative. These approaches also progressed from outdoor to indoor monitoring forecast and simulation and from small-scale single-slope to large-scale regional comprehensive monitoring. Methods for soil erosion monitoring can be classified based on the date of establishment and type of approach. This classification gives rise to five major categories. Other techniques of soil erosion monitoring are basically derived from these five types and are being continuously enhanced for global soil erosion monitoring (Figs. 1 and 2).
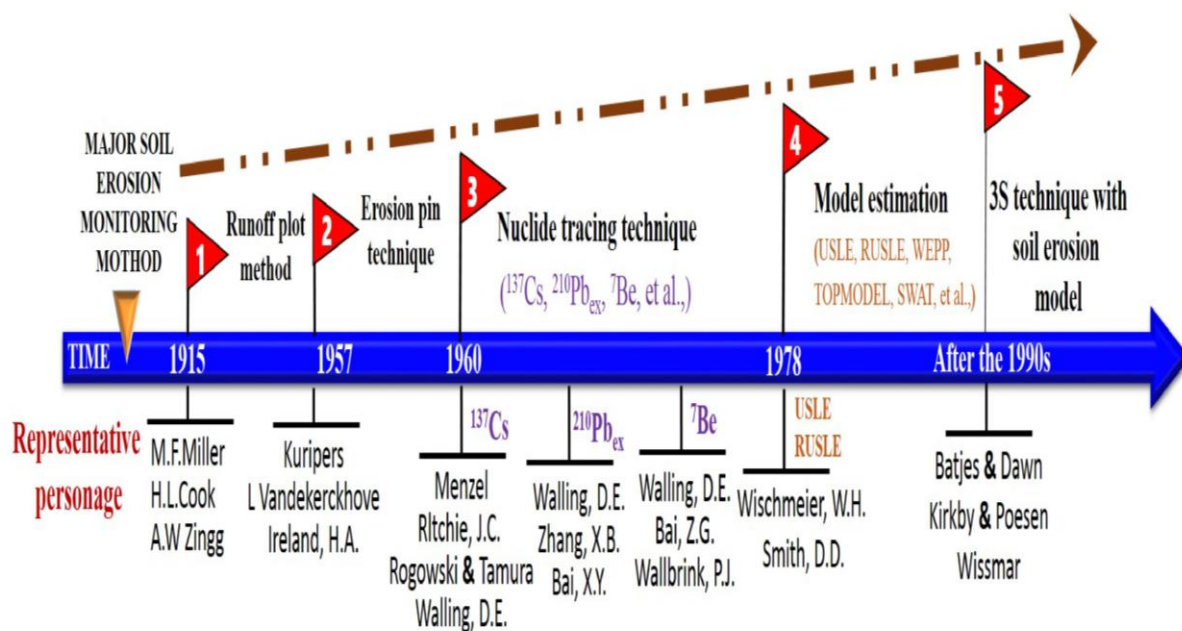

Figure1. The developing process chart of the method of soil erosion monitoring
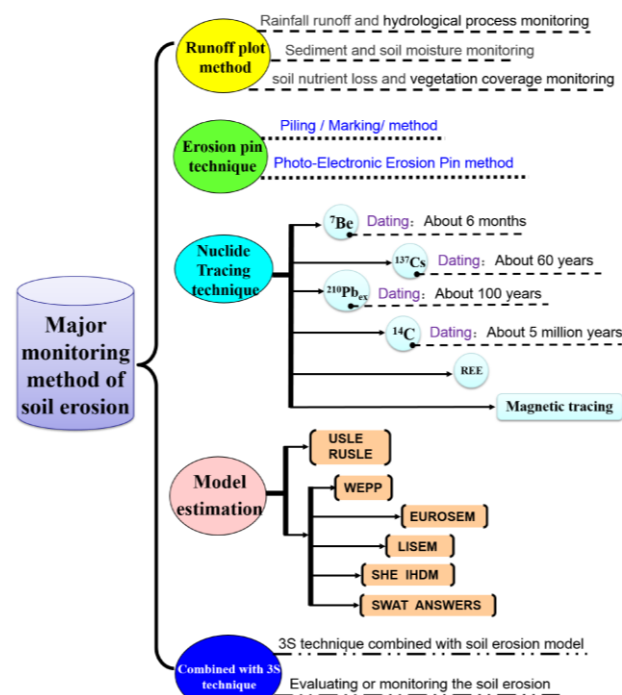
Figure2. The classification chart of the method of soil erosion monitoring

2. Runoff plot method

2.1. Historical review and current research

Soil erosion monitoring was first conducted using runoff plots [7]. The runoff plot method was first used in 1915 by the Missouri Agricultural Experiment Station of America. M. F. Miller and colleagues investigated the effect of crops and crop rotation on soil erosion and used the data to create a runoff plot [8]. The runoff plot method is used in experiments on soil and water conservation. Studies on soil and water conservation usually employ unique ground observation methods. H. L. Cook analysed numerous runoff plots and proposed three major factors that influence soil erosion [9]. This work launched the development of soil erosion forecasting technology and laid a good foundation for follow-up study. After nearly 20 years of exploration and research, the runoff plot method gained increasing attention and application. In 1940, A.W. Zingg simulated runoff plots and applied rain conditions in the field to study the relationships among slope length, slope and building terrace, and soil erosion rate and slope [10]. Subsequently, D. D. Smith added soil and water conservation measures as well as crop factors to simulation studies, results of which established the universal soil loss equation (USLE). This work also further promoted the progress of research on soil erosion and ground monitoring methods, the basic determination of soil erosion, and the monitoring of the rule of soil erosion.

The development of runoff plots in the mid-twentieth century greatly enhanced awareness and understanding of the loss of soil and water during soil erosion. In 1971 and 1978, American scholars Wischmeier and Smith (1965) studied 65000 rains, and observed and analysed data from 8250 and 2500 small watershed erosion areas for a year [11]. The data collected from these investigations were used to formulate the USLE. After the start of the 21st century, the runoff plot method continued to be used and promoted, as well as developed and challenged. For instance, Peng et al applied the Karst slope to six land and vegetation runoffs under the conditions of fixed, continuous field observation of through fall and groundwater level changes. Findings of the study revealed that the surface runoff coefficient is characterized by exponential function variation with changes in rainfall; the surface

runoff coefficient is also easily produced with a growth type of frequent transformation [12]. Cao et al (2015) studied the runoff plot method and simulated rainfall in the Chinese southern forest of Pinus massoniana by using a runoff simulation after rainfall and soil erosion. The results of the study helped in building a model to predict soil erosion and explore the factors influencing this phenomenon [13].

Overall, the runoff plot method developed over the course of nearly 100 years and served as the means for determining the link between soil erosion and slope. Moreover, in-depth analysis of runoff plots provided a collection of data for understanding the occurrence and development of soil erosion.

2.2. Future research direction

The runoff plot method, a soil erosion monitoring approach that applies both traditional and classical means, is anticipated to follow three major trends for future development. First, the trend of model construction will be described by the location of the main existing situation and will be based on dynamic and timely observation. Second, the modernization and diversification of monitoring technology and equipment will gradually continue to be scientific and reasonable. Third, the accurate transition from rough to precise quantitative determination will be achieved, and the discipline will continue to expand. Research results and practical applications will be considered closely, demonstrated, and promoted.

3. Erosion pin technique

The erosion pin method is first proposed by Kuripers[14]. It is a simple and feasible approach for soil erosion monitoring through general survey. It is also a classic method for gully erosion monitoring. L Vandekerckhove investigated soil erosion in 46 banks of the Guadalentin and the Guadix basin in Spain by using the erosion pin method. The findings of the study revealed that the gully head retreat rate difference is mainly due to regional differences in rainfall and gully wall crack rifting activities [15]. Sun G.H et al. used the erosion pin technique to determine the eroded quantities from six gully erosions in Ledu County, Qinghai Province. According to the study, gully erosion is influenced by vegetation coverage at a greater degree than the slope and K [16]. In addition, the erosion pin method is simple, practical, economical, and widely used in the dynamic monitoring of river morphology. The earliest reference to the study on river morphology is Wolman's work on gully erosion in Ireland [17]. Herein, the study of bank collapse was introduced by measuring the length of the earth's surface regularly to reflect the depth of soil erosion. Since then, the erosion pin method has been playing a crucial role in erosion monitoring in riverbanks [18]. Along with the advances in monitoring technology, some scholars have successfully modified and improved the erosion pin method. In 1989, Lawler used photo-electronic erosion pin (PEEP) to monitor the intensity and frequency of soil erosion and accumulation in riverbanks [19]. This modified technique greatly reduced the repetitive use of the traditional erosion pin method in multiple field observations. As a result, the monitoring efficiency was improved and a more scientific and convenient method was formulated for the study of soil erosion.

3.1. Advantages and disadvantages

The erosion pin method entails short-term soil erosion observation. Hence, its advantages are evident, particularly, its suitability for field monitoring, low cost, the lack of need for many related facilities, high precision, and simplicity and ease of operation. However, this method also has some limitations. These limitations include the following: (1) low degree of automation, small range of observation, tedious work outside the industry, arduousness of long-term observations, and difficulty of locating the erosion pin in small ground heights; and the (2) need for close-contact measurement of the height of the pin exposed (buried) after erosion, high susceptibility to human interference in sensitive areas around the erosion pin, the limitations posed by environmental and human activities, and many other factors. The PEEP method also has several shortcomings, such as the loss of data when the detector becomes covered by snow or vegetation and during high-intensity turbulence.

3.2. Future research direction

The erosion pin (pile) method has become the bottleneck of research on soil erosion. It provides a convenient method for investigating bank collapse. Moreover, with related technological development and innovation, the PEEP method has greatly promoted the application and improvement of the erosion pin technique. Overall, the erosion pin method gradually enriches soil erosion research and combines with other technologies to complement and enhance investigations. Its trend of development involves its improvement from simple dynamic observation to explore erosion characteristics and the surface roughness caused by different areas of erosion and deposition. In this regard, the erosion pin method plays a significant role in the dynamic monitoring of the initial stage of gully development and the control of soil erosion.

4. Radionuclide tracer method

4.1. ^{137}Cs tracer method

^{137}Cs is an important radioactive isotope. Its soil distribution was first detected during the late 1950s [20]. This radioactive isotope has an extremely poor ability for self-removal from the soil and hence was exploited for soil erosion monitoring [21]. In the early 1960s, Menzel (1960) was the first to study the relationship between soil erosion and radionuclide deposition and migration [22]. Subsequently, Rogowski (1965) and Tamura (1970) first applied the 137 Cs method to study soil erosion by measuring runoff, soil erosion, and 137 Cs loss. Through this process, the exponential relationship between soil erosion and 137 Cs loss was elucidated [23]. Since then, the ^{137}Cs tracer method has been widely used in soil erosion monitoring and research. ^{137}Cs tracer technology rapidly developed and became the major means for monitoring soil erosion, determining soil erosion and sedimentation rates, quantitatively analysing soil net loss, and other applications in the field. Furthermore, numerous models of ^{137}Cs migration and soil erosion of soil profiles have been established. These models can be divided into two types, namely, empirical and theoretical.

4.1.1. Empirical model. Ritchie (1974) was the first to establish a quantitative relationship between the rate of ^{137}Cs loss and the amount of soil erosion [24]. Since then, several researchers have established a linear estimation model of the logarithmic form of the soil erosion rate and the ^{137}Cs loss rate [25], which is the basic form of ^{137}Cs models as follows:

$$Y = \alpha X^{\beta}, \tag{1}$$

The formula includes the annual soil erosion amount (t/hm2·a), the percentage of soil ^{137}Cs loss, and the undetermined coefficient. Subsequently, Canadian researchers Elliot and Campbell (1984) used the model created by Ritchie to calculate the amount of soil loss from a particular farmland [26]. The generated formula is shown below:

$$S_t = (S_{t-1} + F_t - E_t \times CT) K, \tag{2}$$

Where S_t is the ^{137}Cs area (Bq/m^2) at the end of the concentration of T, F_t is the t ^{137}Cs settlement in the T of the year (Bq/m^2), Et is the annual erosion rate (kg/m^2), CT is the plough layer soil ^{137}Cs concentration (Bq/kg), and K is the ^{137}Cs attenuation coefficient (0.977).

In 1989, Zhang X.B proposed the following simplified formula:

$$X = X_0 (1 - H/H)^{N-1963}, \tag{3}$$

Where X is the concentration ^{137}Cs in the area of study (Bq/m^2), X_0 is the background value of ^{137}Cs (Bq/m^2), H is the depth of the plough layer (CM), H is the thickness of the annual soil loss (CM), and N is the year of soil sampling. In 1997, Zhang X.B considered a past nuclear explosion distributing ^{137}Cs into the soil to show the effect of the enrichment and separation of grain erosion in a farmland and modified the formula accordingly [27].

In 1990, Elliott (1990) proposed the following estimation model based on the loss of ^{137}Cs in non-tillage soil [28]:

$$Y = \alpha \beta^X, \tag{4}$$

Where Y is the loss of soil during erosion (kg/hm^2·a), X is the loss of ^{137}Cs from the soil, and α and β are undetermined coefficients.

4.1.2. Theoretical model. The theoretical model is mainly established through research on the model of profile distribution and mass balance. The earliest mass balance model was proposed by Kachanoski. Subsequently, many other researchers further explored the model and suggested different forms. Meanwhile, its basic form is shown as follows [29]:

$$S_t = (S_{t-1} + T_t - E_t) \, k \, (t = 1, 2, 3, \ldots, N), \tag{5}$$

Where S_t and S_{t-1} represent T and T−1 year's total ^{137}Cs amount in the soil profile (Bq/m^2), F_t is the total settlement of ^{137}Cs in year t (Bq/m^2), E_t is the soil erosion loss in year t (Bq/m^2), K is the radioactive decay constant (0.977) of ^{137}Cs, and N = M − 1954 (M = sampling year).

The establishment of the ^{137}Cs model laid a solid foundation for soil erosion monitoring through the qualitative or quantitative analysis of ^{137}Cs spatial distribution. For instance, Simpson (1976) investigated the deposition in the lower reaches of the Hudson River and found that ^{137}Cs levels vary with different positions and depths in the connecting estuary [30]. This work provided basic data to monitor soil erosion and migration. In Canberra, Australia, Wallbrink (1994) determined that ^{137}Cs content is greater than that in the slope toe [31]. C. Alewell et al. (2013) used the ^{137}Cs tracer method to evaluate and analyse soil erosion in mountain grassland [32]. Whereas H. D. Leckie et al. (2015) studied the wind erosion of Basin Mackenzie with the same technique [33].

Overall, the emergence and development of the ^{137}Cs tracer method greatly contributed to the establishment of the soil erosion estimation model and the development of new technology and methods for soil erosion monitoring. The ^{137}Cs tracer method has also become the most thorough and refined method for the quantitative study of soil erosion, monitoring of soil loss, and investigation of sediments since the 1970s.

4.2. Advantages and disadvantages

The ^{137}Cs tracing method can provide information on soil erosion and deposition that cannot be obtained through traditional means. This technique not only determines the erosion and deposition of the specific particle and the source of the erosion and sediment but also demonstrates the spatial distribution of soil erosion and movement as well as the formation age of different levels of soil. Moreover, the amount of soil erosion of about 40a can be estimated with low cost and short cycles. Evidently, it has become an indispensable method in soil erosion monitoring.

The limitations of the ^{137}Cs tracer method are as follows. (1) ^{137}Cs has a half-life of 30.12 years, which is suitable for the macro estimation of medium and long periods of erosion. (2) Only a small proportion of the ^{137}Cs content remains in seriously eroded areas, especially in the Loess Plateau, with a widely covering steep slope gully erosion zone. In these cases, the application of the ^{137}Cs tracer method has regional limits. (3) The earliest ^{137}Cs subsidence occurred in 1954. Hence, calculations on earlier times of deposition cannot be performed. (4) The spatial variability of ^{137}Cs deposition is relatively large. However, in this method, ^{137}Cs settlement is assumed to be fixed, which may account for some inaccuracies in ^{137}Cs tracer studies.

4.3. Future research direction

The ^{137}Cs tracer method has been used to study and monitor from the starting time of soil erosion. However, its many advantages and rapid development foresee great potential in four aspects. In particular, (1) the ^{137}Cs tracer method should be used to improve the soil erosion estimation model and its application to a large area. Furthermore, a database of the background values of ^{137}Cs in different regions must be established to obtain the spatial variations of soil erosion and provide a scientific basis for soil erosion monitoring and research. (2) The ^{137}Cs tracer method is also implicated in multidisciplinary aspects. For instance, the study of soil erosion can be extended to the investigation of its effect on the water environment in terms of resultant pollution. In this regard, the relationship between soil pollutants and specific water environmental conditions involved in sediment release can

be determined. (3) The complete decay of ^{137}Cs from the nuclear fallout will soon be achieved; hence, the development of a new isotope to replace ^{137}Cs represents the current trend. The distribution of ^{210}Pb in soil profiles is similar to that of ^{137}Cs and is consistent with the rule of soil movement. Therefore, ^{210}Pb appears as the best alternative for ^{137}Cs in soil erosion monitoring applications.

5. ^{210}Pb$_{ex}$ tracer method

5.1. Future research direction

The ^{210}Pb$_{ex}$ tracing method is used in the earliest research on sedimentation rate. It is valuable in determining the basin erosion rate and lake sedimentation rate and their relationship with time [34]. To date, no model has yet been established for the ^{210}Pb$_{ex}$ estimation of soil erosion. The ^{137}Cs model remains the most commonly used model for weight approximation and mass balance [35].

In recent years, some researchers have begun to explore the use of ^{210}Pb$_{ex}$ to study soil erosion rate. Walling (1999) investigated the possibility of using ^{210}Pb$_{ex}$ to trace soil erosion in the United Kingdom and proposed the quantitative model equation for erosion rate [36]. The potential of the ^{210}Pb$_{ex}$ tracer method for estimating long-term soil erosion rates was also suggested. Subsequently, Zhang X.B (2003) conducted an in-depth study on the depth distribution of ^{210}Pb$_{ex}$ in the soil profile of China and the United Kingdom. As a result, a stable-state model of agricultural land erosion rates was formulated, but the actual application in research and the reliability of the method are still to be verified at the time. Porto, P (2013) used both ^{137}Cs and ^{210}Pb$_{ex}$ tracer methods to investigate and analyze the sediments in a small river basin in southern Italy [37]. X. Y. Bai (2013) combined the ^{137}Cs and ^{210}Pb$_{ex}$ tracer techniques to study soil erosion in the Karst depression and explore the effects of land use changes on soil erosion in a small river basin in the Karst region [38].

5.2. Advantages and disadvantages

The ^{210}Pb$_{ex}$ tracer method can distinguish the changes in atmospheric particles and human causes of trace elements, the reconstruction of pollution sources, and the history of river deposition and erosion in the past 100 years. However, its limitations include complex sample processing, high accuracy requirements, and difficulty in obtaining the flux of deposition for a particular year.

5.3. Future research direction

^{210}Pb$_{ex}$ technology can study 100 years of soil redistribution and hence provides a way to compensate for the defects of the soil redistribution rate in a short period. The key in the future development of this technique is to further improve the quantitative relationship between the amount of ^{210}Pb$_{ex}$ loss and soil erosion. Furthermore, combining ^{210}Pb$_{ex}$ technology with ^{137}Cs, ^{7}Be, and other isotopes can facilitate better understanding of soil erosion and help establish a soil erosion prediction model that can improve soil erosion monitoring.

6. ^{7}Be tracer method

6.1. Historical review and current research

^{7}Be is used as a tracer for soil erosion research and monitoring. However, its use is relatively recent and its application has not yet been deeply explored. Bai Z. G. (1997) led the study on the seasonal variation of ^{7}Be in the Karst area. In this work, the potential of using ^{7}Be to study soil erosion was discussed, and a quantitative model for estimating the soil erosion rate of the 7Be tracer was proposed [39]. Consequently, the study laid a solid foundation for the future applications of the ^{7}Be tracing method. Subsequently, Walling (1999) used ^{7}Be to study the seasonal erosion of agricultural land and the effect of ploughs on soil erosion by the ^{137}Cs method. On the basis of the characteristics of the ^{7}Be distribution profile in soil, the Walling model was proposed. Blake (2002) used the ^{7}Be tracer technique to study the erosion, slope erosion rate, distribution, and migration of fine sediments [40]. Zhang Q.W (2014) estimated the rill erosion amount and relative contribution rate via the ^{7}Be tracer

method, thereby providing a novel method and means to understand further the mechanism of soil erosion and the development of soil erosion prediction models [41]. With the development of tracing technology, scholars have begun to combine ^{7}Be with other radionuclides to study and monitor soil erosion. Wallbrink (1996) used ^{137}Cs and ^{7}Be to investigate the relative contribution of different erosion types in soil erosion. Their work proved that ^{7}Be is an ideal means for tracing shallow sources of topsoil [42]. Burch (1998) showed the initial source of sedimentary soil from the soil profile based on the deposition of ^{137}Cs in soil and ^{7}Be activity, and then inferred the possibility of erosion [43] .G. Matisoff (2005) used the ^{210}Pb$_{ex}$ and ^{7}Be tracer methods to develop and improve the measurement of suspended sediment age [44]. Therefore, the ^{7}Be tracer method has gradually become a novel tool for the study of soil erosion, with a very important role in soil erosion monitoring.

6.2. Advantage and disadvantage
The ^{7}Be tracer method has background values that are easy to measure and not subject to site constraints. Given the advantages of this convenient and simple method, the spatial distribution of soil erosion rate and erosion deposition can be well applied to the soil erosion rates in a short term or in specific erosion events (sub rainfall). The method can also be applied to evaluate soil erosion under a particular intensity of land use, thereby providing an important basis for the monitoring and control of soil erosion. However, the application of ^{7}Be tracing still has some problems. For example, the shallowness of ^{7}Be distribution complicates sampling. Moreover, a relatively perfect and simple ^{7}Be erosion tracer model has yet to be established, and research progress is relatively slow. The ^{7}Be tracer method is suitable for low and medium intensity soil erosion events, but its accuracy for high strength soil erosion events is poor.

6.3. Future research directions
The existing model was established without considering the spatial distribution characteristics of ^{7}Be. Therefore, the temporal distribution of precipitation, the temporal distribution of erosion, and the redistribution of rainfall runoff should be considered in the future to strengthen research on the distribution patterns of ^{7}Be in the soil profile and establish a quantitative model with a wide range of applications. ^{7}Be could reflect the effects of soil erosion factors. Therefore, the scope of applications of the ^{7}Be tracer method can be broadened to explore the comprehensive effect on specific small watersheds based on the hydrological and meteorological conditions of soil erosion. The operability of ^{7}Be tracing in soil erosion determines the necessity and importance of designing a novel experimental scheme to study the migration characteristics of ^{7}Be with rainfall runoff. The application of the ^{7}Be tracer in soil erosion research started relatively late; thus, the related quantitative models are few, and their precision needs to be tested. Therefore, research on the ^{7}Be tracer quantitative model should be strengthened. In addition, single radionuclide tracing cannot meet the needs of soil erosion research. Hence, the tracing of ^{7}Be and other radionuclide compounds has become an important direction of future research.

7. Magnetic tracer method

7.1. Historical review and current research
As early as 1986, magnetic tracer technology has been applied to soil particles to determine the surface coverage of soil erosion movement [45]. Caitheon (1993) and Ventura (2001) proposed the feasible use of magnetic tracers as a new method to understand soil erosion [46].

The application of the magnetic tracer technique in soil erosion research has two main aspects. One aspect is the use of environmental magnetism to trace sediment sources. Australian scholar Caitcheon (1993) proposed the use of environmental mineral magnetism to trace sediment sources. Within a certain range of geological and climate conditions, the magnetic minerals of river sediments represented by the magnetic parameter set are stable in space and time [47]. The relationship between magnetic parameters shows the characteristics of the collected magnetic minerals. Therefore, the

tracers can be used to study soil erosion. Subsequently, Delong (1998) used changes in soil magnetic susceptibility to investigate the redistribution of long-term soil erosion [48]. Their results showed that the soil erosion and redistribution of the region near the sedimentary region can be estimated based on the variation in magnetic susceptibility distribution. Jordanova (2013) used the magnetic tracer method to study the formation of dark red soil and its mineralogical properties [49]. The other aspect is the use of sediment magnetism to indicate environmental changes in the basin. Dearing (1981) used the magnetic tracer method in Peris Lake because of the excessive grazing caused by soil erosion and explained the history of land use change in the river basin [50]. Meanwhile, Franciskovic-Bilinski (2014) used the magnetic tracer method to discuss the geochemical and mineralogical characteristics of sediments in Croatia and Slovenia [51].

The magnetic tracer method can reflect the history of land use pattern, vegetation succession, and soil erosion in a watershed. It can also identify the soil distribution and the erosion rate for a certain period. Therefore, this method can be used to provide a theoretical basis for soil erosion prediction and monitoring, and a history of the development of small watersheds.

7.2. Advantages and disadvantages
The magnetic tracer technique has obvious potential advantages. First, the measurement of the magnetic parameters is simple, rapid, and does not involve destruction. The use of the conventional magnetic method can meet the analysis requirements of a large number of samples. Second, the magnetic measurement instrument can be used to directly determine various magnetic parameters. It requires a simple operation and an easy-to-carry instrument, making measurements in the field and laboratory convenient. However, the magnetic properties and the depth of soil erosion or deposition are difficult to determine via the magnetic tracer method. Thus far, no reasonable quantitative model exists for the magnetic tracer method.

7.3. Future research direction
The magnetic tracer method has greatly progressed in the study of soil formation, the classification of soils, and the quantitative description of the evolution, occurrence, and development of erosion. With the continuous progress of science and technology, the study of soil erosion by soil magnetism will be a hot topic in soil science. Therefore, the development trend of the magnetic tracer method in soil erosion research is mainly reflected in the following aspects. (1) The magnetic contribution rate and the separation of soil erosion are quantified by exploring the species, grain shape, and characteristics of magnetic minerals in the soil to completely understand soil erosion on slope and establish a theoretical soil erosion prediction model. (2) The test results of the total magnetism can be incorporated in the empirical or theoretical model to separate magnetic signals from different sources and thus improve soil erosion prediction and monitoring accuracy. (3) A quantitative model of soil magnetic parameters and soil erosion rate is gradually established to improve the accuracy and precision of soil erosion prediction and provide reliable data for the effective prevention and control of soil erosion. (4) The magnetic tracer and other tracer techniques (e.g., ^{137}Cs, ^{7}Be, ^{210}Pb, and REE) were combined for compound tracing to explore the evolution of sediment sources, the different patterns and intensities of erosion, and the spatial differentiation of the basin.

Despite the sensitivity of magnetic minerals to environmental change, the use of magnetic tracers is a novel method to study the spatial distribution of soil erosion and the evolution of erosion patterns. The variable interpretation of magnetic parameters, the effects of soil processes and human activities on magnetic properties, and the total magnetic contribution rate require further research. Magnetic tracers in soil erosion research have broad prospects for improvement with the development of testing methods and the completion of basic theory.

8. Model estimation method

8.1. Historical review and current research

Soil erosion models are indispensable to quantitatively study soil erosion worldwide. The development of a soil erosion model can be divided into three stages: empirical statistical model, physical process model, and distributed model.

(1) Stage I: In 1877, German scientist Ewald Woolly began the construction of a soil erosion model [52]. By the 1960s, the USA USLE for the quantitative analysis of soil erosion was basically empirical. Empirical models of soil erosion are mainly based on the USLE. Wischmeier and Smith (1978) analysed the runoff and sediment data from all over the USA with the empirical USLE [53]. The RUSLE is a representative model. The soil empirical model remains widely used to date. For example, G. S. Pradeep (2015) used the AHP and RUSLE models to estimate the annual soil loss of ghats in southern India [54]. Shi Z.H (2004) combined RUSLE and GIS to evaluate the level of soil and water conservation planning in the Three Gorges area of China [55].

(2) Stage II: With the study of the mechanism of soil erosion, many scholars have found numerous limitations and shortcomings in the use of previous empirical models. During a 1985 workshop in Lafayette, Indiana, USA, a new generation of soil erosion prediction model that can replace the empirical model was created. The advent of a new generation of water erosion prediction model called the WEPP occurred in 1987. This model provides an up-to-date description of the physical process of water erosion parameters. The WEPP model can simulate soil erosion, non-regular steep slope, and soil, tillage, and management measures by calculating the temporal and spatial distribution of soil erosion and predicting the movement of sediment in the slope and basin. The WEPP model reflects the applicability and ductility of the temporal and spatial distribution of erosion and sediment; thus, numerous scholars still use this method. For example, R. E. Brazier (2000) used the WEPP model to assess the uncertainty of a soil erosion model based on physical processes in the UK and the USA [56]. B. Saghafian (2015) applied the WEPP model to determine the runoff and sediment sources in a forest watershed [57].

To describe hydrological processes, the distributed model has been recently developed into the SHE and IHDM models based on the traditional lumped conceptual model and the physical process model. The SWAT model was gradually constructed to simulate watershed management of soil erosion and the deposition effect during and after heavy rain with rainstorm catchment characteristics [58]. These models are widely applied in soil erosion research and monitoring. However, the parameters of the distributed model need to be evaluated. Therefore, numerous semi-distributed models such as TOPMODEL have been used [59].

(3) Stage III: In the 1990s, the soil erosion model was integrated with GIS to survey global and regional soil erosion, understand the ecological effects of soil erosion, and analyze soil erosion dynamics. Batjes and Dawn (2003) combined global earth science data and USLE with RUSLE to quantitatively assess soil erosion on a global scale [60]. Kirkby (1998) and Poesen (1996) used GIS technology for the dynamic monitoring of soil erosion in a small watershed [61]. Aiello (2015) combined GIS technology and RUSLE3D to evaluate the soil erosion in the southern Italy basin [62]. Zhu (2015) used the USLE model to evaluate soil erosion in the Danjiangkou reservoir area. Further improvement of GIS and its applications is necessary to facilitate the scientific, modern, and quantitative research and monitoring of soil erosion [63].

8.2. Advantages and disadvantages
The main advantages of the empirical model (and RUSLE USLE) are the following. (1) The formula is concise and the meaning of each factor is clear. (2) The calculation method of the factor has been basically mature and the parameters are easy to obtain for the continuous improvement and perfection of the model. (3) After several years of verification and testing, the accuracy of the model meets the needs of the application. The model is widely recognized and used in the calculation of soil erosion. However, the empirical model of this series also has some limitations. (1) The limited factors in the model cannot completely explain the complex and changeable phenomena of sediment yield and sediment flow in the river basin. (2) The model is highly regional and difficult to promote because it is based on observation data. (3) Simulation of soil erosion and sediment transport is difficult to perform.

The physical process model is based on the study of the processes and mechanisms of soil erosion. (1) To simulate soil erosion, sediment yield calculation can be realized. (2) The physical process model provides more profound scientific theory and higher adaptability in different regions than the empirical model. Although the physical model greatly compensates for the defects of the empirical model, this approach also has some shortcomings. (1) The physical mechanism of soil erosion is relatively complex and unclear. Some parameters in the physical process model are still dependent on the empirical model. (2) The large range of the study area is the major obstacle that hinders the use of the model because of the exacting demand of the model parameters. (3) The structure of the physical process model is complex and may change because the form has not been unified.

At present, GIS technology can be combined with the experience and physical models. The use of GIS spatial data management and analysis in the study of soil erosion prediction and evaluation has great advantages but still has some problems. For example, GIS will generate errors in the overlay and data operations when the nonlinear operation contains great errors. If no changes occur in the time and space of the response factor or if the acquisition of the factor itself has errors or uncertainty and cannot reflect the scale and space–time characteristics, then the combination with GIS technology will also produce large errors.

8.3. Future research directions
Future research should focus on theoretical analysis, particularly on the quantitative research and theoretical development of an erosion prediction model based on the erosion factor. The factor analysis model has been developed from a single-factor analysis to a comprehensive factor analysis, which is suitable for different regions. GIS is dynamic and capable of powerful spatial analysis; thus, the combination of GIS and soil erosion models has more advantages than the traditional soil erosion model. Present and future research should focus on GIS technology. Moreover, GIS is particularly useful for the description and quantitative distribution of parameters. GIS with spatial-scale conversion methods and models as technical support can maximize data, maps, and remote sensing data to quantify the sloping field system of erosion background conditions and the intensity of simulated and realistic soil erosion.

9. Conclusion
The application and research direction of soil erosion monitoring methods have achieved great progress. These monitoring methods are set up in different environments, terrains, and scales, but none of the methods have general applications. Each method has inherent advantages, disadvantages, and regional characteristics. Therefore, future research on soil erosion monitoring methods should include exploration of the processes, mechanisms, prediction models, and environmental effects soil erosion. Moreover, researchers should focus on the advantages of each method and gradually improve the current defects to develop these methods in the quantitative, accurate, crossover, and composite directions. Development of these methods is indispensable for extensive soil erosion research.

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11. References
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