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Regions and Their Typical Paradigms for Soil and Water Conservation in China

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Abstract: China is experiencing conflicts between its large population and scarce arable land, and between a demand for high productivity and the severe soil erosion of arable land. Since 1949, China has committed to soil and water conservation (SWC), for which eight regions and 41 subregions have been developed to improve the environment and increase land productivity. To obtain information from the regional planning and strategies for SWC and to explore whether SWC practices simultaneously contribute to soil conservation, ecosystem functioning, and the livelihoods of local farmers, and to summarize the successful experiences of various SWC paradigms with distinct characteristics and mechanisms of soil erosion, this paper systematically presents seven SWC regions (excluding the Tibetan Plateau region) and 14 typical SWC paradigms, focusing on erosion mechanisms and the key challenges or issues in the seven regions as well as on the core problems, main objectives, key technologies, and the performance of the 14 typical paradigms. In summary, the 14 typical SWC paradigms successfully prevent and control local soil erosion, and have largely enhanced, or at least do not harm, the livelihoods of local farmers. However, there remain many challenges and issues on SWC and socioeconomic development that need to be addressed in the seven SWC regions. China, thus, still has a long way to go in successfully gaining the win-win objective of SWC and human aspects of development.

Keywords: regions for soil and water conservation; soil erosion; dryland farming; collapse erosion; karst rocky desertification; typical paradigm for soil and water conservation

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1 Introduction

China has an apparent complex natural environment, and is very mountainous; approximately 67% of the entire territory constitutes mountains and hills (Tang, 2004). As the east is adjacent to the Pacific, China experiences typical monsoon conditions and the climate pattern includes three parts of a monsoon humid region in the east, an inland arid region in the northwest, and a cold region around the Tibetan Plateau (Zheng et al., 2015, Fig. 1). Furthermore, China has multiple climate zones including tropical, subtropical, warm temperate, moderate, and cold, accordingly exhibiting a latitudinal distribution of vegetation and soil types from the south to the north (Huang, 1959; Zhao, 1983; Yao et al., 2012; Chen et al., 2019a). China's per-capita cultivated land is scarce. According to the Bulletin of China's Land Resources 2016 (MNR, 2016), the total cultivated land was

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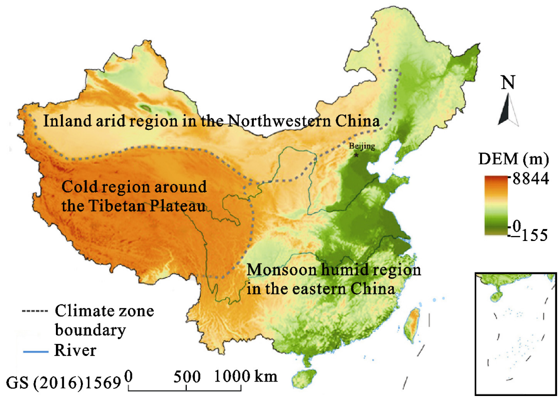

Fig. 1 China's terrain and geographic regions (Data from Zheng et al., 2015)

135.00 × 10^6 ha, and the per-capita cultivated land was 0.10 ha by the end of 2015, accounting for only 34.0% of the world's average value, while nearly 20.0% of the world's total population rely on these cultivated lands. In the early 1950s, to provide basic information on China's natural environment and resources, great efforts were made to present primary research materials and a scientific foundation for the understanding of geographical regionalization, as well as for national and regional economic development planning (Chen et al., 1994).

Owing to the natural mountainous characteristics combined with high-intensity human activities, China experiences the adverse effects of severe soil erosion (Li et al., 2009a). The intense soil erosion of China's Loess Plateau is world-renowned. By 2018, the land area affected by soil erosion was approximately 2.9400 × 10^6 km^2, accounting for 30.7% of its total territory according to the Monitoring Bulletin of China's Soil Erosion 2018 (MWR, 2018).

Using theory to guide the practices in soil and water conservation (SWC), scientists in China have gained useful insights into the heterogeneity of the natural conditions, as well as the differentiated mechanism of soil erosion. They completed a regional map for soil erosion in the middle reaches of the Yellow River (Huang, 1955) and introduced a classification system for China's soil erosion (Zhu, 1956) in the early 1950s. Over the past decades, significant knowledge has been established and progress has been made in identifying the mechanism and characterization of soil erosion (Zhu, 1989; Jiang, 1997; Zhao et al., 2002; Tang, 2004; Li et al., 2009a; Fu et al., 2010; Liu et al., 2011) and developing soil erosion models and simulations (Liu et al., 2001; Yin et al., 2018), as well as in characterizing the effective pathways to water erosion control and evaluations of SWC (Li et al., 1991; Tang, 2004; Cai et al., 2012). In spite of such great progresses in theoretical exploration abovementioned, systematical regionalization for SWC in China remained unavailable for the strategy of soil erosion control until recent years eight regions and 41 subregions for SWC were developed (Ning et al., 2015; CREEI, 2016; Wang et al., 2016b; Yang et al., 2017) based on aforesaid works as well as the comprehensive regionalizations (Huang, 1959; Zhao, 1983) and geomorphological regionalization (Li et al., 2013). The eight regions include the black soil region in Northeast China, windy and sandy region in North China, earth-rock mountain region in North China, the Loess Plateau in Northwest China, red soil region in South China, purple soil region in Southwest China, karst region in Southwest China, and the Tibetan Plateau region (Fig. 2). These regions are considered as the general patterns for the planning of SWC in China. However, the regional planning for soil conservation neglects the dominant mechanisms for soil erosion, which are crucial for composing measures for SWC. The development of the eight regions, for instance, is based on three indicators: precipitation, annual accumulated effective temperature ≥ 10 ℃, and elevation. Based on these regions, only the differences in landforms and the types of soil erosion were considered in the creation of the 41 subregions.

Although there are few special global regionalizations for soil conservation or soil erosion, ecological regions have been created in the United States and Canada since the early 1970s (Bailey, 1976; 1983; Rowe and Sheard, 1981; Bailey et al., 1985). Comparable ecological regionalizations also include the Netherlands' ecoregions and ecodistricts (Klijn and Udo de Haes 1994; Klijn et al., 1995), biogeographic regions in Russia, and ecological functional regionalization in China (Fu et al., 2004), relative to which China's regional planning for soil conservation was established late.

In practice for SWC, in the early 2000s, the Chinese government launched several large programs for soil erosion control and environmental conservation, including various Key Forestry Programs such as the Natural Forest Conservation Program (NFCP), the Grain for Green Program (GGP), Sand Control Programs for

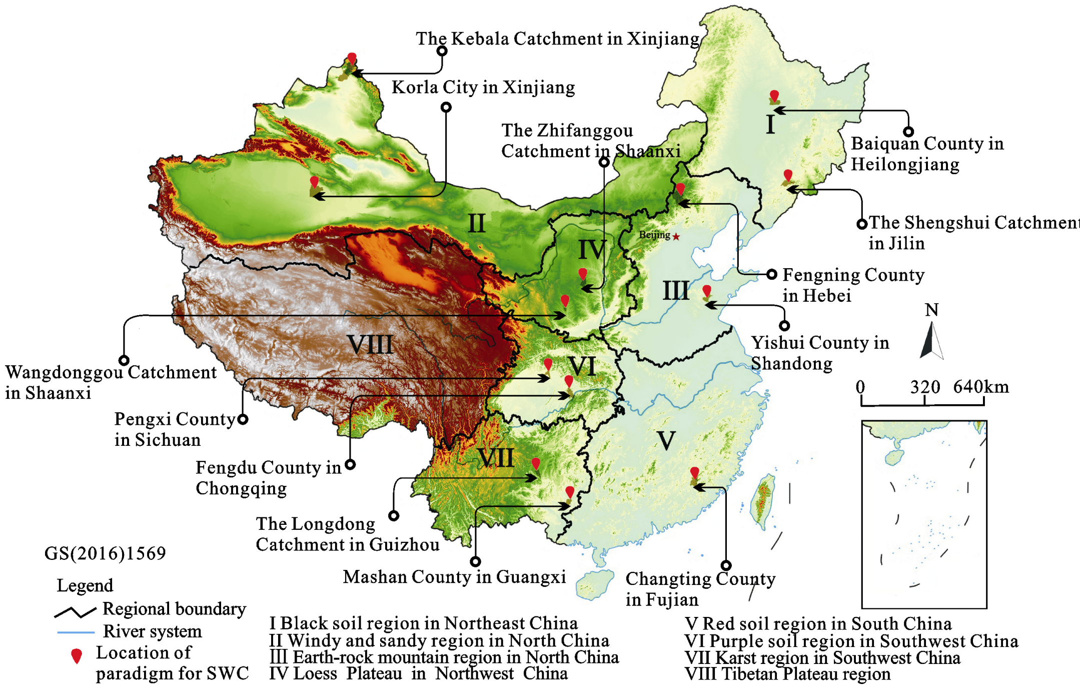

Fig. 2 Regional planning of soil and water conservation (SWC) in China and the location of the paradigms for SWC (Data from CREEI, 2016)

areas in the vicinity of Beijing and Tianjin, the Three-North Shelterbelt Development Program and the Shelterbelt Development Program along the Yangtze River Basin (Liu et al., 2008b; Wang et al., 2008a), as well as other projects such as terracing on sloping arable lands (Chen et al., 2017), and check-dams in valleys (Guo et al., 2019; Shi et al., 2019). Thus far, these programs have made huge progress in increasing land cover, reducing runoff and soil erosion, curbing sediment, and improving land productivity (Liu et al., 2008b; Wang et al., 2008a; Wei et al., 2016; Deng et al., 2019; Li et al., 2019a; Zhao et al., 2019; Zhang et al., 2019a; Wu et al., 2019a). According to four monitoring bulletins of China's soil erosion 2003, 2011, and 2018, respectively, since 1980s there has been a steady decline in the areas affected by soil erosion in China (MWR, 2003; 2011; 2018). Compared with that in 2011, China's area of soil erosion decreased by 0.2123×10^6 km^2 (a decrease of 7.2%) in 2018. Additionally, in the red soil region of south China, for instance, the area affected by soil erosion decreased by 0.0170×10^6 km^2 (a decrease of 11.9%) in 2018, largely due to the GGP and the control of collapse erosion in the hilly granitic areas; similarly, in the karst region of southwest China, the area of water erosion decreased by 0.0250×10^6 km^2 (a decrease of 8.9%) by the end of 2018, mainly attributed to a significant increase in vegetation cover and a reduction of approximately 43.3% in the areas affected by rocky desertification in this region (Tong et al., 2018). In particular, in the Loess Plateau region, the average annual runoff and sediment discharge observed at the Tongguan hydrologic station over the period of 2010–2012 decreased by 45.7% and 82.7%, respectively, compared to those during 1919–1959 (Liu et al., 2017; Zhao et al., 2019; Wu et al., 2019a). Thus, the ecological environment in the Loess Plateau has improved over the past two decades (Deng et al., 2014; Tang et al., 2014; Dang et al., 2017; Gang et al., 2018; Ran et al., 2018; Zhang et al., 2019a).

Despite such large advancements toward SWC, China continues to face many challenges in SWC and environmental conservation. On the one hand, China has the largest population in the world, scarce available croplands, and severe land degradation (Yang, 2004); thus, is confronted with the dual pressures of natural conservation and food security. Therefore, China has a particular demand for the regional planning of soil erosion control that is totally different from other countries.

There are, however, various issues and problems in the practice of soil conservation. For instance, large-scale afforestation or reforestation in the Loess Plateau could have some negative environmental effects (Cao et al., 2009a) and cause the formation of a dry soil layer (Cao et al., 2009a; Wang et al., 2018b). Most policy-makers even commonly misinterpret the relation of afforestation or reforestation with watershed services (Bennett, 2008). Therefore, it is necessary to gain further understanding of regional planning and the strategies for SWC that could be helpful to decision-makers.

On the other hand, there are many small-scale paradigms for SWC across China, some of which were motivated by different administrative tiers, while others were spontaneously implemented by local farmers (Tang, 2004; Dang et al., 2010). However, there is little robust evidence of whether or not these paradigms simultaneously contribute to soil conservation, ecosystem functions, and the livelihoods of local farmers.

To address these shortcomings, in this paper, we first present seven regions for SWC (excluding the Tibetan Plateau region), summarize the mechanisms of soil erosion, and identify the key issues and challenges in the SWC of the seven regions. To introduce successful practices in the SWC of some small catchments with distinct characteristics and mechanisms of soil erosion, we then elaborate 14 small-scale paradigms for soil conservation in the seven regions by reviewing existing literature, mainly focusing on their core problems, main objectives, key technologies, and performance and looking through if the paradigms make a synergy or trade-off between the erosion control and local livelihood development. Finally, we conclude this paper with our arguments. We also expect that the seven regions and the modes and paradigms discussed would help advance the expertise of other countries that affected by similar issues.

2 Typical Paradigms for the Seven Regions of Soil and Water Conservation (SWC) in China

2.1 Black soil region in Northeast China

The black soil region in Northeast China is dominated by low mountains, hills, and rolling hills. The black soil layer (Mollisols) is the dominant ground substance, covering a total area of 1.0900×10^6 km^2 (Tang, 2004), and includes four subregions: mountainous and hills, rolling hills, wind and sand in the Songliao Plain, and the Hulun Buir hill and plain.

2.1.1 Dominant mechanisms for soil erosion in this region

In the black soil region, the area affected by soil erosion is 0.2200×10^6 km^2, representing 30.7% of its total land area; specifically, the area affected by water erosion is 0.1650×10^6 km^2, approximately 62.8% of which is attributed to sloping farmlands (CREEI 2016). Since the period of land reclamation in the early 20th century, this region has become a key area for food production in China, where soybean and corn are the primary crops grown. Mountain-front tablelands, low mountains and hills, and rolling hills are major areas that have been affected by soil erosion.

The dominant mechanisms for soil erosion in this region include: 1) Erosive precipitation that accounts for approximately 60.0% of annual precipitation with strong soil detachments, and yields a large amount of runoff with heavy sediment loads (Chen et al., 2019c). Existing literature has also indicated that soil detached by raindrops and sediment yielded by overland runoff are two important components of rain-induced erosion (Wakiyama et al., 2010; Kiani-Harchegani et al., 2018); 2) Landform with long and gentle slopes that increase the upslope contributing area and thus lead to a substantial surface runoff capable of carrying out heavy sediment loads; 3) Erodible black soil with a loose surface and shallow plough pan that eases overland runoff and erosion (Chen et al., 2019c). The abovementioned factors combined with freezing and thawing processes as well as intensive cultivation lead to substantial overland runoff, soil erosion, and gullies (Tang, 2004).

2.1.2 Main issues and challenges in the SWC of this region

First, the black soil region is the largest area for food production in China, sourcing nearly 17.0% of the total food production in China; thus, arable lands represent a significant amount (> 30.0%) of the total area and have increased by 2.9%–17.5% over the period of 1990–2010, dependent on different subregions (Liu et al., 2011). More importantly, sloping arable lands account for more than 67.9% of the arable lands in this region (REDCP, 2018). The soil erosion originating from large-scale sloping arable lands is easily ignored until it eventually accumulates to a severe magnitude, and thereby can potentially significantly damage agricultural productivity (Xing et al., 2005; Liu et al., 2011; Fang et al., 2012; Yang et al., 2016; Gu et al., 2018).

Second, in the black soil region, the current Mollisols layer depth of cropland varies between 20 and 40 cm; the average rate of soil erosion is approximately 2.2 mm/yr and the maximum rate of soil erosion is 60.8 mm/yr; thus, the Mollisols layer of cropland will disappear in the next five years (Zhang et al., 2007b; Liu et al., 2008a) if no measures for soil conservation are taken (Liu et al., 2008a; Xu, 2012).

2.1.3 Typical paradigms for black soil region in Northeast China

(1) The forest-fruit-reservoir-rice integrated development in the Shengshui catchment

The Shengshui catchment is located in the Changbai-Wanda mountainous and hilly subregion, and covers an area of 177.80 km². Here, the area of soil erosion is 38.40 km^2 and water erosion is dominant. Soil erosion predominantly occurs in the middle and lower mountains and hills as well as the undulating tablelands with severe topsoil erosion and eroded gullies. Generally, rice fields are located in valley plains. In this context, it would be a sound design of integrated catchment management if synthetically protective systems against soil erosion were constructed in the upper part, with the development of compound agriculture in the lower part of this catchment. Specifically, to obtain the double objectives of soil conservation and the development of farmers' livelihoods, vegetations have been restored to curb soil detachments in the middle and lower mountains with altitudes > 500 m and terraced orchards have been established on the hills and tablelands with altitudes of 200–500 m, while small reservoirs or check dams have been constructed to develop the compound agriculture of rice planting and duck and fish breeding in valley plains with altitudes < 200 m. Through practicing such an agroforestry (i.e., a combination of forestry, agriculture, husbandry, and fishery), the so-called forest-fruit-reservoir-rice integrated development mode has been formed in this catchment. A synergy has been reached between soil conservation and improvement of farmers' lives (Table 1), thus has been commonly accepted by farmers in similar areas to this catchment.

Table 1 Summary of typical paradigms for Soil and Water Conservation (SWC) in the black soil region in Northeast China

Typical paradigm	Core problem	Main objective	Key technology	Performance	Reference
Forest-fruit-reservoir-rice integrated development	Severe surface erosion on farmlands and intensive gully erosion	Achieve a synergy between soil conservation and farming via vegetation restoration in low mountains, terraced orchards in tablelands, as well as rice cultivation and animal breeding in valley plains	Terraces and water works, such as ponds, small reservoirs, and check dams	After treatments, soil erosion decreased by 71.5%, biomass increased by 27.4 t/ha, and farmers' cash income increased by 3369 yuan RMB/ha	Song et al., 2003
Comprehensive management in the black soil rolling hill area	Severe soil degradation due to intensive farming	Control soil erosion via forest restoration, terraces, and gully erosion control works	Pond-like fields (Fig. 3), bamboo joint-like trenches (Fig. 4), and check dams (Fig. 5)	After treatments, runoff reduced by 37.0%, soil erosion decreased by 50.0%, and the productivity of croplands increased by 56.0%	CREEI, 2016

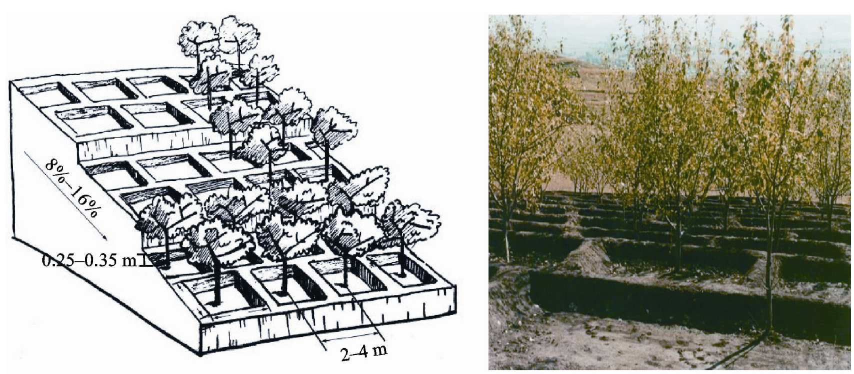

Fig. 3 Diagram and image of a pond-like field for Soil and Water Conservation (SWC) on slope in Baiquan Paradigms, Heilongjiang Province

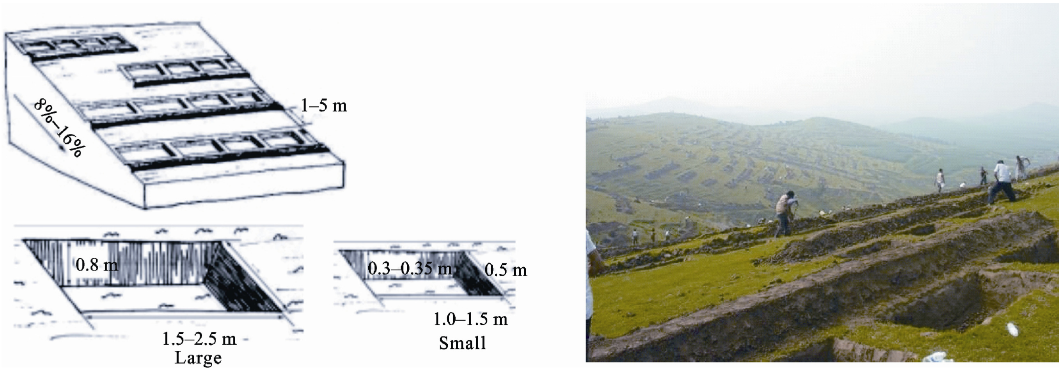

Fig. 4 Diagram and image of a bamboo joint-like trench for Soil and Water Conservation (SWC) on slope in Baiquan paradigms, Heilongjiang Province

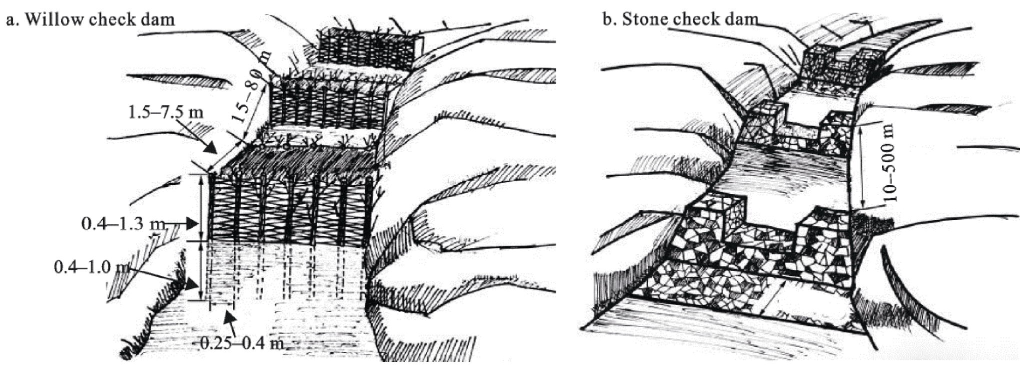

Fig. 5 Diagrams of check dams for Soil and Water Conservation (SWC) in gully in Baiquan paradigms, Heilongjiang Province

(2) Comprehensive management of the black soil rolling hills in Baiquan

Baiquan belongs to Heilongjiang Province and is dominated by black soil rolling hills. It covers an area of 3599 km^2, and the area affected by soil erosion is up to 3505 km^2. As a result of long-standing land reclamation and high-intensity cultivation, black soil on cultivated lands is severely eroded. The thickness of the black soil layer has consequently decreased from 1 m to 30 cm (Zhang et al., 2007b; Liu et al., 2008a). Therefore, the core objective for this paradigm is to curb black soil erosion on cultivated lands. To achieve a synergy between soil conservation and agricultural development, both engineering measures (such as terraces on gentle slope cultivated lands and check dams in eroded gullies) and biomeasures (such as afforestation/reforestation for preventing soil detachments on wastelands) must be adopted to form a synthetically protective system against soil erosion. Given the long and gentle slope landforms in this site, the establishment of orchards on pond-like fields or terraces is a good idea to achieve the dual goals of soil conservation and development of farmers' livelihoods (Figs. 3 and 6). After the implementation of SWC programs, Baiquan has successfully controlled the soil erosion induced by farming and simultaneously achieved agricultural development (Table 1).

2.2 Windy and sandy region in North China

The windy and sandy region in North China (i.e., the basins in the Xinjiang, Gansu, and Inner Mongolia plateau regions) is a region where exposed sand is the dominant ground substance. This region covers an area

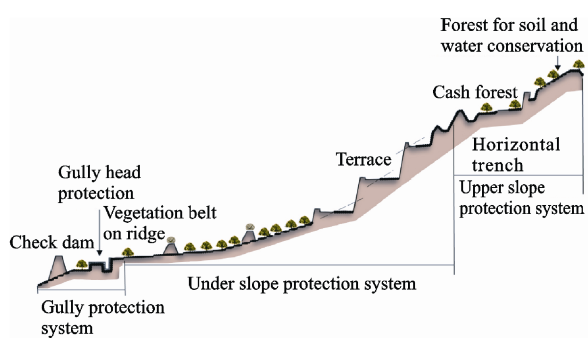

Fig. 6 Structure of paradigms in the black soil region in Northeast China

of 2.3900 × 10^6 km^2, and comprises four subregions, namely the plateau and hill subregion in central Inner Mongolia, the Hexi Corridor and Alxa Plateau subregion, the basin subregion in north Xinjiang, and the basin subregion in south Xinjiang (CREEI, 2016).

2.2.1 Dominant mechanism for soil erosion in this region

In the windy and sandy region, the area affected by soil erosion is 1.4160 ×10^6 km^2, which represents 60.3% of its total land area. Meanwhile, the area of water erosion is only 0.1150 × 10^6 km^2, accounting for 4.9% of the total land area of this region (CREEI, 2016). The dominant mechanisms for soil erosion here include: 1) Annual precipitation is generally < 200 mm and is even below 100 mm for more than 80.0% of the region, but approximately 70.0% of the annual precipitation falls between June and September, usually by heavy rainfall with a strong soil detachment; 2) Subject to the continental climate, the region has frequently been affected by windy weather, e.g., above force eight wind for more than 170 d in the basin subregion of south Xinjiang, which is responsible for severe wind erosion in this region (Shen et al., 2018; Wu et al., 2019b; Zhang et al., 2019b); 3) The region has a characteristic diurnal temperature range capable of freezing and thawing to form many loose-knit surface substances. In arid and semi-arid areas, wind erosion is significantly affected by topsoil features (Li and Liu, 2003) and results in land degradation (Pimentel et al., 1995). The abovementioned climate characteristics combined with low vegetation coverage have caused substantial soil erosion, gullies, and mud-rock flows.

2.2.2 Main issues and challenges in the SWC of this region

First, considering that oasis farming represents approximately 48.0% of the agricultural area in this region (Ren and Tang, 2004), the excessive withdrawal of water, which has largely been used for oasis farming irrigation, has cut off the flows downstream of many rivers and has led to a decline in the groundwater table. Meanwhile, since this region has a dry continental climate with very high evapotranspiration and low annual precipitation, large-scale irrigations with poor drainage systems cause secondary soil salinization (Yang, 2004). This is an urgent issue to be addressed.

Second, overgrazing has led to the severe loss of vegetative cover and topsoil. Although some conservation programs have established amelioration of ecosystems, land degradation and desertification induced by soil erosion remain severe in this region (Guo et al., 2014).

Finally, the region also has abundant resources of coal, oil, and gas. The exploitation of these resources would destroy the ground vegetation, and lead to soil erosion and land degradation, which are huge challenges faced by the community of soil conservation in this region (CREEI, 2016).

2.2.3 Typical paradigms for the windy and sandy region in North China

(1) The protective oasis agriculture of the Kebala catchment in north Xinjiang

The Kebala catchment belongs to the Burqin River basin, and covers an area of 38.0 km^2. Here, the area of soil erosion is 26.2 km^2, which is dominated by wind erosion with an annual erosion rate of 2000 t/(km^2·yr) (Wang et al., 2018a). Soil desertification is significant because of the vegetation degradation and declined water capacity. Although the annual precipitation is only 118.7 mm, the water resources for irrigation are relatively abundant due to the plentiful flow of the Burqin River. Therefore, the agriculture in this catchment is predominantly oasis farming. To combat the severe wind erosion and soil desertification, and to restore the degraded grasslands, the periodic enclosure of natural grasslands in the upper reaches of the Kanas Lake, and establishment of shelterbelt networks to prevent land desertification in oasis areas are sound choices. As such, this paradigm is characterized by a mixed agriculture of livestock breeding in the upper reaches of the Kanas Lake and oasis farming in the river plains, and proves successful in simultaneously controlling wind erosion and developing local livelihoods (Table 2). The area around the Kanas Lake, however, is a popular tourist destination in mainland China, thus policymakers should pay more attention to the increasing environmental pressure from the overloaded tourism.

(2) The desert oasis of the Tarim Basin in south Xinjiang

This mode is applicable to desert oases in south Xinjiang and similar regions. A typical region is Korla City in the Tarim Basin, which practices desert oasis farming.

Table 2 Summary of typical paradigms for wind erosion control in the windy and sandy region in North China

Typical paradigm	Core problem	Main objective	Key technology	Performance	Reference
Protective oasis agriculture of the Kebala catchment	Severe wind erosion, natural grassland degradation, and land desertification	Restore degraded natural grassland in the upper reaches of the Kanas Lake, and establish shelterbelt networks to prevent land desertification in oasis areas	Rotational grazing, exploiting water resources for pasture-land and artificial grassland, and farmland shelterbelt network	The treated area represents nearly 99.0% of the total area, the area of degraded grassland decreased by 61.0%, and local livelihoods were substantially enhanced	Wang et al., 2018a
Desert oasis of the Tarim Basin	Severe quicksand and desertification	Prevent wind and fix sand by establishing physical and vegetative sand-fixing belts in quicksand zones, and build shelterbelt networks in oasis areas	Grass pane sand fence (straws embedded into quicksand surface to form 1 m × 1 m continuous sand-fixing panes, within which plants can be grown), and brackish water desalination	Constructed sand-fixing belts prevented oasis areas from quicksand, and shelterbelt networks protected oasis from desertification	CREEI, 2016

It is extremely arid and ecologically vulnerable. The annual mean precipitation here ranges from 10–80 mm, and the annual frost-free period is as long as 200 d. Quicksand and desertification in this site are severe due to the combination of erodible aeolian sandy soil, extreme drought and windy weather, and frequent freezing and thawing erosion (CREEI, 2016). In this context, the primary objective for this mode is to protect oasis farming by constructing sand-fixing belts in quicksand zones and building shelterbelt networks in oasis areas. Regarding the completely irrigated farming in this basin, soil salinization is a big challenge the basin is facing and implementation of the trial projects of brackish water desalination is important in oasis areas. Additionally, it is necessary to take full advantage of the ample light, heat, and wind energy resources for power generation to reduce damages to the ecological environment (Table 2 and Fig. 7). In particular, Grass pane sand fence has successfully fixed the quicksand in the basin and has been extended to similar regions nationwide.

2.3 Earth-rock mountain region in North China

The earth-rock mountain region in North China covers an area of 0.7300 × 10^6 km^2 and comprises five subregions, i.e., circum-Bohai-Sea mountainous and hilly subregion in Liaoning Province, mountainous and hilly subregion in the Yanshan Mountains and west Liaoning, mountainous and hilly subregion in the Taihang Mountains, mountainous and hilly subregion in southwest Henan, and the plain subregion in North China.

2.3.1 Dominant mechanism for soil erosion in this region

In the earth-rock mountain region, the area affected by soil erosion is 0.1162 ×10^6 km^2 and accounts for 16.0% of its total land area (CREEI, 2016). The dominant soil erosion is water erosion, and sloping farmlands are the main water erosion areas. Some areas are affected by wind erosion. The combination of steep slopes, the frequent and intense rainfall, lower soil infiltration rates, and intensive cultivation result in substantial soil erosion and gully formation (Ding et al., 2016).

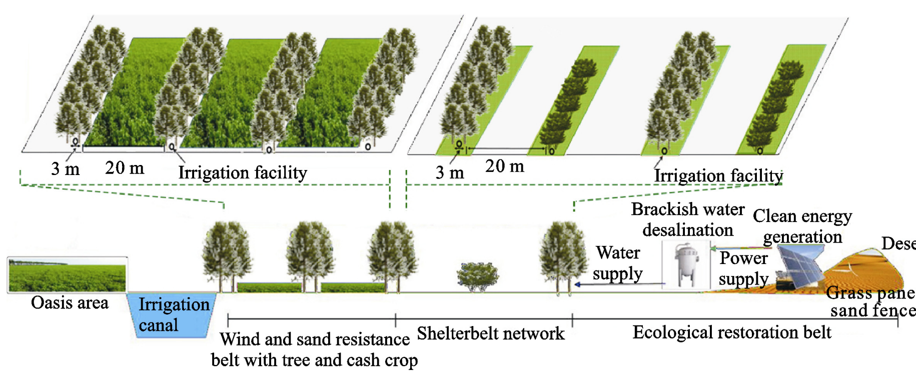

Fig. 7 Structure of paradigm for wind and sand resistance with vegetation belts in the oasis areas of the Tarim Basin

2.3.2 Main issues and challenges in the SWC of this region

Soil types in the region include cinnamon soil, brown soil, and moisture soil; the soil layer is shallow, with an approximate thickness of 50 cm of soil and parent material. Due to long-term soil erosion, the soil quality of many arable lands and cash forests on the slope is clearly degraded and is difficult to recover in the short term. Thus, the conservation of the shallow soil in this region remains a challenge.

Another challenge is how to govern the erosion and water pollution induced by human activities, such as agricultural activities, mining, and infrastructure development. In particular, the Huang-huai-hai Plain is the most developed area in this region, with a huge economy, large population, and dense cities. It is doubly troubled by severe water scarcity and water pollution, particularly nonpoint source pollution. Therefore, it is difficult to gain a synergy between agricultural production and water quality.

2.3.3 Typical paradigms for the earth-rock mountain region in North China

(1) Environmentally friendly catchment management

For some catchments located in areas that source drinking water, or with the function of headwater conservation while suffering from surface soil erosion, the core tasks for such modes of environmentally friendly catchment management are to protect the environment, and reduce water erosion and N and P nutrient loads for improving the water quality in their lower reaches. Regarding this, the key idea is to enhance the ecosystem regulation service via vegetation restoration. Empirical studies indicated it is reasonable at least to maintain 65.0% of the vegetation coverage for SWC and a relative low proportion of cash forests and terraced croplands in such catchments (Table 3). Such modes of environmentally friendly catchment management are widely accepted in the upper reaches of rivers or reservoirs in the Yanshan Mountains and west Liaoning. Typical examples include the Toudaoying catchment of Fengning County in Hebei Province, the Zhuanghugou catchment of Huairou County and the Shixia catchment of Miyun in Beijing, and the Tonglugou catchment of Fanzi County in Shanxi Province. It is necessary to further monitor the dynamics of ecosystem functioning and services in the treated areas in the future.

(2) Farming-oriented catchment management

Opposite to the modes of environmentally friendly catchment management, some catchments located in shallow mountainous subregions have the potential to ensure local food security, but often suffer from mixed water and wind erosion; thus, their core tasks are to enhance land productivity by terracing croplands on gentle slopes to curb water erosion and establish shelterbelt networks on unused lands to protect farming from wind erosion. In this regard, the proportion of terraced fields would be approximately 60.0% of the total cropland area; whereas, shelterbelt forests would account at most for 40.0% in such catchments (Table 3). Such modes are successfully adopted in the zones of mixed water and wind erosion in the Bashang Plateau as well as the front hill areas of the Yimeng Mountain, of which sloping farmlands account for a high proportion, although there remain a few of debates on the shares between croplands and shelterbelt forests in the treated areas. Typical examples include the Guoguoshan catchment of Guyuan County in Hebei Province, the Lushanhe catchment of Donghai County in Jiangsu Province, and the Yangzhuang catchment of Yishui County in Shandong Province.

Table 3 Summary of typical paradigms for catchment management in the earth-rock mountain region in North China

Typical paradigm	Core problem	Main objective	Key technology	Performance	Reference
Environmentally friendly catchment management	Suffer from severe surface soil erosion and water pollution	Enhance ecosystem function by restoring vegetation and reducing soil erosion	Closing of natural grassland, and ecological restoration	The ecosystem functions were significantly improved, and farmers' livelihoods shifted from subsistence farming to off-farm activities	Li et al., 2008; Li et al., 2009c
Farming-oriented catchment management	Large area of cultivated land with low productivity; mixed wind and water erosion	Create terraces on sloping arable land to increase the productivity and construct shelterbelt networks on unused lands to protect farming	Terraces and shelterbelt forests	The soil erosion reduced by 75.0% in the treated area; the productivity of arable lands increased by 41.0%	Li et al., 2008; Li et al., 2009c

2.4 Loess Plateau in Northwest China

The Loess Plateau in Northwest China covers an area of 0.5750×10^6 km² and comprises four subregions, i.e., the windy and sandy hills subregion in the north, Loess Hills subregion in the middle and south, loess tableland subregion in the west, and earth-rock mountain subregion in the southeast. This region is dominated by a warm temperate, semi-humid, and semi-arid climate. The annual precipitation ranges from 150–750 mm and gradually declines from the southeast to the northwest. Nearly 80.0% of annual precipitation falls between July and September. The 400-mm annual precipitation isopleth goes through Yulin and Guyuan, and divides the plateau into two distinct parts: the southeast and northwest (Yan et al., 2014). The vegetation zones change from forest to desert along a declining precipitation gradient from southeast to northwest.

2.4.1 Dominant mechanism for soil erosion in this region

The Loess Plateau in northwest China delivers nearly 90.0% of the total sediment load of the Yellow River (Chen et al., 2019b). The area affected by soil erosion is 0.2140×10^6 km^2, accounting for 37.2% of its total land area (Tang, 2004). Soil erosion is dominated by water erosion, while the areas in the north experience mixed wind-water erosion. The hilly subregion accounts for 60.7% of this area (Tang, 2004) and suffers from the most severe soil erosion in China. Moreover, gully erosion and surface erosion are dominant. The complex topography, high loess soil erodibility, frequent summer rainstorms, and long-term intensive human activities on the plateau conjointly cause the most severe soil erosion of China (Tang, 2004; Cai et al., 2012; Zheng and Wang, 2014).

Wind erosion is the second most important environmental problem in the Loess Plateau region, dominating the windy and sandy hills subregion and covering a total area of 0.1800×10^6 km^2, which represents approximately 25.0% of the Loess Plateau region (Tang, 2004).

Another form of erosion in the Loess Plateau region is wind-water mixed erosion. This mixed erosion mainly occurs in the transition zone between the water and wind erosion areas at the juncture of Shanxi and Shaanxi Provinces and the Inner Mongolia Autonomous Region (Zhu, 1989; Tang, 2004; Jing et al., 2005).

2.4.2 Main issues and challenges in the SWC of this region

Although soil erosion has greatly decreased as a result of the implementation of some conservation programs aforementioned after the 1990s, the Loess plateau ecosystem remains ecologically vulnerable, and soil erosion control remains a priority for the environmental management in this region (Chen et al., 2019b). In such a context, managing the recent human-induced soil erosion soundly is a big challenge. On the one hand, soil erosion in the region is caused by the combination of natural and human-induced erosion processes. Human-induced erosion arises from forest clearance, overgrazing, large-scale monoculture, mining, and construction, among other activities (Zheng and Wang, 2014). On the other hand, the rapid development of the oil, coal, and natural gas industries has led to large amounts of discharged stones and waste, and increases the erosion intensity in some parts of this region. Furthermore, construction-related activities such as infrastructure can cause landslides and soil collapse, as well as increase new soil erosion.

Another challenge for SWC in the Loess plateau is maintaining a runoff-sediment balance. While the sediment discharge observed at the Tongguan hydrologic station significantly decreased from 15.92×10^8 t in the period of 1919–1959 to 2.76×10^8 t between 2010 and 2012; correspondingly, the annual average runoff observed in the same station declined from 426.1×10^8 m^3 to 231.2×10^8 m^3 for the same periods (Liu et al., 2017; Zhao et al., 2019; Wu et al., 2019a). Wang et al. (2016a) attributed approximately 58.0% of the reduction in sediment load to the reduced runoff yield, 30.0% to the decreased sediment yield, and 12.0% to precipitation variation in the Loess plateau over the past six decades. Thus, in the context of climate variation, more attention should be paid to the balance between runoff and sediment load in this region.

Furthermore, as the size of planted forestlands and vegetations have approached the threshold of the water-carrying capacity of the plateau (Feng et al., 2016; Wang et al., 2018b), large-scale afforestation or reforestation would further deplete soil water and compete for water resources with other sectors (Ren et al., 2018; Wang et al., 2018b). In particular, the agricultural sector on the plateau heavily relies on rain-fed farming and has been trapped as a result of water resource shortages, insufficient inputs, soil degradation of farmlands, a decrease in the area of cultivable lands, and monoculture.

Finally, the total size of apple plantations has over expanded in the past decades. The total area of apple trees planted was 90.00 × 10^4 ha and the total production was 17.00 × 10^6 t in 2015, accounting for approximately 45.0% and 50.0% of China's counterparts for the same period, respectively. While the total area of apple plantations and the total production increased by 1.3 and 2.7 times, respectively, compared to their counterparts in 2000 (NBSC, 2000–2015; NBSC, 2019). Given that the Loess plateau is an arid and semi-arid region and the water-carrying capacity is limited, apple production is at an increased risk. In addition, as apple plantations have nearly no understory, they suffer from a much higher rate of soil erosion than woodlands and grasslands (Li et al., 2015; Wang et al., 2019). Therefore, simultaneously maintaining the sustainable development and reduction of soil loss of apple plantations in the plateau is a huge challenge.

2.4.3 Typical paradigms for the Loess plateau in Northwest China

(1) Soil conservation-oriented ecological farming of the Zhifanggou catchment in Ansai

The Zhifanggou catchment is located in the Loess Hills subregion. It is a tributary of the Yanhe River, which is a first-tiered tributary of the Yellow River, and covers an area of 8.27 km^2. It has fragmented landforms with numerous gullies. The gully density is as high as 8.1 km/km^2, and the ground dissected degree is 63.2%. The annual mean precipitation is 541 mm, approximately 75.0% of which falls from June to September every year (Jiao, 2014). Rainfall is usually in the form of erosive rainstorms. Prior to catchment management, the combination of extremely fragmented landforms, erosive rainfall, and intensive reclamation leads to a serious water erosion, and the annual erosion rate is as high as 14 000 t/(km^2·yr) in this catchment (Tang, 2004; Zheng and Wang, 2014). To restore severely degraded ecosystems and to control soil erosion, a project of cropland retirement was piloted since the 1970s until the GGP was initiated in 1999 in this catchment. Since this time, all arable lands on steep slopes over 15° have been environmentally restored (Fig. 8) and the erosion rate has reduced to 1153 t/(km^2·yr). As there are many eroded gullies, check dams have been built to control gully erosion and to retain sediment for the formation of farmlands in gully areas. Moreover, rain-fed orchards in gentle-slope areas have been developed for cash income, although their development is facing the aforementioned challenges. Despite the significant reduction in soil erosion and environmental enhancement after implementation of soil conservation plans (Table 4), farmers in this catchment have not yet directly obtained a significant cash income from the conservation activities.

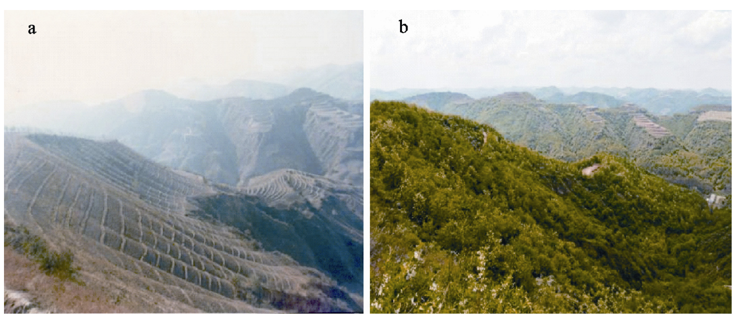

Fig. 8 Comparison between the land coverage of a site in the Zhifanggou catchment of Shaanxi Province in (a) 1998 and that in (b) 2008

Table 4 Summary of typical paradigms for dryland farming in the Loess Plateau in Northwest China

Typical paradigm	Core problem	Main objective	Key technology	Performance	Reference
Soil conservation-oriented ecological farming of the Zhifanggou catchment	Severe soil erosion and degraded ecosystem	Restore ecosystem services and control gully erosion	Vegetation restoration on steep slope lands, rain-fed orchard on gentle slope lands, and check dam in gullies	After treatment, the soil erosion rate reduced from 14 000 t/(km^2·yr) to 1153 t/(km^2·yr), and ecosystem services have been enhanced	Jiao, 2014; Xu et al., 2018b
Wangdonggou catchment of Changwu County	Severe gully erosion cutting tablelands and eroding farmland	Control the dissection into tablelands by dispersing runoff on tablelands and reducing gully erosion	Terrace, runoff-dispersing works of impoundment, drainage and diversion on tablelands, and gully control works such as check dams	After treatment, gully control works reduced approximately 20.0% of runoff, the soil erosion rate reduced from 1860 t/(km^2·yr) to 504 t/(km^2·yr); and farmers' income significantly increased	Lü et al., 2014

(2) Wangdonggou catchment of Changwu County in the loess tableland and gully subregion

Wangdonggou catchment is located in Changwu County of Shaanxi Province and belongs to the loess tableland and gully subregion. The catchment is dominated by a warm temperate, semi-humid continental monsoon climate, and its annual mean precipitation ranges from 200 to 710 mm. As the climatic conditions are suitable for the growth of apple trees, this subregion is a valuable area for apple production in the Loess plateau region. In addition, this subregion has a long agricultural history and good conditions for agricultural production; thus, is a typical area for dryland farming. The Wangdonggou catchment is located in the tableland and dominant landforms include tablelands and gully slopes, among which tablelands account for 35.0%, ridge slops account for 35.0%, and modern gullies account for 30.0% (Lü et al., 2014). Its population density is 258/km^2, associated with densely populated areas in the Loess Plateau region. Due to the dense population and long history of reclamation, severe gully erosion has significantly divided the loess tableland and damaged the arable lands. Therefore, the core tasks for such catchments are to apply runoff-dispersing and gully control works to prevent the dissection into tablelands. Besides, another issue currently necessary to address is to update the aging apple trees to maintain or enhance farmers' cash income in this catchment. Table 4 describes the detailed strategies for soil conservation in this catchment.

2.5 Red soil region in South China

The red soil region in South China covers a total area of 1.2400 × 10^6 km^2 and comprises nine subregions, i.e., hills and lower-reach plain subregion of the Yangtze River and Huaihe River, hills and plain subregion in the middle reaches of the Yangtze River, mountain and hills subregion in the Dabie Mountains and Tongbai Mountains, Jiangnan mountain and hills subregion, Nanling mountain and hills subregion, mountain and hills subregion in Zhejiang and Fujian, hills and tableland subregion in coastal areas of South China, hills and tableland subregion in Hainan and South China Sea islands, and mountain and hills subregion in Taiwan. The hilly and mountainous subregions cover approximately 60.6% of the land area (Tu at al., 2018). The average annual precipitation ranges from 800 to 3500 mm, approximately 80.0% of which falls between April and September.

2.5.1 Dominant mechanism for soil erosion in this region

In the red soil region in south China, the area affected by soil erosion is 0.2088 × 10^6 km^2. Collapse erosion (also locally called 'Benggang erosion') is a common erosion phenomenon (Xu, 1996; Jiang et al., 2014; Xia et al., 2015) and a dominant form of environmental deterioration that is difficult to manage (Xia et al., 2019) in the granitic areas of south China. Soil erosion predominantly arises from a combination of natural factors, such as hot and humid climate, high rainfall intensity, steep landforms, and erodible soil parent material, and socioeconomic forces, such as high population density, severe human-land conflict, and human-induced vegetation degradation (Liang et al., 2010; Chen et al., 2019d). In particular, the hot and humid climate accelerates the weathering process and the formation of thick granitic residues (Sheng and Liao, 1997).

2.5.2 Main issues and challenges in the SWC of this region

The conflict between populations and available lands is increasingly intensified; thus, the pressure on the sustainable development of this region has steadily increased. This region is an important area for the production of grains, cash crops, and aquatic products and fruits, as well as a production base for nonferrous metals and nuclear power, which present many environmental risks. The Yangtze River delta and Pearl River delta are the most developed areas in China; thus, they face the challenge of simultaneously feeding the increased populations while improving the ecological environment.

Reasonable management of the mining of rare-earth elements and the associated erosion of tailings is a critical challenge for policy-makers in this region. China is a dominant rare-earth element provider, accounting for over 95.0% of the world production (Tse, 2011). The relatively enriched rare-earth elements are contained in the lateritic ion-adsorption clay deposits in south China, and have been extracted since the 1970s. The long-term extraction of these rare-earth elements has caused lasting environmental damages, erosion of tailings, and contamination (Kynicky et al., 2012), and will continue to lead to new erosion of tailings in the future (Lu et al., 2017).

2.5.3 Paradigms for red soil region in South China

(1) The mixed pig-feeding-fishing-biogas-orchard agroeco-

system in Changting County

Changting County of Fujian Province experienced severe water erosion and extremely degraded vegetation before the 1980s. 'Bald mountains, turbid water, barren fields, and poor people' provides a vivid description of the consequences of severe soil erosion that Changting has suffered in the past years, due to the fact that the combination of the forest exploitation and monoculture planting for over 50 yr leaded to the county's forests and ecological degradation (Cao et al., 2009b). Since the 1980s, and in particular after 2000, Changting has realized soil erosion control projects to improve the ecosystem functioning. In the site selected for the demonstrated paradigm of the mixed agroecosystem, first and foremost, extremely eroded highlands must be prepared for the restoration of vegetation to curb soil erosion. Meanwhile, on eroded gentle mountainsides, some degraded orchards exist that require updating for cash income. In settlement areas, ponds for ducks and fish breeding, hog houses for pig-breeding, and biogas digesters should be constructed for rural energy. To encourage water conservation and diversity of income sources for farmers, local government has provided cash subsidies for the raising of pigs and fish. As such, the compound biozones on the highlands and mountainsides can produce fodders for livestock breeding; biogas digesters (methane-generating facilities), hog houses, and lavatories are integrated into an artificial ecosystem to recycle biogas residues and biogas slurry. In this way, the livestock farming, rural energy, and orchard farming are ecologically organized to form the so-called mixed pig-feeding-biogas-orchard agroecosystem that would provide livelihoods to farmers without damaging their environment (Table 5 and Fig. 9).

(2) The paradigm for collapse erosion control in the granitic areas

In the site selected for the demonstrated paradigm of collapsed erosion control in Changting County, the primary objective is to synthetically manage the collapsed erosion (i.e., Benggang erosion). The collapsed erosion also is a kind of ecological hazard very common in the granitic areas and potentially threats to ecological, agricultural, and settling securities of the affected areas. For this purpose, steep slope areas, which are prone to collapsed erosion, should be transformed into gentle slopes to prevent collapse. Subsequently, vegetations would be restored and erosion control works, such as horizontal trenches, would be constructed for further steadiness. Furthermore, in the gentle slope areas, vegetation zones, and check dam systems would be constructed to enhance the ecosystem functions (Table 5 and Fig. 10). Although collapsed erosion control might not bring direct net benefit to the farmers of treated areas in the short term, the environmental improvement and protective effect would make local farming more productive and them economically better off in the long run.

2.6 Purple soil region in Southwest China

The purple soil region in Southwest China (i.e., Sichuan Basin and ambient mountainous and hilly areas) covers a total area of 0.5100×10^6 km^2 and comprises three subregions: the Qinling mountainous subregion, Wuling mountainous and hilly subregion, and mountainous and hilly subregion in Sichuan and Chongqing. The average annual precipitation ranges from 1000 to 1200 mm and frequently falls as rainstorms. Approximately 85.0% of the annual rain occurs in summer (June−September) (CREEI, 2016).

Table 5 Summary of typical paradigms for Soil and Water Conservation (SWC) in the red soil region in South China

Typical paradigm	Core problem	Main objective	Key technology	Performance	Reference
Mixed pig-feeding-biogas-orchard agroecosystem	Severe contradiction between population and available land; dilemma of shallow soil layer and sever soil erosion	Attain ecological protection via practicing mixed agroecosystem	Compound biozone (trees, shrubs, and grass), biogas digester(methane-generating facility), and water storage works	After treatments, the vegetation coverage increased by approximately 33.0%; the soil erosion area decreased by 37.7%; and local farmers' livelihoods are substantially enhance	Cao et al., 2009b
Collapse erosion control	Severe slope collapse	Integration of vegetation restoration and engineering measures to control collapse erosion	Vegetation restoration as well as slope cutting, horizontal trenches, and check dams	After treatments, vegetation coverage increased by 48.0%, the soil erosion rate of the treated areas decreased from 30 488 t/(km^2·yr) to 3175 t/(km^2·yr), and collapsed areas became stable	Chen et al., 2006

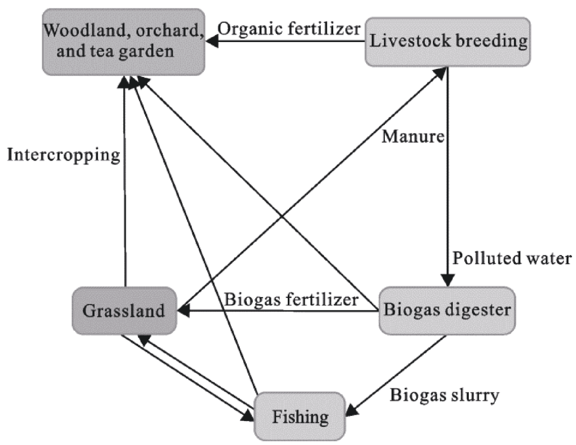

Fig. 9 Structure of the 'mixed pig-feeding-fishing-biogas-orchard agroecosystem' in Changting County of Fujian Province

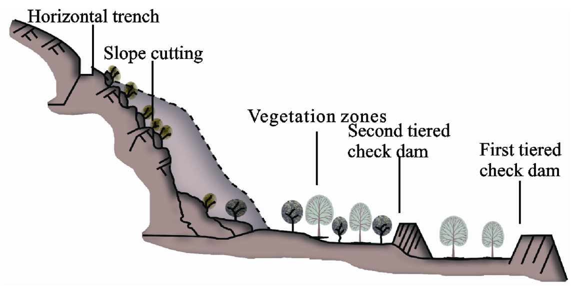

Fig. 10 Structure of the 'paradigm for collapse erosion control' in Changting County of Fujian Province

2.6.1 Dominant mechanism for soil erosion in this region

In this region, the area of soil erosion is 0.1617×10^6 km^2, and is dominated by water erosion. Purple soil is dominant as ground substances weathered from purplish rocks (Chen et al., 2015), and is highly susceptible to water erosion (Fu et al., 2009). Water erosion mainly occurs on sloping farmlands, barren mountains and slopes, deteriorated forestlands, and bare land formed by mining and construction. Among them, sloping farmlands are severely eroded. Slope, surface cover, and rainfall intensity have been widely identified as key natural factors influencing the erosion processes in this region (Fu et al., 2009; Li et al., 2009b; Mu et al., 2015; Khan et al., 2016; Xu et al., 2018a). In addition, coupled with the abovementioned natural factors, the land use changes in this region may cause a low carrying capacity (Heggelund, 2006) and the highest soil erosion rates in China (Zhou et al., 2006). Given that purple soil is widely distributed in the Sichuan Basin and the major tributaries in the upper reaches of the Yangtze River, SWC for this region plays an indispensable role on the sustainable development of the Yangtze River basin.

2.6.2 Main issues and challenges in the SWC of this region

Purple soil has a rich mineral composition, and high natural fertility and productivity (Zhu et al., 2008). Due to the large population (87.24×10^6 persons in the Chengdu-Chongqing region alone) and intensive farming activities, however, the purple soil in this region is heavily degraded.

In addition, the Chengdu-Chongqing region has experienced rapid economic development; thus, has been subject to intensive human activities, such as urban sprawl, mining, and infrastructure development, which lead to soil erosion and environmental pollution.

2.6.3 Paradigms for the purple soil region in Southwest China

(1) Small catchment management characterized by 'terrace and slope-surface water system'

Pengxi County is situated in the mountainous and hilly subregion and has an annual mean precipitation of approximately 1000 mm, nearly 80.0% of which falls during between May and September each year. Pengxi County has a high cultivation index and low vegetation coverage because of the high population density of 600/km^2. Therefore, this county suffers from severe soil erosion on its sloping croplands. In this context, this mode is featured by comprehensive control for slope water erosion in Pengxi County, Sichuan Province.

The protective system for this mode comprises two dominant components: terracing on the upper part and a slope-surface water system on the lower part. The terraces on the slope consist of stair-stepping field bunds on the slope of hills and gentle-slope drylands, which can effectively curb surface soil erosion. The slope-surface water works that mainly include flood diversion and drainage channel systems, reservoirs, and water cellars can not only retain runoff, but provide terraced fields with water resources (Table 6 and Fig. 11). This mode provides an effective approach to the harnessing of steep-slope farmlands with shallow soil in the upper reaches of the Yangtze River.

(2) Small catchment management characterized by 'terraced field with stone bund and plant hedgerow'

The selected site in Fengdu County is characterized by very shallow soil and severe slope water erosion on large-scale sloping arable lands. The ideal practice for

Table 6 Summary of typical paradigms for Soil and Water Conservation (SWC) in the purple soil region in Southwest China

Typical paradigm	Core problem	Main objective	Key technology	Performance	Reference
Small catchment management characterized by terraces and a slope-surface water system	Severe soil erosion on sloping farmlands with declined productivity	Control the water erosion on sloping farmlands	Terraces on sloping farmlands, slope-surface water works, such as reservoirs, ponds, and a rainwater harvesting cellar	After treatments, the soil erosion rate decreased from 5279 t/(km^2·yr) to 3565 t/(km^2·yr), cropland productivity and farmers' income increased 1.8 and 5.0 times, respectively	Deng et al., 2011
Small catchment management characterized by field bunds and a plant hedgerow	Severe soil erosion on sloping farmlands with very shallow soil	Improve the productivity of sloping farmlands	Terraces with a stone dike (mulching soil on stone dike) and plants on the dike	After treatments, the annual soil erosion rate on sloping farmlands decreased by 63.5%, and farmers' cash income significantly increased	Luo et al., 2005

Fig. 11 Structure of small catchment management characterized by 'terrace and slope-surface water system' of Sichuan Province

soil conservation in such sites is to construct sloping terraces with stone bunds and plant hedgerows. Such a mode for SWC involves two processes: 1) the growth of multiple species of plants to form a vegetation belt (or hedgerow) with a specific breadth and a proper interval between two vegetation belts on the sloping farmlands; the eroded soil in the upper part of which is gradually displaced to the lower part of the farmland during subsequent farming; and most of the eroded soil is deposited on the ground surface near the vegetation belt (or hedgerow) to form the terraced field with the plant hedgerow; 2) the artificial construction of stone bunds of the field on sloping farmlands as per certain design criteria, and then approximately 30-cm depth of soil is covered and herbaceous plants or shrubs are grown on the bunds to form plant hedgerows. SWC is mainly achieved by field bunds and plant hedgerows on a sloping farmland. Table 6 describes the characteristics of this catchment management.

2.7 Karst region in Southwest China

In the karst region in southwest China (i.e., the Yunnan-Guizhou Plateau region), limestone matrix and earthy materials are the dominant ground substances. The region covers a total area of 1.0570 × 10^6 km^2 and comprises three subregions, i.e., the mountainous and hilly subregion in Yunnan, Guizhou, and Guangxi, the alpine valley subregion in north Yunnan and southwest Sichuan, and the mountainous subregion in southwest Yunnan. In this region, karst landforms are widely developed, and include peak cluster depressions, peak forest plains, graben basins, karst valleys, karst plateaus, karst gorges, and middle and high mountains. Its average annual precipitation ranges from 1000 to 2500 mm (CREEI, 2016).

2.7.1 Dominant mechanism for soil erosion in this region

The area affected by soil erosion is 0.2520 × 10^6 km^2, accounting for 21.9% of the total land area of this region. Water erosion and karst rocky desertification are the dominant forms of soil erosion (Zhang et al., 2016; Li et al., 2019b). The combination of high rainfall intensity, highly soluble carbonate rocks, a shallow and broken soil layer, as well as intensive land use results in severe water erosion (Wang et al., 2004; Zhang et al., 2016; Dai et al., 2017; Li et al., 2019b; Gao and Wang, 2019). In the mountainous and hilly subregion in Yunnan, Guizhou, and Guangxi, karst rocky desertification is widely distributed due to the characteristics of the lithology (such as dolomite cover) and the complexity of the geomorphology coupled with intensive human activities (Zhang et al., 2016; Li et al., 2019b). Large quantities of soil are eroded, and run off through heavy bedrock fractures and underground conduit systems, particularly after the removal of vegetations (Wang et al., 2004; Zhang et al., 2007a). In the alpine valley subregion in north Yunnan and southwest Sichuan and the mountainous subregion in southwest Yunnan, water erosion and gravitational erosion are dominant, and collapse and landslides occur frequently.

2.7.2 Main issues and challenges in the SWC of this region

First, the process of karst rocky desertification is almost irreversible in a short time and its damage is arguably permanent (Zhang et al., 2016). Thus, karst rocky desertification and the resulting soil erosion pose key challenges and obstacles of the sustainable development of this region (Zhang et al., 2018).

Second, soil erosion and rocky desertification control programs have been established by the government, while the role of farmers and enterprises is limited. As a result, the effectiveness of implementing the policies for soil conservation and rocky desertification control is low.

Finally, the assessment of soil conservation and rocky desertification control emphasizes the reduction in erosion as well as changes in surface properties (Xie et al., 2015), and ignores ecosystem services and the resilience to perturbation (Zhang et al., 2016). In this region, the environmental services of existing afforestation and reforestation are weak; instead, dense grasses are widely available in the areas affected by soil erosion and rocky desertification (Peng et al., 2013). However, grass planting has not been widely promoted in existing soil conservation and rocky desertification control programs.

2.7.3 Paradigms for karst region in Southwest China

(1) Comprehensive catchment management centered on surface water system

As a typical example, the Longdong catchment lies within the northwest of Guanling County, Guizhou Province and belongs to the mountainous and hilly subregion. This catchment covers an area of 8.42 km^2, and the area affected by soil erosion is 6.8 km^2 with a soil erosion rate of 1805 t/(km^2·yr) (CREEI, 2016). Its average annual precipitation is 1337 mm. This catchment is dominated by water erosion because of barren mountains and large- scale sloping farmlands, coupled with concentrated runoff and loose soil. In this case, the protective system should comprise compound vegetation belts aimed at controlling the rocky desertification on the barren mountains in the upper part, and terraced farmlands or orchards to curb the slope soil erosion in the lower part of the catchment. Additionally, the surface water system should be equipped on the terraced farmlands and orchards to retain runoff for irrigation and to reduce the damage induced by concentrated runoff. The details and structure of this mode are described in Table 7.

(2) Ecological farming system focused on the utilization of karst water in peak cluster depressions

The demonstration site for such a mode in Guohua Town is an inhabited area of the Yao ethnic group, which covers a total area of 6.0 km^2. It has a typical landform of peak cluster depression. Before 2000, this site was stricken by severe karst rocky desertification, which represented more than 70.0% of its total area (Jin et al., 2006). Therefore, the core objectives of this mode are to: 1) build compound vegetation belts to combat karst rocky desertification in the upper reaches, construct terraces and rainwater harvesting works to curb soil erosion on the sloping farmlands in the middle reaches, and impound surface-layer karst water in the lower reaches

Table 7 Summary of typical paradigms for the management of leakage in the karst region in Southwest China

Typical paradigm	Core problem	Main objective	Key technology	Performance	Reference
Comprehensive catchment management centered on a surface water system	Severe water erosion on sloping farmlands and rocky desertification on barren mountains	Control rocky desertification on barren mountains; and curb soil erosion on sloping farmlands or orchards to enhance their productivity	Compound vegetation belts, terraces, water resource works, and a rural road network	After treatments, soil erosion significantly decreased, farmlands' productivity substantially increased, and farmers' income increased to 24 900 RMB/yr	CREEI, 2016
Ecological farming system centered on the utilization of karst water in peak cluster depressions	Severe leakage of karst water and rocky desertification	Combat karst rocky desertification in the upper reaches, retain karst water and reduce soil erosion in the middle reaches, and develop an integrated agricultural system in the residential areas of the catchment	Terraces, a rainwater harvesting system and karst water-using system, and a biogas digester	After treatments, the rocky desertification area decreased by 20.0%, the soil erosion rate decreased by over 40.0%, land productivity increased by nearly 50.0%, and farmers' income significantly increased	Jin et al., 2006

of this small basin; 2) develop an integrated system of hog houses, fish ponds, and biogas digesters to recycle animal manures, biogas residues, and biogas slurry that are extremely similar to the modes in Changting County; and 3) finally develop an ecological farming system to obtain a synergy between soil conservation, environmental improvement, and local livelihood development in the peak cluster depressions (Table 7 and Fig. 12). Such paradigms have been adopted widely by farmers in Guohua Town, Pingguo County, and Nongla Village, Mashan County, in Guangxi.

3 Discussion

In this paper, we only reviewed seven regions for SWC and excluded the Tibetan Plateau region because there few studies exist on soil erosion control in this region. Moreover, 14 typical paradigms were a part of the successful practices for SWC in rural China, also because of the few literatures available.

As abovementioned, 14 paradigms that suffered from typical issues and problems of soil erosion and human development before provide valuable insights into environmental conservation and livelihood development in the rest of seven regions in China or in developing countries subject to similar issues and problems. However, among these regions and their typical paradigms, some issues and problems continue to exist that need to be further addressed in researches and practices of soil conservation. For instance, for agriculture in the black soil region in Northeast China, the principal target of soil conservation is to protect the fertile black soil from erosion. However, this is difficult to achieve because intensive farming activities continue in this region. In the windy and sandy region in North China, the conflict between water and land resources remains unsolved in most of the subregions. For oasis agriculture in this region, soil salinization and desertification remain far from resolved. SWC in the earth-rock mountain region in North China should coordinate the rapid loss of shallow soil and the water shortage, as well as make a tradeoff between the ecological regulation function and grain production function in the concerned ecosystems. However, the conflict between increasing population and available water and land resources remains severe because of the rapid urban sprawl in the earth-rock mountain region. Dryland farming in the Loess Plateau region is a key agricultural practice and is heavily sourced by rain. The sustainable development of its dryland farming and apple orchards, however, is facing huge challenges. Another challenge in the Loess Plateau is how to diversify farmers' income sources given that over two thirds of their arable lands were converted to ecological-environmental uses under the GGP, a conservation program which was initiated in 1999 with two goals: reducing soil erosion and alleviating poverty in major river basins of China (Dang et al., 2020). Additionally, enhancing the ecological function of the large-scale planted forests remains an urgent task in the Loess Plateau region.

Similarly, in South China, there is a contradiction between rapid socioeconomic development and ecological functions in the densely-populated red soil region. This contradiction coupled with soil erosion, particularly collapse erosion, present a big challenge to sustainable development in this region.

Given that the purple soil region in Southwest China has an ample rainfall runoff, erodible and shallow soil, and intensive human activities, it is difficult to effectively reduce the soil erosion, improve the productivity

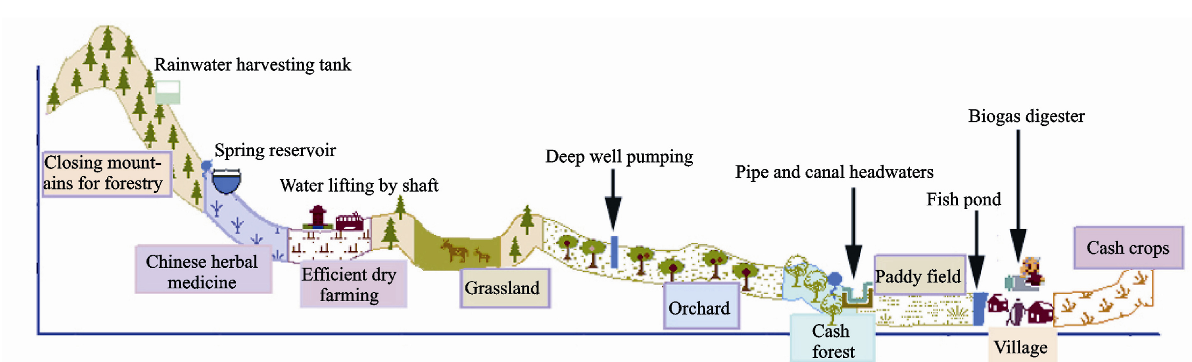

Fig. 12 Structure of ecological farming focused on the utilization of karst water in peak cluster depressions

of farmlands, and enhance farmers' livelihoods in this region. In the karst region in southwest China, effectively sequestrating the severe leakage of karst water and successfully controlling karst rocky desertification are the predominant challenges in the practices of SWC. In this sense, China, as a mountainous nation, still has a long way to go in successfully gaining the win-win objective of SWC and human aspects of development.

4 Conclusions

As the overall patterns of planning for SWC, eight regions for SWC in China were developed from geographic regions and a classification system for soil erosion in the early 1950s, and were formed in terms of elevation, annual precipitation, and annual accumulated effective temperature ≥ 10 ℃ across the country. In 41 subregions, the differences in the landforms and the types of soil erosion were also considered. The creation of both the regions and subregions, however, failed to consider the respective mechanisms of soil erosion.

A total of 14 typical paradigms for SWC across China fully consider climate, landform, erosion mechanism, and socioeconomic condition; therefore, in the past decades, they contributed to successfully preventing and controlling soil erosion, and largely enhanced or at least did no harm to the livelihoods of local farmers. However, there remain many challenges and issues on SWC and socioeconomic development that need to be addressed in the seven SWC regions. China, thus, still has a long way to go in successfully gaining the win-win objective of SWC and human aspects of development.

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