Science of the Total Environment 508 (2015) 166–177

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Co-evolution of soil and water conservation policy and human–environment linkages in the Yellow River Basin since 1949

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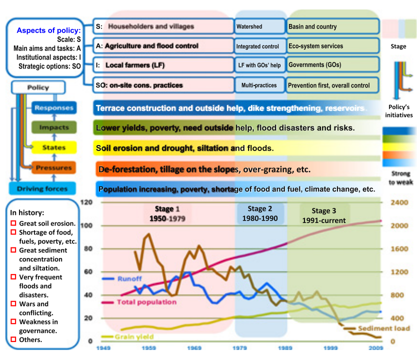
HIGHLIGHTS

- Outlining complex problems and policy responses in China's soil erosion hotspot
- Detecting policy co-evolution with human–environment linkages using DPSIR
- Policy addressing real conditions mainly affected the environment initially.
- Policy improved the rural economic and ecosystem when solving river's problems.
- Providing a historical perspective on resource management with an actual story

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 4 May 2014
Received in revised form 13 November 2014
Accepted 16 November 2014
Available online 2 December 2014

Editor: Simon Pollard

Keywords:
Driving force–Pressure–State–Impact–Response (DPSIR) framework
Policy
Co-evolution
China
Environmental management
Erosion
Sedimentation
Flood risk

ABSTRACT

Policy plays a very important role in natural resource management as it lays out a government framework for guiding long-term decisions, and evolves in light of the interactions between human and environment. This paper focuses on soil and water conservation (SWC) policy in the Yellow River Basin (YRB), China. The problems, rural poverty, severe soil erosion, great sediment loads and high flood risks, are analyzed over the period of 1949–present using the Driving force–Pressure–State–Impact–Response (DPSIR) framework as a way to organize analysis of the evolution of SWC policy. Three stages are identified in which SWC policy interacts differently with institutional, financial and technology support. In Stage 1 (1949–1979), SWC policy focused on rural development in eroded areas and on reducing sediment loads. Local farmers were mainly responsible for SWC. The aim of Stage 2 (1980–1990) was the overall development of rural industry and SWC. A more integrated management perspective was implemented taking a small watershed as a geographic interactional unit. This approach greatly improved the efficiency of SWC activities. In Stage 3 (1991 till now), SWC has been treated as the main measure for natural resource conservation, environmental protection, disaster mitigation and agriculture development. Prevention of new degradation became a priority. The government began to be responsible for SWC, using administrative, legal and financial approaches and various technologies that made large-scale SWC engineering possible. Over the historical period considered, with the implementation of the various SWC policies, the rural economic and ecological system improved continuously while the sediment load and flood risk decreased

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http://dx.doi.org/10.1016/j.scitotenv.2014.11.055

dramatically. The findings assist in providing a historical perspective that could inform more rational, scientific and effective natural resource management going forward.

1. Introduction

Soil erosion has important impacts, both on-site and off-site (Vignola et al., 2010; Wossink and Swinton, 2007), including the reduction of soil depth, impairing the land's productivity, and the transport of sediments, leading to deposition that degrades streams, lakes, and estuaries (Uri, 2001). In China's Loess Plateau, extensive soil erosion and water loss have historically induced soil degradation and soil water shortages, lowering crop yields, and exacerbating rural poverty, arable land and biodiversity loss on-site (Meng, 1997). It has also induced sedimentation in the Yellow River (which has the greatest sediment load in the world), reducing reservoir capacity, causing the riverbed to rise, increasing the risk of flood disasters, increasing the maintenance costs of the river banks, and requiring more water to flush the sediment to the sea (Zhao, 1996; Wu et al., 2005; Mu et al., 2004).

Management of soil erosion in the China's Loess Plateau has relied largely on the development and implementation of policies, which, over time have greatly decreased the sediment load of the Yellow River. Indeed, the mean annual suspended sediment load at Huayuankou declined from 1.36 billion tons in 1956–1970 to 0.23 billion tons in 1996–2010 (15 years) (Meng, 1997; Tang, 2004). This paper unpacks how policy approaches have changed over time to achieve this improvement.

Science and policy are both relevant to land management (Freyfogle and Newton, 2002; Stringer and Dougill, 2013). Although policy plays an increasingly important role in environment and resource management, and is considered fundamental to biodiversity conservation and watershed management (Jansen et al., 2006; Miller et al., 2009), the success of policy initiatives is contingent on effective stakeholder engagement or public involvement (Cocklin et al., 2007; Stern and Mortimer, 2009). Policies can include land rent change, voluntary or 'soft' policy based mainly on education, legal regulation, and national and local laws and actions (Bennett and Vitale, 2001; Kelly, 2006; Hanna et al., 2007; Gotmark et al., 2009; Stern and Mortimer, 2009; Angelsen, 2010). Policy in this article is defined as "a set of decisions which are oriented towards a long-term purpose or to a particular problem. Such decisions by governments are often embodied in legislation and usually apply to a country as a whole rather than to one part of it" (Sandford, 1985, p. 4).

Research in the Yellow River Basin (YRB) to date has focused mostly on SWC practices on the catchment slopes and how to dam the main stream to reduce sedimentation on the riverbed of the lower reach (YRCC ECR, 1991; Meng, 1997; Tang, 2004). Research on the role of SWC policies is sorely lacking. While some analyses on SWC policy changes exist at a regional scale in China (Ding, 1989; Guo, 1995), they just describe the policy and pay very little attention to the impacts. In focusing on the co-evolution of SWC policy and human–environment linkages in the YRB in this paper, we argue that it allows an opportunity for policy learning and to see what kinds of interventions have the desired environmental impacts. These lessons can then be applied in future policy developing, helping to guide it to better address some of the key drivers, pressures and impacts of soil erosion.

The goal of this paper is to analyze the SWC policy changes in the YRB since the foundation of the People's Republic of China in 1949. This period fits well with document availability. The next section sets out our study area and methods used. After that, we use the Driving force–Pressure–State–Impact–Response (DPSIR) framework as an organizational tool in order to explore on the whole picture of the SWC challenge and the ways in which the policies affected the drivers, pressures and states of the environment.

2. Research design and methodology

2.1. Study area

The Yellow River is the second largest river in China (Fig. 1) with a drainage area of 752,000 km^2 and a length of 5464 km. It originates from the Qinghai–Tibet Plateau, flows through the Loess Plateau and the North China Plain (elevation below 100 m), and empties into the Bohai Sea. The basin covers 9 provinces or autonomous regions, was home to 110 million people in 2000, and accounted for around 9% of China's total population (Giordano et al., 2004). The YRB covers a wide range of vegetation types and climatic zones because of this large area and elevation gradient. Mean annual precipitation in the basin is approximately 479 mm, but the regional and seasonal distribution is very uneven due to the great influence of the monsoon season. About 60% of precipitation falls in the rainy season from June to September (Zhao, 1996). The loess in the middle reaches of YRB is very prone to erosion, causing the sediment load and concentration of the Yellow River to be very large (Zhao, 1996; Walling and Webb, 1996). The mean annual sediment load was 1.6 billion tons and the average sediment concentration 37.8 kg m^{-3} based on measured data at Sanmenxia Hydrologic Station from 1919 to 1986 (Zhao, 1996). Over time, sediment deposition in the downstream river channel has caused the riverbed to be up to 10 m higher than the surrounding land surface in some places, a condition known as a "suspended river" or "perched river" (Wu et al., 2005). Over thousands of years of Chinese history, frequent catastrophic floods in the YRB have resulted in tremendous losses of life and property (Hu et al., 1998).

2.2. Method and data

2.2.1. Framework of analysis

DPSIR framework (OECD, 1993; Gabrielsen and Bosch, 2003; Gobin et al., 2004; Borja et al., 2006; Martins et al., 2012) provides the conceptual framework for better understanding the complex relationship between soil erosion and policy responses (see Fig. 2 for a brief overview). In the context of its application in the present study, it allows us to explore the effects of responses on drivers, pressures, states and impacts. Driving forces for SWC in the YRB include both natural and socio-economic factors that disrupt the environment's ability to provide provisioning ecosystem services, including e.g. food, fuel and forage (Fig. 2). Shortages of these services drive environmental pressures such as cultivation on slopes, deforestation and over-grazing. This leads to soil erosion that has both on- and off-site effects. Society nevertheless responds with various policy measures such as regulation and information provision, and in some cases, negative strategies that could worsen the pressures. Feedbacks between responses mean that the ways in which the problem of soil erosion is handled could affect driving forces (R1), pressures (R2) and/or states (R3). Responses to states (R3) might thereby have limited effect as they merely addresses symptoms of land degradation, whereas positive responses to the driving forces (R1) could improve the regional economic and food condition over the long-run as a solution to soil erosion control. These kinds of relationships form the focus of our analysis.

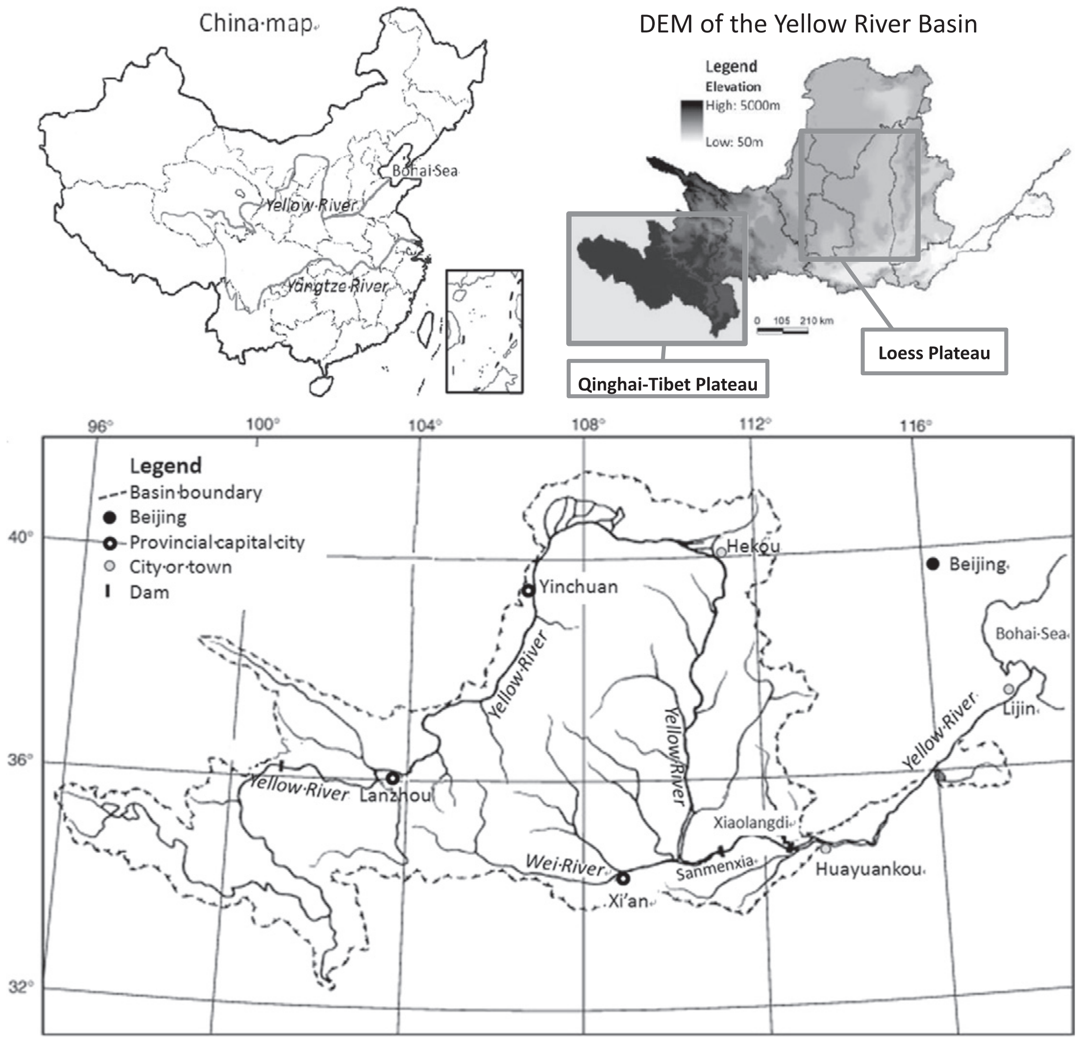

Fig. 1. Location and sketch map of YRB (upper left: YRB in China; upper right: elevation of YRB; below: main cities, towns, branches and hydrologic stations of YRB).

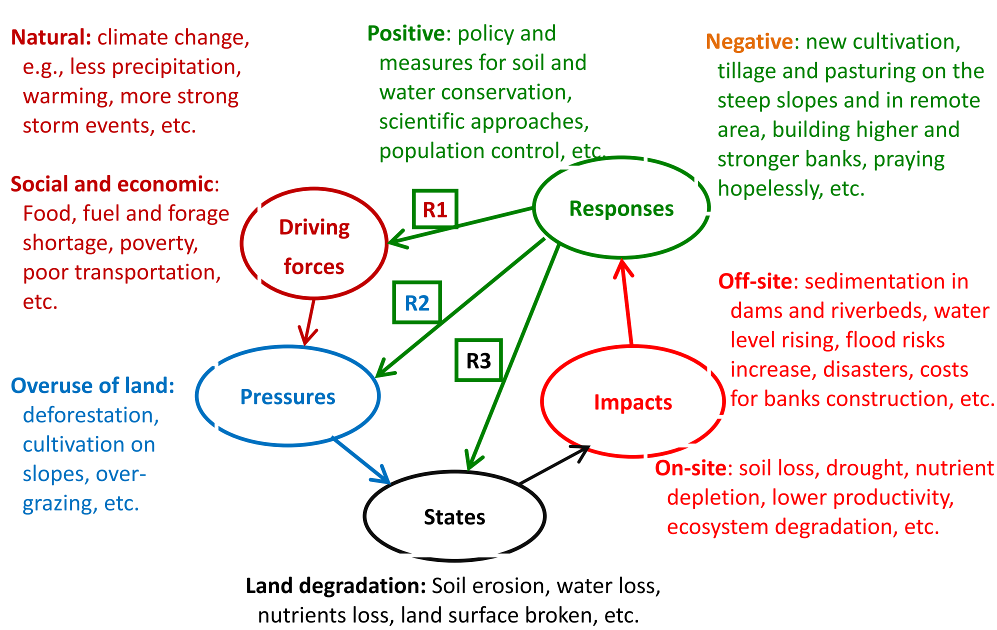

Fig. 2. DPSIR framework for soil and water conservation in YRB (main DPSIR framework with description of each factors; R1, R2 and R3 mean the 3 responses to Driving forces, Pressures, and States. In this article, we mainly discussed the policy aspects of responses).

Even though climate change in YRB could drive changes in soil erosion (Cenacchi et al., 2011), human influence has been (and still is) the most important factor in driving soil erosion (Zhao, 1996; Wang et al., 2007). The human population in YRB demands food and fuel for survival. Poverty and poor transportation determine whether local people can get the necessities for life from other regions.

In this study, we select food shortages as the main driving force (Li, 1996; Zhao, 1996) and regional floods as the main impacts that we analyze (Luo and Le, 1996; Zhao, 1996). We first identified and analyzed historical documents on SWC policies, and used these to elucidate the state, impact and driving forces to describe the problems, demands and the suggested or encouraged solutions that could influence the problems by addressing driving forces, pressures and/or states. Subsequently, the implementation and effects of specific SWC measures were identified, considering especially the policy objectives, tasks and principles, and the institutional set-up (and responsibilities). The main practices (measures and actions) at each stage were compared to allow detailed analysis of the evolution of SWC policy.

2.2.2. Data and analysis

Documents relating to SWC policy in the Yellow River were sourced from national administrative departments including the Government Administration Council (GAC, from October 21, 1949 to September 27, 1954, the then highest administrative department equivalent to the State Council), National People's Congress (NPC), the State Council (SC), Ministry of Water Resources (MWR), Ministry of Agriculture (MOA), managing department of basins including Yellow River Water Resources Commission (YRCC) and research institutes including the Chinese Academy of Sciences (CAS). The types of document included directives, decisions, reports, regulations and laws. According to the importance of their functions in conducting SWC actions at the basin scale, 20 important formal documents were selected for analysis (Table 1).

A 60-year annual dataset from 1949 to 2010 of total population, area of grain crops, grain yield, average yield and average grain per person of 4 main provinces of Shaanxi, Gansu, Shanxi Province and Ningxia Autonomous Region (which cover most of the basin) (NBS NEGSD, 2010) was analyzed to detect the driving forces of food production and supply. Data of cropland gradients of the 4 provinces in 1986 (CAS SSTlp, 1990a) were used to show the state of land use and cover in relation to soil erosion. The gradient of croplands distinguished 6 categories of land: flat lands — including level terraces, alluvial lands along the rivers like plains and check-dam land (lands built up behind check-dams and flat enough for agriculture, normally the gradient is gentler than 1°), and sloping croplands with gradient <3°, 3°–7°, 7°–15°, 15°–25° and >25° respectively.

To analyze the impacts of soil erosion and water loss, flood data was included based on available historical records from 1841 to 1990 (Luo and Le, 1996). The rush of runoff and sedimentation in the lower reach induced by soil and water losses were the main causes of floods in this region. Flood levels were classed according to the frequency of flood disaster possibility, and great flood disaster, big flood disaster and normal flood disaster were rarer than 5%, 5%–10% and 10%–20% probabilities respectively.

Annual data on runoff and suspended sediment load in 1956–2010 at Huayuankou Hydrological Station (Fig. 1) were abstracted from the China River Sediment Bulletin (published by MWR) from 2000 (with datasets before 2000 as appendix) to 2010 to describe the river characteristics. The watershed of the station is 730,036 km^2, accounting for 97.1% of the whole basin.

2.2.3. Three distinct stages in SWC policy

We divided our analysis of SWC policy into three stages according to two important events: the publication of the Act of Soil and Water Conservation at the small watershed scale (P10) and Law of The People's Republic of China on Water and Soil Conservation (P14). This provides a novel approach, different from that taken in other research (Ding, 1989; CAS SSTlp, 1991b; YRCC UMB, 1993; Guo, 1995; CCoG, 1999). The stages thus distinguished are as follows:

Stage 1 (from 1949 to 1979): Historical flood disasters and the desire for hydropower and irrigation made the government and basin manager plan to change the Yellow River from a harmful river into a beneficial river.

Stage 2 (from 1980 to 1990): Integrated control, taking a small watershed as a whole unit was introduced (P10), reflecting a need to

Table 1
Selected policy documents on SWC from 1949 to 2011 in YRB.[a]

Code	Issued by	Issued date	Policy
P1	GAC	Dec 19, 1952	Directive to arouse the masses for drought control and drought resistance and popularization of soil and water conservation
P2	YRCC	Feb 15, 1953	The decision of the harness the Yellow River in 1953
P3	MWR	Dec 31, 1953	Summary of the water conservancy in the last four years and the policy and task in future
P4	MWR, CAS, et al.	May to Dec, 1953	Working Report of Soil and Water Conservation in Northwest China of Investigation Mission (draft)
P5	NPC Standing Committee	Jul 30, 1955	The decision of integrate planning for radical solution of disasters and exploration of water conservancy of the Yellow River
P6	SC	Jul. 24, 1957	The Provisional Outline of Soil and Water Conservation of the People's Republic of China
P7	YRCC	Aug 2, 1958	The soil and water conservation planning in the middle reaches of the Yellow River from 1958 to 1962 (draft)
P8	SWCC of SC	Apr 13, 1962	Report on the strengthening the soil and water conservation
P9	SC	Apr 18, 1963	Decision on the Soil and Water Conservation in the Middle Reaches of the Yellow River
P10	MWR	Apr 29, 1980	Act of Soil and Water Conservation at the small watershed scale
P11	SC	Jun 3, 1982	The Regulations on the Work of Water and Soil Conservation
P12	NWLCG of SC	Sep, 1983	The Provisional Rule to Strengthen the Soil and Water Conservation in Key Areas of water and soil loss
P13	CPC CC and SC	Jan 1, 1985	The Ten Policies on Further Animating the Rural Economic
P14	NPC Standing Committee	Jun 29, 1991 (issued) and Dec 25, 2010 (revised)	Law of The People's Republic of China on Water and Soil Conservation
P15	SC	Aug 1, 1993	Implementation of the Law of the People's Republic of Soil and Water Conservation
P16	SC	Jan 7, 1999	National Plan for Eco-environmental Improvement
P17	SC	Dec 21, 2000	National Program for Eco-environmental Protection
P18	SC	Jan 20, 2003	Regulations on Conversion of Farmland to Forest
P19	SC	Aug 9, 2007	Circular of Policy on Conversion of Farmland to Forest
P20	CPC CC and SC	Dec 31, 2011	Decision on accelerating water conservancy reform and development

Abbreviation: CPC CC: Central Committee of the Chinese Communist Party; NWLCG: National Water and Land Conservation Work Coordination Group of State Council, a branch of the State Council founded in 1982 and canceled in 1988, and a National Water Resources and Soil Conservation Leading Group in 1988; SFA: State Forestry Administration.

[a] Pn in this paper means the relative document in this table.

explore natural resources and build on a systematic management principle of watersheds based on previous experiences including soil erosion control practices on the slopes, and sediment retention and flash flood control with dams in the gullies.

Stage 3 (from 1991 till now): Since the issue of SWC law in 1991 (P14), the aims and tasks of SWC policy became broader and more central. Prevention of new lands being destroyed began to be the priority, after which technology and other approaches were considered.

3. The evolving backdrop of policy through a DPSIR framework

Policies mainly embody the positive responses of humans to other elements in the DPSIR framework. In this section, the continuous changes of driving forces, pressures, states and impacts are described to sketch the complex interconnections between conditions and processes. Special attention is given to dynamics over the three policy stages distinguished because such factors changed continuously and the interactions between elements varied in intensity.

3.1. Driving force evolution

In Stage 1, because of the great effect of long-term conflicts including the World War II and the Chinese Inner Wars, living conditions in the YRB and whole of China were very poor before 1949. There were 36.86 million people in the 4 provinces in 1949, the average yield of grain was very low (0.8 ton ha^{-1} in 1949) and the average food availability expressed as grain per person was 224.8 kg (Fig. 3). This meant local people had to cultivate more and more land for food because traditional agricultural productivity was very low. The area of grain crops increased from 10.94 million ha in 1949 to 12.97 million ha in 1966 (the largest in the whole research period), a change of up to 18.5%. However, the population increased even faster in this period, to 57.33 million people (a 55.5% increase) by 1966 and 75.12 million people by 1979 (Fig. 3).

In Stage 2, the population continued to increase to 89.35 million people in 1990 (Fig. 3). Average yields increased from just 2.0 t ha^{-1} in 1980 to about 2.6 t ha^{-1} in 1990. However, the total area of grain crops in the YRB decreased to 11.02 million ha during this period, which combined with the increase in population, means that food production has seen no great improvement (fluctuating around 300 kg $person^{-1}$ since 1979). Nevertheless it has proven to be enough to increase food security in this region, as infrastructure development and an increase in incomes have enabled people to purchase some various food and meat produced in other regions, but the food was not enough for local people and animal husbandry (CAS SSTlp, 1991b).

In Stage 3, the population increase continued and in 2010 was up to 105.02 million people (about 2.85 times the population in 1949) (Fig. 3). However, the rate of population change has started to slow down since 1990. The area under grain crops continued to decrease after 1991, and although average yields continued to rise, total grain production started to stabilize. Another important driving force has been the economic development in China since 1988 (Supplementary material 1, Fig. S1). In the four provinces, the gross regional product (GRP) of primary industry (including crops, forests, animal husbandry, sidelines and inner water fishery) increased fast, but nevertheless the share of direct output of agriculture reduced. The local people could earn more money from other industries and purchase more and enough food from other regions, leading to relieve of human pressure on the land.

3.2. Pressure evolution

In Stage 1, pressures were mainly exerted by the expansion of cropland on slopes because of population increases and food shortage, deforestation due to new cultivation and rural fuel, and over-grazing as more livestock were added in the hope of gaining more meat and money. Animal husbandry was a traditional livelihood activity in the Loess Plateau because there were plenty of areas supporting grasses that were not feasible for cultivation both because of steep slopes and poor soil properties (CAS SSTlp, 1991a).

The share of cropland in the Loess Plateau was more than 30.0% in 1986 (CAS SSTlp, 1990a), but most cropland was on sloping land. In the 4 selected provinces in 1986 (Fig. 4), the share of flat lands and sloping croplands with gradient <3°, 3°–7°, 7°–15°, 15°–25° and >25° was 18.06%, 36.17%, 9.22%, 16.47%, 14.80% and 5.28%, respectively. Croplands steeper than 7° accounted for 36.55% of cultivated lands and 11.68% of the whole area, respectively. Indeed, this condition was the result of long-term implementation of SWC practices on the slopes before 1986 (P1, P2, P7 and P9), and evidence of the degree of human pressure on the land in preceding decades.

Despite a gradual decline in the cultivated area after 1966, the availability of grasses has never been sufficient because of the over-grazing

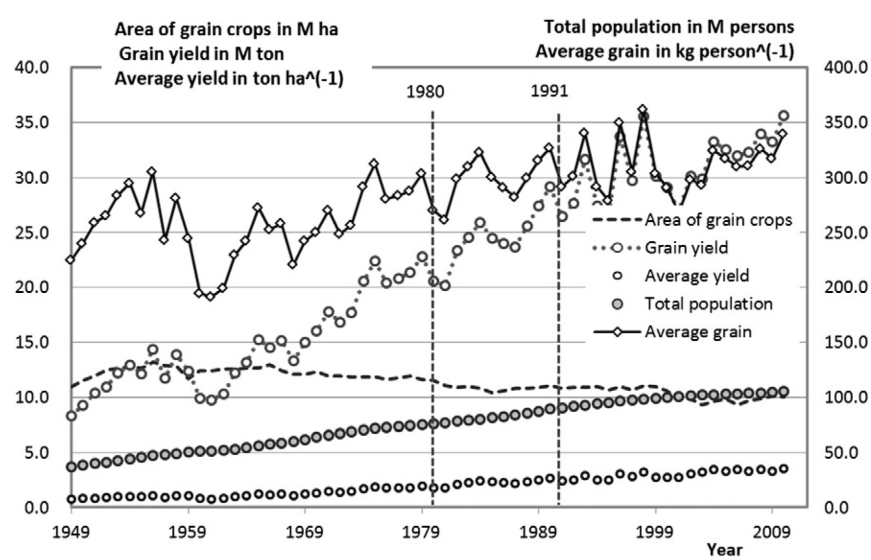

Fig. 3. Population, area of grain crops and grain yield of the 4 provinces in 1949–2010 (the 4 provinces include Shaanxi, Shanxi, Gansu Province and Ningxia autonomous region).

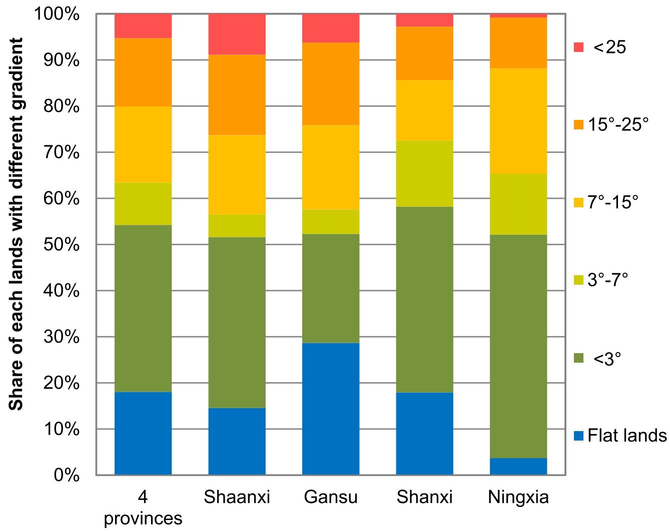

Fig. 4. Gradient of cropland of the 4 provinces in YRB in 1996.

of very intensive free-ranging livestock, e.g. about 1.5 goats per ha of grassland in 1998 in Yan'an City (Shaanxi Bureau of Statistics, 1999). The domestic animals could pull out the roots of grasses and some small shrubs, and even eat the bark of shrubs and trees. This causes destruction of the natural vegetation more widely, leaving the soil loose and exposed (Zhao, 1996).

In Stage 2 and Stage 3, the pressure on land reduced because of SWC practices driven by policies. For example, 225.6 thousand km^2 of degraded land was controlled from 1949 to 2009, but more than 80% of these works were realized since 1970 (Sun et al., 2009). The SWC practices could last for several years to many decades and induced less soil erosion and sediment load in the river. There were 8.27 million ha of sloping cropland converted from 1999 to 2006 in YRB involving 8 million households and 30 million people, with investment from central government amounting to 5.1 billion US$ (38.8 billion Yuan RMB) (Gu and Gu, 2007).

3.3. State and impact evolution

The continuing driving forces and pressures induced changes in land use and the land degradation state (Fig. 2). Cultivated land is the main source of sediment of the Yellow River, contributing more than 50% of the sediment load (Tang, 2004; Lü et al., 2012). With cultivation of steeper slopes, the soil erosion rate increased dramatically; on newly cultivated lands steeper than 25° and 35°, the annual soil erosion rate was around 15 thousand tons km^{-2} and 30 thousand tons km^{-2} respectively (Tang, 2004) because of the natural intensive storms and very little vegetation cover (CAS SSTlp, 1990b).

The state and impact relating to SWC are separate elements in the DPSIR framework but they are closely interlinked. The state of land degradation refers to soil erosion, water loss, nutrient loss, land surface broken (Fig. 2), while the impacts of such state include 2 different types. The on-site impact includes soil loss, drought, nutrient depletion, lower productivity, ecosystem degradation, etc., and the off-site impact includes sedimentation in dams and riverbeds, water level rising, increased flood risk, disasters, costs for banks construction, etc. The sediment load and floods of the Yellow River were selected as impacts to reflect the soil and water losses.

3.3.1. Flood disasters

Flood disasters have throughout history constituted the main impact of the degraded state of land in the YRB. Floods broke out every year from 1841 to 1949 (before Stage 1) affecting on average 149 counties annually in China; there were 288 flood disasters during that period, of which 42 events were in YRB (Luo and Le, 1996). Flood disasters in YRB occurred very frequently (2.3–5.7 events per decade in 1871–1960). Most of them were big or great disasters (Table 2). Flood disasters affected all areas from the upper to the lower reaches but most flood disasters were in the densely populated and intensively used lower reaches. Damages resulting from flood disasters have been terrible in the history of the YRB. For example, the great flood disasters in 1933 and 1935 affected 67 counties and 27 counties, resulting in 3.64 million and 3.41 million victims, and more than 18 thousand and 3065 people died, respectively (Luo and Le, 1996).

Table 2
Flood disasters in the Yellow River Basin from 1841 to 1990.

Period	Level			Total number	Frequency
	Great	Big	Normal		Events per decade
1841–1870	5	2	3	10	3.3
1871–1900	8	9	0	17	5.7
1901–1930	4	2	1	7	2.3
1931–1960	6	1	4	11	3.7
1961–1990	2	1	1	4	1.3

Even though the flood disasters were to a great extent induced by weather conditions, the raising of the riverbed due to sediment deposition in the lower reach has aggravated flood risk (Zhao, 1996). Furthermore, the river banks in the lower reach have seen a great influx of people, dramatically worsening potential damages of flood disasters and reminding us all the time of the risk of catastrophes even if there were very few flood disasters in Stages 2 and 3.

3.3.2. Sediment load change in each stage

In Stage 1, the mean sediment load between 1956 and 1979 was 1.29 billion tons at Huayuankou Station, although peaks of more than 2 billion tons occurred in 1958, 1959 and 1967 (Fig. 5). The total sediment load in this stage amounted to 2.99 billion tons. At the beginning of Stage 1 (1950–1959), the sediment load of the Yellow River was very high (1.78 billion tons on average) (YRCC UMB, 1993), and sediment deposition in the river bed of the lower reach amounted to 473 million tons annually (Xu, 2004), raising the river bed and increasing flood risk.

In Stages 2 and 3, the mean sediment load reduced to 764 million tons and 366 million tons respectively, reflecting a 40.7% and 71.6% reduction compared to Stage 1. The sediment load was less than 100 million tons in 2006, 2007, 2008 and 2009, meaning that soil erosion and sediment load were controlled very effectively and also implying that the human response should now change focus (Fig. 2).

4. Understanding policy evolution in each stage through a DPSIR framework

4.1. Policy responses in Stage 1

Before Wan mentioned SWC in 1936, people did not link flood disasters to soil erosion of the upper streams. They considered flooding a natural process, and the long-term strategy to prevent flood disasters focused on flushing the sediment into the sea and re-constructing the river banks (YRCC ECR, 1991). Even until 1955, people believed "it was proved that the flooding and sediment were endless in the Yellow River and the sediment should be flushed away" (P5). But the new understanding of SWC promoted a more integrated policy, controlling food supply, flood prevention and environmental protection (Table 1).

4.1.1. Main aims and tasks

In the beginning of new China, SWC was listed as an independent action of agricultural development (Ding, 1989). Since 1952, it was mainly implemented to combat drought (P1), as a complementary strategy to improve grain production with more irrigation (P5). It was also

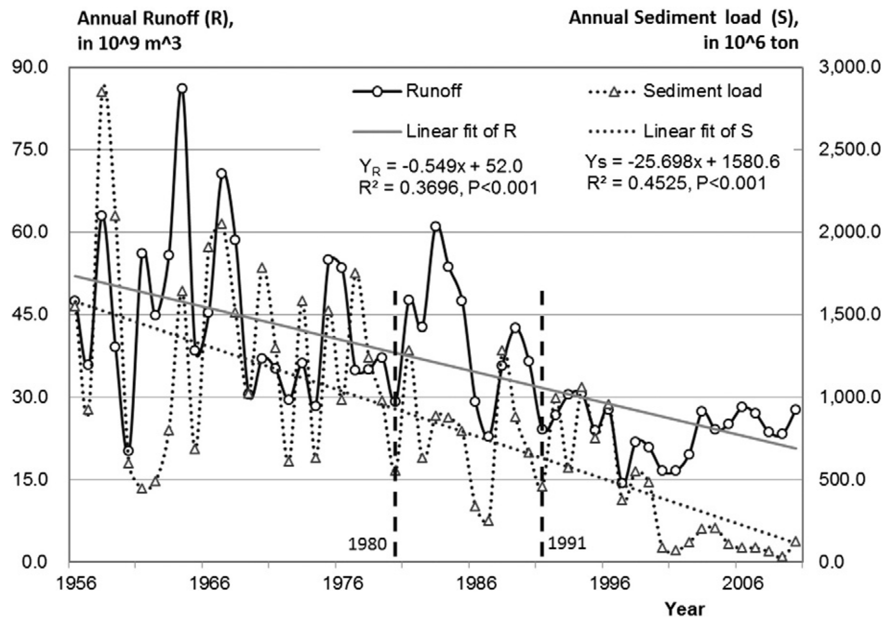

Fig. 5. Annual runoff and sediment load change at Huayuankou Hydrologic Station (YR) in 1956–2010.

regarded as the key to "change the Yellow River from a harmful river to a beneficial river" because it allowed the rational use of water for irrigation and hydropower exploration (P3). Some responses were more compulsory and included legal elements. For example, as a response to pressures (R2, Fig. 2), cultivation of new cropland on steep slopes was forbidden on land steeper than 25° (P1).

It was soon realized that to obtain synergies between R3 and R2 responses required the integrated control and treatment of the natural watershed as a whole. The geographical focus changed from some branches with very severe erosion problems (P1) to the regional scale, covering an area from Hekou Town (Inner Mongolia) to Longmen Town (Shannxi Province) (about 100 thousand km^2) (P4, P8).

SWC also started paying attention to driving forces (R1) through local economic development and integrated river management in 1955 (P5, P6, P7), considering management or control both for reduction of flooding and improvement of hydropower. The SWC of the Loess Plateau was thus highlighted in national planning. The policy stated: "For the objectives of development of mountain region, improvement of living standards, radical solution of disasters and exploration of water conservancy of the Yellow River, we should try to conserve water and soil, improve food production, promote the development of each of the industries of agriculture, forestry and animal husbandry, and do our utmost to use the water and soil resources (P5)".

4.1.2. Institutional aspects

The economic condition was poor and the managing ability of local and central governments was weak in the beginning of new China. The main stakeholders responsible for SWC were the local farmers in 1952 (P1). Since 1961, the CSWC SC pointed out that "to conserve soil and water based on production teams, the major power of it is local people and secondary is assistance from the state". SWCC and YRCC of MWR stated the same main institutional set-up, i.e. local people with assistance from the government (P8, P9).

4.1.3. Strategic options

In Stage 1, a policy on "overall survey, test and demonstration, progressive and careful extension" was put forward in 1953 (P4). It was a rational policy and implied SWC should have scientific and cautious strategies and that they needed more research and testing. Then, 1st SWC Meeting of YRCC of MWR and SWCC of SC launched a policy of "comprehensive planning, overall development, control the slopes and gullies together and concentrated control" in 1956 and 1957 respectively (P5, P6). It not only covered the fundamental principles of planning, measurement and development, but targeted what was considered more important to control at the time: the slopes and gullies in areas with poor economic and social conditions and flooding risks. There were many integrated multidisciplinary investigations to identify the soil erosion types, intensity and distribution, rural economic condition, SWC practices and planning, regional development and so on, to support policy implementation. For example, the investigation organized by MWR and YRCC with 500 experts from CAS, MOA, MOF and their branch institutes (P4); the integrated investigation organized by CAS for SWC in the middle reaches of the Yellow River from 1955 to 1958 on a pilot area of 350 km^2.

Before the climax of SWC was implemented by the local people, the 3rd National SWC Meeting developed the policy to "pay the same attention to prevention and control, conserve the results of control, develop the area and quality together for the final control and stable and high yield of crops" in 1958 according to the aims of agriculture development at that time (P8).

Construction of reservoirs and dams for siltation was put forward as fast and decisive practice as a response to states (R3, Fig. 2) in the beginning (P1, P2, P3, P5), but later SWC practices on the slopes became more important than practices further downstream (P1, P2, P7 and P9). Documents pointed specifically to "SWC on the sloping croplands first" (P9), to reduce soil erosion and the sediment load of the rivers. But soon after that, in 1961, the SWCC of SC changed it: "the main target area is the sloping cropland and the control of sloping cropland should be combined with the control of uncultivated slopes, wind erosion area and gullies through re-vegetation practices, such as grass-planting, reforestation and closure" (P8). The main SWC practices became vegetative practices. From 1970 to 1977, MWR paid more attention to land construction to improve agricultural conditions.

4.1.4. Evaluation of effects of policy responses

In Stage 1, SWC played an important role for the recovery and development of the local economy after the long social upheaval of World War II and the Chinese Inner Wars before the foundation of new China in 1949. Average yields were initially fluctuating around 1 t ha^{-1} (1949–1969) but almost doubled in the last 10 years of Stage 1 (Fig. 3). There were large disparities however: crop yield on the sloping cropland was about 0.9 t ha^{-1}, but amounted to 3.5 t ha^{-1} on the terraces and check-dam land (YRCC UMB, 1993). Even though the extent of SWC developed quickly, it could not keep up with the requirements of society. Some actions, such as tillage on steep slopes induced greater soil erosion, and showed negative impacts. Over-ambitious planning of SWC was put forward as a policy against the social background of "the Great Leap Forward Movement" from 1958 to 1960. The government wanted to radically solve problems of flooding disasters and exploration of water for irrigation and hydropower resources of the Yellow River (P7). The mean suspended sediment load at Huayuankou was 1.36 billion tons in 1956–1970 (15 years), illustrating some success in reducing sedimentation, and flood disasters were reduced (Table 2).

However, some policies were not implemented according to plan. The main reason was that the SWC policy was too bold to implement, e.g. a good policy based on "entire planning, integrated measures and continuing implementation" in 1958 (P7) set a grand task to change agricultural conditions and control the entire area affected by soil erosion (158.9 thousand km^2 before 1958 and the remaining 355.3 thousand km^2 before 1964). Such integrated control would require no soil erosion on the slopes and no runoff out of the gullies under the conditions of (1) daily rainfall up to 100 mm in Inner Mongolia Autonomy Region, Ningxia Autonomy Region, central area of Gansu Province and Qinghai Province, (2) daily rainfall up to 150 mm in west region of Shanxi Province, north region of Shaanxi Province, west region and south region of Gansu Province, and (3) daily rainfall up to 200 mm in Henan Province. It was neither feasible nor necessary in terms of either physical process or economic capacity. It is a typical example of policy failure because planning was too ambitious and far beyond of the ability of society and citizens (Jansen et al., 2006).

4.2. Policy responses in Stage 2

4.2.1. Main aims and tasks

With the development of SWC, the main aims and tasks evolved to become more complex, starting with separate aims to reduce sediment load and flooding, improve production, and move towards integrated watershed control and more holistic resource and environmental management. In Stage 2, the main aim was to efficiently improve SWC based on multidisciplinary appraisal which treated small watersheds as special complex natural and economic units in this region (P10, P11). MWR put forward a policy in which "integrated control should treat a small watershed as a unit with overall planning and different efficient on-site practices" (Guo, 1995; Duan, 1999; CCoG, 1999; MWR SWCD, 1995). "Hills, water, forest, cropland and roads" were harnessed together (P10) for holistic control (R1–R3) and long-term benefits (P11, P14, P16 and P18). A second characteristic response in Stage 2 was the identification of key areas for SWC. The area of high erodibility is so large that it was necessary to select some areas to prioritize according to the soil erosion rate (R3) and impacts. Dedicated responses to pressures (R2) were also considered: cultivation of reclaimed land with slopes between 5° and 25° required permission from the local government (P13, P14); logging without permission or digging for the roots of herbs was forbidden to avoid new soil erosion (P6, P12, P14, P16, and P17). Those engaging in these activities were fined and even imprisoned if the consequences were bad enough (P14, P15).

4.2.2. Institutional aspects

The increasingly integrated approach to SWC in this stage could not be implemented by local farmers themselves because the capacities of investment, technology and labor of local farmers were insufficient to carry out the envisaged engineering works like check-dams and roads. SC presented a structure of organizations involved in SWC and their duties to enable implementing this policy and stated the principle to encourage communities to participate in SWC, which was until then mainly carried out by citizens, assisted by the State (P11).

4.2.3. Strategic options

In Stage 2, the strategy emphasized the direction, suitability, integration and sustainability of SWC (P10). Engineering and vegetation practices were especially important, using grass and shrubs first and then trees. The slopes and gullies were to be controlled with different efficient practices; starting with overall planning, the control process should start with severely eroded areas and only subsequently continue with less eroded areas. Cropland on slopes steeper than 25° should be gradually converted for forestry and animal husbandry, and the government should provide cheaper food to the local people if the food production there was not enough (P13). The focal area also shifted to consider smaller coarse sediment source areas (78.6 thousand km^2) from where the sediment particles are big and difficult to transfer to the sea (YRCC EC, 2002). This helped the government to improve the efficiency of sediment load control of the Yellow River.

SWC was mainly characterized as taking a small watershed as a whole unit to plan and control with integrated control measures. As the functions and suitability of SWC practices vary greatly depending on soil erosion intensity, soil moisture and vegetation in different sites, integrated control with different proper practices is necessary both for SWC and agricultural development (Fig. 6). Integrated control measures considering a small watershed as a whole have been put forward since 1950s (Tang, 2004), but the systematic generalization, extension and implementation as action (P10) began in 1980 (Guo, 1995; MWR SWCD, 1995; CCoG, 1999; Duan, 1999).

4.2.4. Evaluation of effects of policy responses

Since the implementation of the Act of Soil and Water Conservation at the small watershed scale (P10), there were 5 phases which overall involved surveying, planning and measurement of 164 small watersheds in YRB as experimental sites. During the process of implementation, many technical regulations, procedures for planning, investment, research, checking and qualification were brought forward that promoted the implementation of policy institutionally (Cao, 2007).

Besides, an investigation of the water conservancy management department and the integrated investigation team for SWC of the Loess Plateau was organized by CAS in 1983. A project on integrated control of the Loess Plateau was carried out by CAS from 1986 and began to identify an overall strategy of soil erosion control and rural development with real experimental and demonstration watersheds till 2000 (Li, 1996; Li and Sun, 1998; Wang et al., 2005a, 2005b).

The sediment load of the Yellow River decreased from an average of 1.29 billion tons to 764 million tons during this stage (Fig. 4) and the cropland area and grain yield increased (Fig. 3).

4.3. Policy responses in Stage 3

4.3.1. Main aims and tasks

In Stage 3, the aim of the law was "the prevention and control of soil erosion, the protection and rational utilization of water and soil resources, the mitigation of flood disasters, drought and sandstorms, the improvement of the ecological environment and the development of production (P14, Article 1)". The law expressed the policy as "the state shall, in relation to the work of water and soil conservation, implement the policy of prevention first, overall planning, comprehensive prevention and control, adoption of measures suited to local conditions, strengthening management and stress on beneficial results (Article 4, Chapter 1)" (P14) and changed the former policy of "paying the same attention to prevention and control" (P6) to prioritizing prevention. Under the P14, a series of laws and regulations were issued according to this policy. Furthermore, the National Program for Eco-environmental Protection and Regulations on Conversion of Farmland to Forest was published by the State Council in 2000 and 2003 respectively (P17, P18). These stated that SWC is not only an action for harnessing the Yellow River and controlling soil erosion (i.e. R3 response) for agricultural

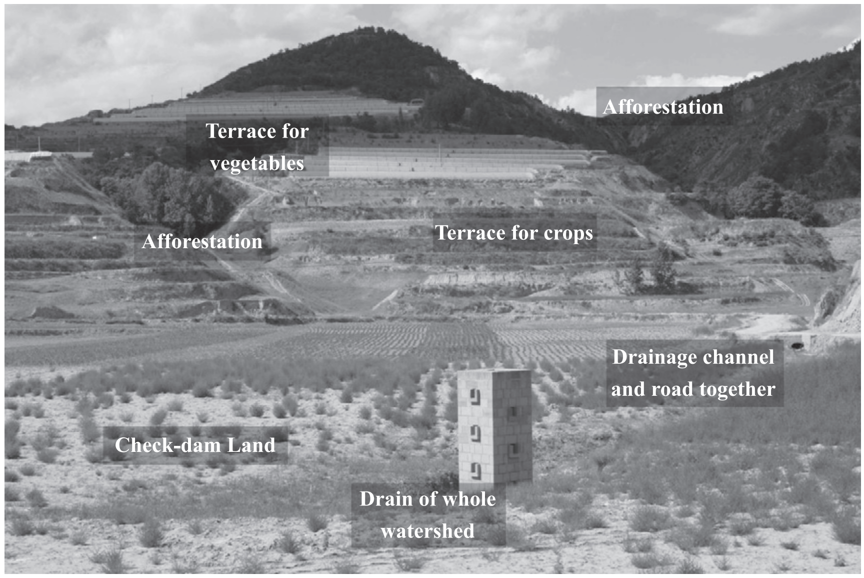

Fig. 6. Integrate control of Majiagou Watershed, Ansai County, China (Taken by Fei Wang in 2010). Terraces mainly are on the moderate to gentle slopes, afforestation on the steep slopes and small gullies, and check-dam for small watershed. The check-dam land is formatted after a long-term siltation and is flat and fertile enough for cultivation. The drainage system is set to prevent the flash floods induced by extreme storms).

development, but that it is a fundamental action to restore ecosystems and safeguard the environment, economy and society (R1-3 response).

Policies were especially targeting reducing the driving force (R1 response) of intensification of food production and encouraging the development of various renewable energies to relieve fuel shortages (P14, and revised version in 2010). Pressures were also tackled specifically (R2 responses); initially, local people who converted their cropland into grasslands and forests could get subsidies of grain for food and cash for seedlings directly from the central government (P18). Later, they could get cash through a new policy on conversion of farmland to forest (P19). Most recently, a policy on ecological compensation for SWC was put forward formally in 2010 and could promote SWC in many regions that currently experience a lower benefit return (P20).

4.3.2. Institutional aspects

Since 1991, responsibility for SWC shifted to become the vital duty of government and the responsibility of multiple stakeholders. The law (P14) made it clear that “all organizations and individuals should have the obligation to protect water and soil resources, prevent and control soil erosion, and have the right to report against any unit or individual that damages water and soil resources and causes soil erosion”(Article 3, Chapter 1), “The State Council and the local people's government at various levels should regard the work of water and soil conservation as an important duty, and adopt measures to ensure the prevention and control of soil erosion” (Article 5, Chapter 1), and put the missions of the planning of SWC into the development plan of public economy and society (Article 7, Chapter 1). Legally, SWC should be carried out by whoever was responsible for causing the loss of soil and water; the conservation measures should rely on scientific technologies and personnel training to achieve progress; while the administrations of water resource management and management organizations of SWC supervision should be responsible for examining and approving the SWC programs (P14). State policies to help rural businesses and farmers to conserve soil and water followed a principle that whoever took charge managed the conservation and benefited from it. For example, construction companies and individuals were responsible for the losses of soil and water they caused and for the SWC measures to counter the losses (Guo, 1995; Duan, 1999).

4.3.3. Strategic options

Prevention and containment of soil erosion have been given higher priority than controlling the on-going erosion problems in the Law of Soil and Water Conservation of China (P14). Ecological recovery and environmental construction have become the main purpose of implementing SWC (P17, P18). The “Grain for Green Project” (P18), in which the local farmers could get food and cash subsidies from the government after they converted sloping cropland into forests and grasslands, has been widely implemented in this region (Cao et al., 2009). SWC has been considered not only as an action of “soil protection and sediment control of the Yellow River”, but as the basic engineering approach towards the “Eco-environmental Construction of China” for enhanced ecological functions, natural resource management and the sustainable development of China (P16, P17, P18, P19).

4.3.4. Evaluation of effects of policy responses

SWC progress and benefits in the YRB were great in the last 60 years (Sun et al., 2009): the area of grain crops decreased, but food production increased stably, satisfying the changing demands linked to population growth (Fig. 2).

The sediment load of the Yellow River at Huayuankou Station decreased greatly with a very significant linear trend (Fig. 5), and about 30% of the decrease in sediment load (350 to 450 million tons annually) has been attributed to SWC on the slopes (Meng, 1997; Tang, 2004). The ecological, economic and social benefits of conversion of farmland to forest (well known as the “Grain for Green Project”) were very clear: e.g. vegetation cover in the Loess Plateau increased quickly, and the land area with a vegetation cover of more than 30% changed from <1% of the total area of Wuqi County, Shaanxi Province in 2000 to 91.96% in 2009 (Xin and Yu, 2009; Xu et al., 2011). In the whole Loess Plateau, soil erosion reduced by 63.3% and the carbon sequestration increased by 35.3 Tg from 2000 to 2008 (Lü et al., 2012).

5. Discussion

5.1. Framework of DPSIR

Using the DPSIR framework we have reconstructed the story of SWC policy change showing the detailed interaction between elements

(Borja et al., 2006; Potschin, 2009) as a cyclical cause–effect model describing the driving forces, pressures, states, impacts and the policy responses induced by impacts which in turn had feedback effects on driving forces, pressures and states. The issues addressed by policy are made obvious so that the DPSIR framework could not only make the policy-making process more efficient and pertinent, but also help to identify practices and approaches to cope with soil erosion, heavy sediment load of river, flood risk and local poverty and their effects in different time periods.

Normally policy development needs broad participation of different stakeholders from local farmers, researchers to governmental policy makers, but there is no clear place in which these aspects can obviously be analyzed using the DPSIR framework. Hence better policies may be devised if we combine DPSIR and other methods, like stakeholder analysis, which allows identification of the key actors in the implementation of each policy stage (Atkins et al., 2011).

5.2. On policy

There are many factors affecting the adoption of SWC policy (Ervin and Ervin, 1982; Knowler and Bradshaw, 2007), but it seems to work well in China because there are no great conflicts between local farmers and downstream regions. Other human behaviors play a role in SWC and natural resource management though. For instance, economic activities are often driven by motivation for survival or other benefits (Wossink and Swinton, 2007; Vignola et al., 2010), and can be changed by policy; religion, culture and awareness also play a role (indirectly) in both economic activities and policy making (Fig. 6) (Wang et al., 2002; Throsby, 2008; Bhagwat et al., 2011). The motivation of survival and money drives local people to cultivate or dig out medical herbs with little consideration of policy, law or social responsibility. Poorly conceived policy also could destroy the land. For instance, the government encouraged people to cultivate in the early Qing Dynasty (220 B.C.) and the policy introduced a tax-free period for new cropland in the first several years. The effects of this were that cropland expanded rapidly, leading to frequent flash floods (Wang et al., 2001). Generally, the policy evolved with pressure and state in this region based on the relationship between different stakeholders and among the environmental problems.

The SWC policy in YRB has a long-term purpose and targets a particular problem, but some policies were too bold and/or urgent and did not pay careful consideration to biophysical and economic feasibility, e.g. proposing to build many reservoirs for siltation (P1, P2, P3 and P5), and over-optimistically planning for total soil erosion control (P7) in a way that neglected the complexity of the ecological system and power of natural processes (Mu and Li, 1999). With enhanced understanding about the intricacies of environmental and socio-economic processes in the whole of the YRB, SWC became the most important solution to address both rural development and flood disasters, and therefore, SWC policy improved rationally.

SWC policy nevertheless paid very little attention to the water shortage issue of the whole basin. The annual water resource availability is about 520 m^3 per person (near the lower threshold of water scarcity of 500–1000 m^3 per capita per annum) (Falkenmark et al., 1989), but the runoff at Sanmenxia Hydrological Station decreased by 30%–50% or more since 1990, and the lower reach became dry in every year during the period 1991–1999 (Mu et al., 2004). The runoff at Huayuankou Hydrological Station showed the same trends (Fig. 7). Impacts of water shortages on the development of the lower reaches have already appeared. Our analysis suggests that in light of this gap, present policy should pay more attention to water shortages when reducing the sediment load, as there are no policies focusing on RRS (Ratio of Runoff detained to Sediment detained) (Wang et al., 2005a, 2005b; Mo et al., 2007).

6. Conclusion

Soil erosion, the sediment load and flooding are issues of great concern in the YRB. SWC has been demonstrated to play an important role over the long-term when considering the on-site and off-site effects of these issues. The implementation of SWC policy has remarkably changed the condition of the environment, economy and society in the YRB, mitigating local poverty in eroded areas, improving food production and reducing flood risk in the lower reaches.

DPSIR has been used to analyze the development of SWC in the study area in a historical perspective to describe the conceptualization and operation of SWC policy since 1949 as a response to the impacts of soil erosion and flooding. The SWC policy could act on the driving forces, pressures and states directly because it was developed based on the environmental and social problems and necessities of the whole basin. It was carried out with institutional, financial and technological support from the government and the motivation of local people. Even though approaches to SWC changed continuously, based on an overview of the problem, important documents and actual SWC measures, 3 clear stages were distinguished which coincided with changes in main aims and tasks, institutional set-up and strategies.

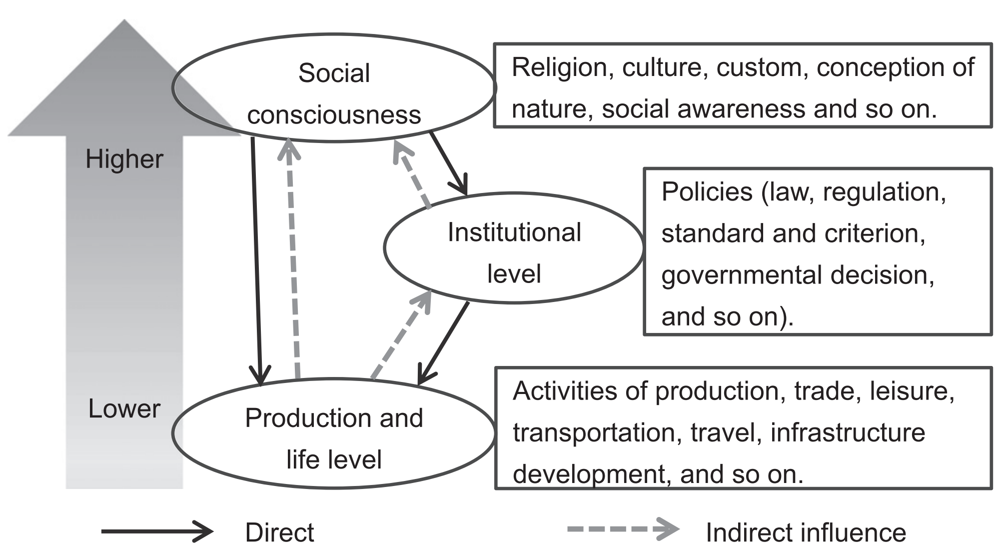

Fig. 7. Levels of human activities.
Revised based on Wang et al. (2002).

The aims and tasks of transforming the Yellow River from a harmful to a beneficial river in Stage 1 (1950–1979) were so charming in the beginning of a new poor country suffering from wars that they encouraged people to set policies for rural development (especially for food and fuel) in eroded areas and to reduce the sediment load of the river with reservoirs for siltation and SWC. The local farmers were required to fulfill SWC at that time as their own responsibility to improve living conditions. The results of SWC on rural development and on sediment control on the slopes and in the river were very great.

The overall development of rural industry and soil erosion control with integrated SWC practices was the main aim of Stage 2 (1980–1990). The public powers, like companies, united SWC groups and SWC teams of local governments, were encouraged to engage in SWC with local farmers. The people could get help from the government because well-controlled watersheds needed good practices and the efforts and investment they could undertake in some strongly eroded watersheds were not enough. The SWC in this stage resulted in many watersheds with no sediment flowing away and the integrated control continues working today.

With the economic improvement of China, the government started paying even more attention to SWC and treated it as a primary measure for natural resource conservation, environment protection, disaster mitigation and agriculture development in Stage 3 (1991–present). The government assumed responsibility for SWC with administrative, legal and financial approaches and various technologies that made large-scale SWC engineering possible. Agricultural conditions in the eroded area improved greatly and the ecological system restored significantly during this stage. The runoff and sediment load of the Yellow River decreased dramatically.

Even though SWC had a great contribution to rural development and sediment reduction over the last 60 years, some challenges remain. For example, the Yellow River is still one of the muddiest rivers, with the riverbed continuing to rise above the land outside of the river for many meters (Zhao, 1996; Wu et al., 2005). Water shortages in the lower reaches are still worsening which is of particular concern given the increasing influence of climate change in this region (Wang et al., 2007). Consequently, is necessary to further improve SWC policy to continue to develop better environmental and economic functions.

Acknowledgments

The research was supported by the National Natural Science Foundation of China (41171420 and 41271295), the West Light Foundation of the Chinese Academy of Sciences ([2013]165); the Key Research Program of the Chinese Academy of Sciences (KZZD-EW-04); the External Cooperation Program of Chinese Academy of Sciences (GJHZ1018); the Netherlands Organization for Scientific Research (OND1339291); the Chinese Fundamental Research Funds for the Central Universities (QN2011150) and the National Key Basic Research Special Foundation of China (2014FY210100).

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2014.11.055.

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