Afforestation in China: The Role of Integrated Watershed Management

LWS 548 Major Project

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Abstract

Afforestation has been promoted as a remedial process for degraded land. However, afforestation does not always have a positive impact in terms of water supply. Taking into account key factors such as tree species and local variations, this study delves into the relationship between afforestation and water supply and the possible impacts on local water supplies. The findings suggest that the effects of afforestation on water supply are complex. For example, non-native deep-rooted trees consume more water than shallow-rooted vegetation. Thus, increased water consumption by deep-rooted trees can lower the groundwater level, directly affecting local water supplies. In some cases, large-scale afforestation projects can lead to increased water deficits and competition for water resources, potentially affecting the water supply in the area or even in other areas within the watershed. Therefore, this study highlights the potential of Integrated Watershed Management (IWM) as a framework for mitigating the adverse impacts of afforestation on water resources. By integrating IWM principles into afforestation projects, it is possible to achieve a balance between increasing forest cover and ensuring sustainable water management.

Introduction

Forest resources are an important component of the Earth's ecosystem, playing a key role in mitigating the effects of climate change and providing food and habitat for a diverse number of organisms (Raj et al., 2020). Human activities, including deforestation, unsustainable harvesting practices, and the conversion of land to agriculture and urbanization, significantly impact forest resources. These activities have resulted in the loss of forest cover and degradation of ecosystems, leading to negative consequences such as damage to the water cycle, increased greenhouse gas emissions, and the loss of biodiversity and ecosystem services provided by forests (Igini, 2023). As the world grapples with these significant negative consequences, a glimmer of hope has emerged in the form of afforestation.

Afforestation involves the establishment of forests on unforested land, which helps prevent desertification, reduces soil erosion, and increases carbon sequestration to combat climate change (Kim, 2021). Afforestation has been successful in increasing forest cover by deliberately seeding and planting trees (Ritchie and Roser, 2021). The article "Afforestation of Abandoned Agricultural and Degraded Land" provides valuable insights into how afforestation can be a valuable tool for restoring abandoned agricultural and degraded lands (Wang, 2022). It highlights the potential of afforestation to promote carbon sequestration and increase biodiversity, particularly microbial activity, to maximize restoration success (Wang, 2022).

In China, afforestation has been the primary strategy for combating desertification and soil erosion (Cao et al., 2011). To alleviate the serious problems of soil erosion and desertification caused by unsustainable agriculture, overgrazing and human activities, China has invested heavily in large-scale afforestation programs, especially in the arid and semi-arid regions of northern China (Lu et al., 2018). Non-native species with deep root systems, such as black locust (*Robinia pseudoacacia*), have been introduced into China, mainly for afforestation. The black locust, known for its fast growth, nitrogen-fixing abilities, and exceptional drought resistance, is extensively planted in northern China, notably on the Loess Plateau (Wu et al., 2023). Figure 1 shows the dramatic increase in the total area afforested in China between 1952 and 2005. The upward trend depicted in the Figure indicates that significant efforts in afforestation have continued in China. In line with these efforts, China has set a target for the future. The country aims to increase forest coverage to 24.1% and increase forest stock volume to 19 billion cubic meters by 2025 (World Economic Forum, 2022). In addition, China has made significant investments in afforestation projects. For example, it is estimated that by the end of 2016, the investment was one of the largest afforestation programs, “Grain for Green Project” (GGP) was expected to reach a substantial amount of at least 431.8 billion RMB (Delang et al., 2015).

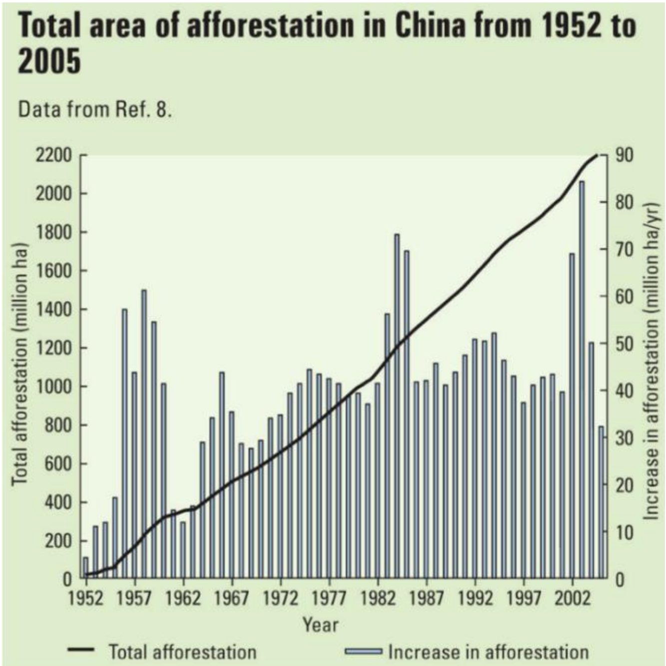

Figure 1 China's afforestation area from 1952 to 2005 (Cao, 2018)

However, despite significant investments and concerted efforts, afforestation activities may not always yield the desired outcomes and, in some cases, may lead to deleterious consequences not only for groundwater resources but also for available water supplies. This is particularly important because the long-term consequences of using non-native deep-rooted tree species in afforestation were not well-understood beforehand. For example, many afforestation programs implemented in northern China are not designed to consider local variations in precipitation, hydrology, soils, climate, and landscape factors (Lu et al., 2018). As a result, environmentally fragile arid or semi-arid areas may exacerbate existing water scarcity risks. In addition, large-scale afforestation programs in ecologically fragile areas of southwest China, aimed at mitigating the region's relatively severe soil erosion and desertification trends, may have potential impacts on water availability due to altered hydrologic processes and increased water demand from planted trees (Xiao et al., 2020).

To address these challenges, Integrated Watershed Management (IWM) has been proposed as a framework. The IWM is an adaptive and comprehensive planning process that balances ecological, economic, and social conditions, considering land and water resources and the interaction between them within the physical boundaries of a watershed (Wang et al., 2016). This paper adopts IWM, defined as an integrated framework for a multidisciplinary and transdisciplinary systems management approach to protect important components of a watershed, including water resources, soil quality, plant and animal productivity, and ecosystem integrity (Wang et al., 2016). This paper focuses on afforestation efforts and specific challenges in the Loess Plateau region of China. In this paper, the term "Grain for Green Project (GGP)" specifically pertains to the afforestation component of China's comprehensive ecological restoration program, the largest afforestation and reforestation program at the turn of the century in China (Chen et al., 2016).

It is important to note that these findings may not directly apply to other regions with a different ecological context. However, understanding the lessons learned from afforestation projects on the Loess Plateau can provide valuable insights for other regions facing similar challenges. By examining the successes and limitations of afforestation projects in this context, we can gain a deeper understanding of the complex interactions between afforestation, water resources, and ecological restoration, including the impact of different afforestation species on the ecological system. Through the lens of IWM, it is possible to manage natural resources better and minimize the adverse impacts of afforestation on water resources. Moreover, the integration of IWM principles into afforestation programs is essential for achieving the goal of increasing forest cover and forest stock while ensuring the sustainable management of China's water resources. This approach presents an opportunity to engage local communities and stakeholders in the management of natural resources and to promote sustainable development practices that benefit people and the environment.

Objectives

The goal of this paper was to examine the challenges faced by afforestation projects in China, particularly the Loess Plateau, and to explore how the IWM framework addresses these challenges. The specific objectives are as follows:

1. To understand the benefits of afforestation and its potential negative impacts on water resources.
2. To examine the water-related consequences of afforestation with non-native tree species in the Loess Plateau region of China, considering changes in local factors. This involved assessing the impact of afforestation methods on water consumption and deep layer soil moisture content.
3. To assess the potential benefits of the IWM approach in the planning and implementing afforestation projects, including managing natural resources and minimizing negative impacts on water resources.
4. To suggest potential steps and recommendations for effective integration of IWM principals into afforestation projects in China.

The information provided in this study is intended to be important for policymakers and practitioners involved in afforestation projects in the Loess Plateau region of China and similar areas.

Methods

The methodology used in this study is based on a systematic literature review and a synthesis approach. Specifically, the methodology for this study involved the following:

1. To conduct a literature review on the potential impacts of afforestation on water resources in arid, semi-arid, and southwestern China to synthesize the existing knowledge and research on how afforestation affects water resources.
2. To conduct a literature review on land use changes, vegetation types, and climate on the Loess Plateau. Additionally, analyzed case studies of afforestation projects implemented in the region to examine the water-related consequences of selecting non-native species in afforestation projects, including their effects on soil water consumption and soil moisture content in deep soil layer on the Loess Plateau (Zhu et al., 2020; Zhu et al., 2021; Zhang et al., 2018), and how these impacts affect the effectiveness of afforestation projects.

3. To conduct a literature review and a synthesis to explore the advantages of IWM and its interaction with afforestation projects to understand how IWM could mitigate the negative impacts of afforestation, including a review of the effectiveness and limitations of Integrated Water Resources Management (IWRM) that has been adopted in the northern watersheds of China (Mao et al., 2020).
4. And in addition, relevant studies and cases were reviewed to examine the benefits of stakeholder consultation and local community participation in afforestation projects.

Results and Discussion

Background of afforestation in China

The Grain for Green Project (GGP), also known as the Conversion of Cropland to Forestland Program (CCFP), is a globally recognized large-scale ecological restoration project in China (Wang et al., 2019). The GGP was implemented in 1999 with the main objective of restoring steep slopes previously cleared for farming to their original state of forest or grassland to address major challenges: soil erosion, desertification, and impoverishment of farmers' livelihood (Delang et al., 2015). The GGP encompasses three key land conversion strategies: cropland to forest, farmland to grassland, and wasteland to forest (Zhou et al., 2012). According to agricultural census data, there has been a significant increase in forest cover between 1999 and 2009. During this period, about 28 million hectares of cropland were successfully converted into forested areas (Zhou et al., 2012). Figure 2 depicts the land cover changes from 1978 to 2010 in Ansai County, which is part of the GGP. The graph clearly illustrates the significant expansion of forest land and the corresponding decrease in cropland as a direct result of the GGP.

Figure 2 Land cover changes influenced by GGP in Ansai County, 1978-2010 (Zhou et al., 2012)

The Green Grain Program (GGP) is a large-scale initiative that stands out not only for its extensive coverage of the land but also for the significant investment it has received compared to other conservation programs. As illustrated in Figure 3, the investment in the GGP (CCFP) remained essentially at the highest level compared to several other conservation programs from 1999 to 2015.

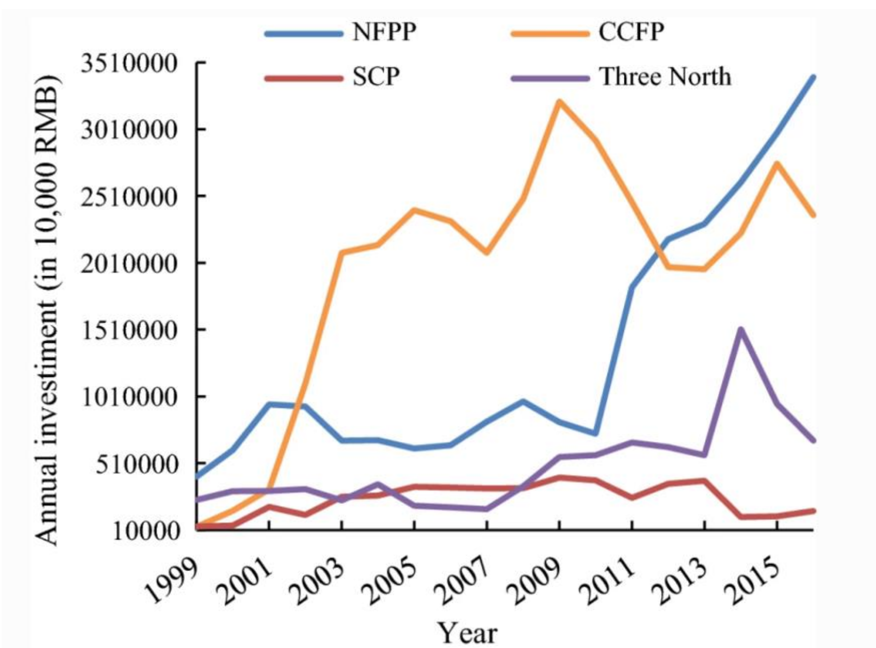

Figure 3 Comparison of total annual investment in GGP and other conservation programs (Natural Forest Protection Program (NFPP), Sand Control Program for Areas in the vicinity of Beijing and Tianjin (SCP), Three North Shelterbelt Development Program and the Shelterbelt Development Program (Three North)) based on SFA 2017 data (Wang et al., 2019)

Benefits and negative impacts of afforestation in China

Benefits of afforestation

China has been implementing large-scale afforestation programs, such as the GGP, in the semi-arid and arid regions of the north as a measure to combat desertification and mitigate the risk of dust storms, which pose a threat to densely populated areas in the south and east (Lu et al., 2018). In addition, similar programs such as the GGP and Natural Forest Protection Program (NFPP) have been implemented in the southwest to address severe ecological degradation in the highlands and to protect fragile ecosystems (Xiao et al., 2020). The expansion of forest cover by afforestation programs in China has brought about significant impacts on local ecosystem services and climate dynamics (Li et al., 2020). By contributing to increased carbon sequestration, afforestation activities have also reduced soil erosion, prevented soil acidification in northern regions, and enhanced local climate cooling through increased forest cover (Li et al., 2020; Chen et al., 2016). These positive results highlight the critical role of afforestation in promoting ecological stability and addressing climate-related challenges.

While China's afforestation programs have brought numerous benefits, it is necessary to acknowledge that they can also have some negative impacts on water resources.

Impacts on groundwater level

Freshwater, including groundwater and surface water, is vital for human survival (Lu et al., 2018). However, freshwater resources have been under increasing threat in recent years, especially in semi-arid and arid regions that may already be experiencing freshwater scarcity. Improper afforestation practices could further deplete groundwater resources and exacerbate freshwater scarcity.

Natural succession in arid areas is slow because of the limited availability of water, which greatly restricts the growth of vegetation (Lu et al., 2018). While the carrying capacity of forest vegetation in many areas is determined by precipitation and the depth of the groundwater, afforestation programs implemented in semi-arid and arid of northern China overlooked local precipitation conditions and other factors such as the local hydrology, soil, climate, and the landscape (Lu et al., 2018). This oversight has resulted in planting trees and shrubs with higher transpiration rates compared to natural vegetation, leading to increased water consumption (Lu et al., 2018). In addition, where precipitation is the primary source of recharge, the water table will gradually decrease over time until it becomes too deep for trees to reach, thus shallow-rooted vegetations (the primary type of natural vegetation in arid regions of northern China) that depend on near-surface soil water may have difficulty surviving (Lu et al., 2018). Figure 4 illustrates the cumulative changes in the actual groundwater table, considering factors such as lateral inflow and tree mortality (Lu et al., 2018). As shown in the Figure, the groundwater level in the arid areas of the Loess Plateau, including Shanxi and Shaanxi provinces, experienced a significant decrease. Specifically, the groundwater level in Shaanxi Province decreased by 2 m by 2011 due to large-scale afforestation activities. Beijing has experienced the most significant decline in groundwater levels, dropping by 3 meters by 2011. This can be attributed to several factors, including its smaller area, highest tree survival rate (Table 1), and rapid population growth, all of which have contributed to the decline in groundwater. There are several reasons for the low survival rate of trees in areas such as Ningxia, Shanxi and Gansu. These areas have arid or semi-arid climates with low precipitation and high evapotranspiration rates, leaving limited water available for tree roots. In addition, the use of non-native tree species that are not suited to local soil and climatic conditions can complicate the problem, especially if these species are fast-growing but have high water demands.

Thus, the widespread selection of fast-growing, short-lived tree species for afforestation projects could also have adverse impacts, such as accelerated groundwater shortages and failure to meet desired ecological restoration goals. In semi-arid and arid regions where precipitation is already limited, large-scale afforestation and fast-growing species selection may lead to higher evapotranspiration, exacerbating groundwater shortages. In addition, water loss from evapotranspiration due to afforestation cannot be used for essential uses such as residential, industrial, and agricultural needs (Lu et al., 2018).

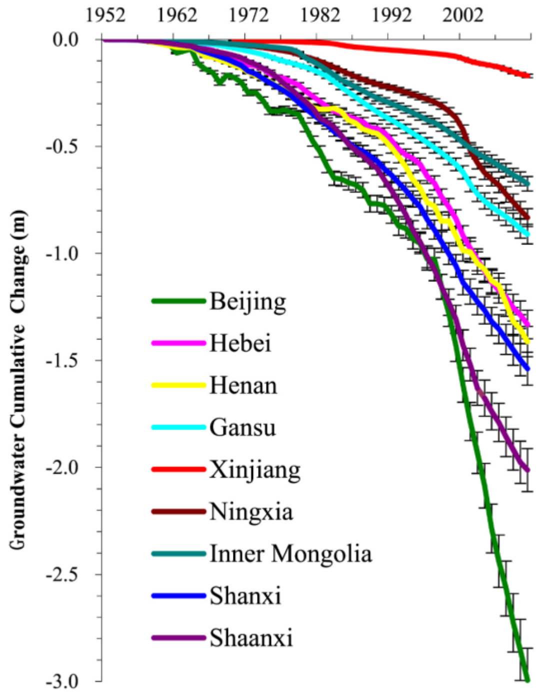

Figure 4 The annual decline in groundwater levels (meters) due to afforestation projects in nine arid and semi-arid provinces located in northern China between 1952 and 2011 estimated under the assumption that a combination of precipitation and lateral flow within each province causes groundwater recharge (Lu et al., 2018)

Table 1 Tree survival rates for nine arid and semi-arid provinces in China with afforestation programs (Lu et al., 2018)

Province	Survival rate (%)
Beijing	34
Hebei	16
Henan	30
Shanxi	7
Shaanxi	15
Gansu	9
Ningxia	5
Xinjiang	15
Inner Mongolia	14

In addition, as mentioned, afforestation has inadvertently led to local and regional water scarcity, which may have negative and unintended impacts on water security of both local communities and larger regions (Schwärzel et al., 2020).

Impacts on the regional water supply balance

Southwest China is an ecologically fragile region characterized by severe soil erosion and an increased risk of rocky desertification (Xiao et al., 2020). The ongoing drought of southwest China experienced in this region since 2010 has led to far-reaching consequences that not only affect fragile ecosystems but also pose a substantial threat to the region's cropland and drinking water supply (Xiao et al., 2020). Rocky desertification is the deleterious transformation of karst areas covered by vegetation and soil into rock-dominated barren land through human activities, by practices such as livestock farming and extensive tree felling to produce charcoal for iron production (Jiang et al., 2014).

The Chinese government has recognized the urgent need to protect the fragile ecosystems of the southwest and to address the ecological degradation caused by rocky desertification. To tackle this issue, southwest China has implemented various large-scale afforestation projects, including the Slope Land Conversion Program (SLCP), also known as the GGP, Natural Forest Protection Project (NFPP), and the River Shelterbelt Project (Xiao et al., 2020). While it is true that forest cover in southwest China has increased significantly in recent years due to large-scale reforestation projects, the extent to which it has been effective in combating drought and promoting drought resilience within the region is questionable.

Figure 5 shows that the total afforested area in southwest China has increased significantly since 2010 under a series of large-scale afforestation projects. Unfortunately, the current survival rate of tree plantings in the region is less than 20% (Xiao et al., 2020), raising concerns about the effectiveness of afforestation efforts. It is noteworthy that there is a general tendency to promote non-native tree species in areas governed mainly by the SLCP and the

NFPP in the region (Xiao et al., 2020). According to Xiao et al. (2020), it is estimated that plantations in the southwest have consumed about 40.42 billion m^3 of water since 2000, which is equivalent to about 10.69% of the region's annual water supply.

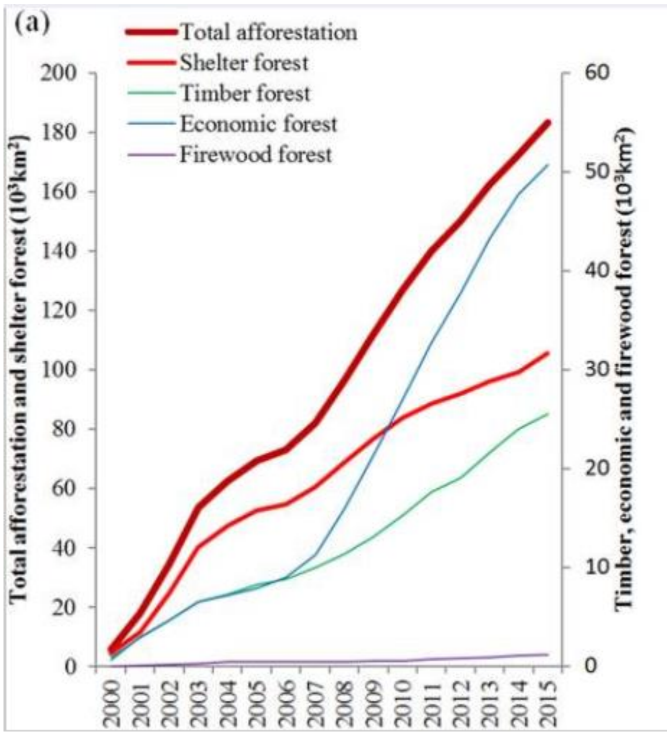

Figure 5 Afforestation area in Southwest China from 2000 to 2015 (Xiao et al., 2020)

The process of absorbing large amounts of available water from the soil as a result of extensive afforestation can cause drought conditions and a reduction in soil surface moisture, which exacerbates the stress on local water resources and disrupts the balance of the water supply (Xiao et al., 2020). Furthermore, the study by Xiao et al. (2020) is aligned with the findings of Lu et al. (2018) that artificial or newly planted forests have higher evapotranspiration rates than natural forests. This phenomenon, coupled with limited precipitation, further exacerbates the water scarcity.

Loess Plateau

The Loess Plateau, situated in the middle and upper reaches of the Yellow River, is identified as a priority and hotspot region for the implementation of the GGP (Zhou et al., 2012; Schwärzelet al., 2020). This region plays a crucial role in water and sediment supply for the lower reaches of the Yellow River (Schwärzel et al., 2020). The Loess Plateau covers an area of 628,000 square

kilometres, accounting for approximately 6.5% of China's total land area (Dang et al., 2015). The Loess Plateau is characterized by the presence of fertile wind-blown silt-sized deposits known as loess, which can reach a thickness of 300 meters and are suitable for cultivation (Schwärzel et al., 2020). However, the loess is prone to erosion, which makes the Loess Plateau as one of the most severely affected areas in the world by soil erosion, posing a major environmental challenge to China (Shi & Shao, 2000). The Loess Plateau experiences a semi-arid to arid climate, with the northwestern region receiving an average annual precipitation of about 150 mm, while in the southeast, it rises to about 800 mm (Shi & Shao, 2000; Ren et al., 2018).
Ansai County (Figure 4) is used as an example to describe the basic situation of the Loess Plateau region:

1. It is located in the middle of the Loess Plateau and is characterized by loess covered hilly terrain.
2. The area has an altitude ranging from 921 to 1730 meters and experiences a semi-arid climate with an average annual precipitation of 520 mm and an average temperature of 8.6°C.
3. Prior to the implementation of the GGP, Ansai County was predominantly characterized by shrub grassland and sloping cropland.
4. As part of the GGP initiative, non-native tree species, including *Robinia pseudoacacia, Prunus armeniaca, Hippophae rhamnoides, Platycladus orientalis,*

and Caragana korshinskii were used primarily in the area, with *Robinia pseudoacacia* being the most popular species due to its greater resilience in drought conditions. (The information on Ansai County mentioned above was obtained from Zhou et al. (2012).)

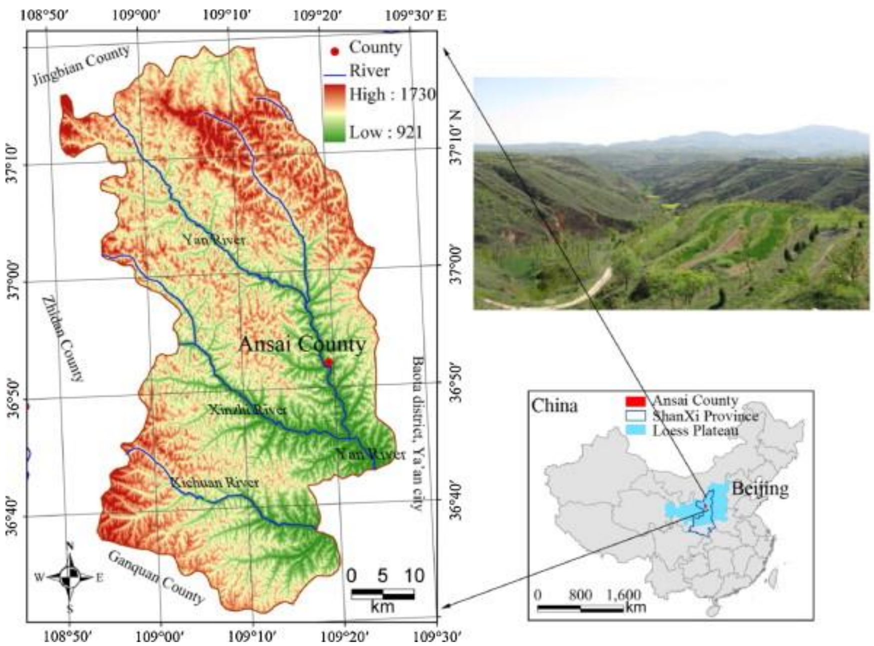

Figure 6 The location of Ansai County (Zhou et al., 2012)

Afforestation with non-native species on the Loess Plateau

Afforestation brings potential positive effects for restoring native biodiversity as it provides various benefits such as enhanced soil nutrients, improved vegetation structure and increased species diversity (Wang et al., 2017). *Robinia pseudoacacia*, also known as black locust, plays an important role among non-native tree species in China. Its rapid growth rate makes it the primary choice for afforestation projects on the Loess Plateau (Zhu et al., 2021). A noteworthy study conducted by Wang et al. in 2017 focused on Ansai County, located on the Loess Plateau. The results of the study showed that the presence of plantation forests comprised of *R. pseudoacacia* in gully areas with severe soil erosion resulted in a significant improvement in the quality of topsoil nutrients and moisture levels over time (Wang et al., 2017). Another study conducted by Zhu et al. in 2020 showed that non-native forests containing *R. pseudoacacia* exhibited higher densities of soil microarthropods compared to native forests. The activities of these soil microarthropods are of considerable significance in maintaining the overall health and function of ecosystems, as they contribute to the decomposition of organic matter and nutrient cycling processes (Zhu et al., 2020). Similar studies have shown that planting *R. pseudoacacia* on degraded land can increase the total abundance and richness of macroinvertebrates, which plays a key role in maintaining soil function (Zhu et al., 2021).

However, while *R. pseudoacacia* is widely used for afforestation on the Loess Plateau, it is critical to consider the potential ecological consequences of selecting non-native species in the region. The potential ecological consequences, including soil desiccation, decreased soil moisture content, and soil water deficit (Wang et al., 2021; Zhang et al., 2018; Ge et al., 2020; Yang and Li, 2022), could be interrelated with the impacts of afforestation on water resources discussed previously in this paper. For example, these potential ecological consequences could exacerbate water scarcity and pose a challenge to achieving ecological restoration goals.

Impacts on water consumption

The extensive large-scale afforestation practices in the Loess Plateau region have led to the overconsumption of deep soil water, which may cause various hydrological problems. These problems include soil desiccation, reduced groundwater recharge, and decreased forest productivity and efficiency (Wu et al., 2021). The implications of these hydrologic issues further exacerbate the existing water scarcity in the region, directly affecting regional water security and the long-term sustainability of afforestation projects (Wu et al., 2021). Notably, that water yield in 12 major sub-catchments of the Loess Plateau region within the Yellow River Basin decreased significantly by 26% between 1998 and 2010, which was mainly attributed to large-scale afforestation efforts (Jia et al., 2017).

In some fields planted with three deep-rooted non-native species, namely *R. pseudoacacia*, *P. tabulaeformis* and *C. korshinskii*, soil water storage within 1 m depth showed a continuous decrease during the growing season due to evapotranspiration from shrubs and forests planted in the area being higher than the recharge from precipitation (Jia et al., 2017). The higher rate of decline in soil water content in *C. korshinskii* fields in the northern part of the Loess Plateau, compared to cropland, is mainly the result of the higher water absorption capacity of the soil (Jia et al., 2017). As a result, *C. korshinskii* fields tend to consume more water, especially deep soil water, which could have an impact on sustainability of using deep soil water resources. Excessive consumption of deep soil water without adequate replenishment can lead to an unsustainable situation, as it depletes water reserves beyond the natural recharge capacity.

In the tropics, however, abundant rainfall during the rainy season replenishes deep soil moisture reserves that can then be utilized by trees during the subsequent dry season (Wu et al., 2021). This replenishment process allows trees to access and use the water reserves in the deep soil during periods of limited rainfall, contributing to their ability to withstand the dry season. The findings of Wu et al. (2021) highlight that unlike tropical forests, deep soil water may not provide a sustainable source of water for plantation forests in semi-arid and semi-humid areas. In addition, this study showed that deep soil reservoirs were depleted after afforestation. Specifically, after about 15 years of afforestation, soil water storage below 2 meters in *R. pseudoacacia* forests was reduced by 1926 mm compared to shallow-rooted grassland, suggesting that *R. pseudoacacia* has a potential to consume more water (Wu et al., 2021). Indeed, another important aspect to consider is water deficit in *R. pseudoacacia* forest may prevent groundwater recharge in the forest (Wu et al., 2021). In areas with deep-rooted planted forests such as *R. pseudoacacia* forests, the combination of water scarcity and slow water flow in the soil can limit groundwater recharge and cause the water table to drop, thus exacerbating the water crisis in the area.

Impacts on deeper soil moisture

As stated earlier, the planting of non-native species, such as *C. korshinskii*, leads to a decrease in the average depth of moisture content, indicating a decrease in available soil water (Jia et al., 2017). Given that the depth of groundwater in the Loess Plateau usually exceeds 20 meters below the surface, local vegetation relies heavily on precipitation as its main source of water (Zhang et al., 2018). The planting of non-native species has a significant water absorption effect on the soil, leading to the drying of the soil layer (Wang et al., 2021). In addition, microwave remote sensing data from 1988 to 2010 showed a significant decrease in surface soil moisture in most areas of the Loess Plateau (Zhang et al., 2018).

Wang et al. (2021) examined soil moisture content changes at 10, 20, 30, and 40 years after the afforestation of two tree species (*R. pseudoacacia and C. korshinskii*) on the Loess Plateau and the relationship between deep soil moisture consumption and afforestation of these two species. Their results showed that the soil moisture content of *R. pseudoacacia* plots was highest in the top 20 cm soil depth. However, the soil moisture content decreased with increasing soil depth to 20-200 cm for all vegetation types, with the most noticeable decrease in *R. pseudoacacia* compared to other vegetation types. Figure 7 shows that *R. pseudoacacia* plots exhibited greater soil water consumption in the 20-200 cm soil layer compared to *C. korshinskii* and natural grassland, with positive values indicating a decrease in soil moisture content, while negative values indicating an increase. Tree species such as *R. pseudoacacia* and shrub species such as *C. korshinskii* have well-developed root systems than natural grasslands and absorb large amounts of water for above-ground growth (Wang et al., 2021). Therefore, the soil moisture content in afforested sites is usually lower in both species compared to natural grasslands.

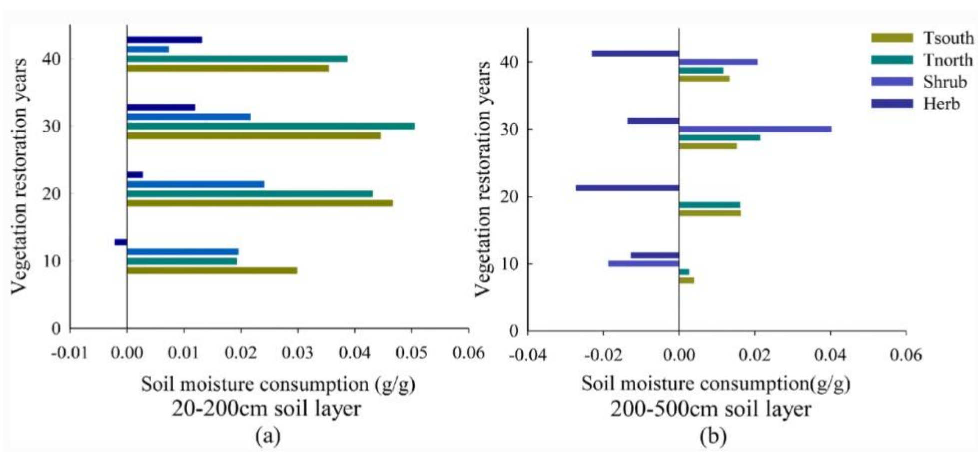

Figure 7 Comparison of deep soil water consumption of R. pseudoacacia, C. korshinskii and natural vegetation at 20-200 cm and 200-500 cm, where "Tsouth" and "Tnorth" represent R. pseudoacacia plots on the north-facing slope of the south-facing slope, "Shrub" represents C. korshinskii plots on the north-facing slope, and "Herb" represents natural grassland on the north-facing slope (Wang et al., 2021)

Overplanting with non-native species may further reduce soil moisture and disrupt the available water balance. Extensive overplanting exists in about 53% of the Loess Plateau, especially in the central and northeastern regions where the local climate does not adequately support revegetation due to insufficient precipitation (Zhang et al., 2018). According to a study conducted by Zhang et al. in 2018, extensive overplanting was identified as a major factor contributing to the dryness of local soils. Significantly, the afforestation of planting trees resulted in approximately twice as much soil moisture reduction compared to grass planting (Figure 8), even though both vegetation types provided the same level of cover (Zhang et al., 2018). Impacts of extensive overplanting and the resulting reduction in soil moisture content, can have a significant impact on water availability and may exacerbate water shortages in local communities.

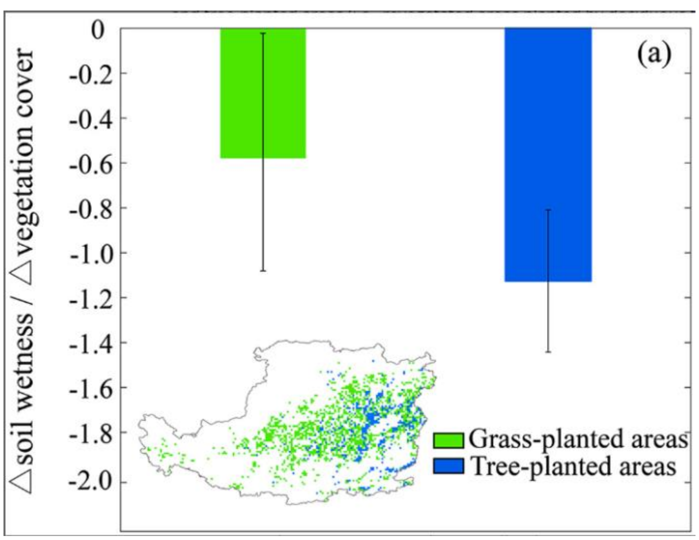

Figure 8 Changes in soil wetness caused by vegetative cover of grasses and trees (Zhang et al., 2018)

Integrated Watershed Management

To ensure the effectiveness of watershed management strategies, afforestation is often identified as a key component of ecological restoration. An example is the watershed management implemented in the basin of Poyang Lake, the largest freshwater lake in China. Through afforestation, the forest area in the region increased by 623,333 hectares between 2001 and 2008 (Wang et al., 2016). However, it is equally important to recognize and address the potential counterproductive effects of inappropriate afforestation practices. While afforestation has many benefits as mentioned earlier, such as controlling soil erosion, regulating water, and protecting biodiversity, in some cases, it can lead to unintended negative effects, such as decreased underground water level. Therefore, to achieve more effective management and ecological restoration goals, it is advisable to use IWM as a strategy for afforestation rather than just afforestation as a component of IWM.

The lack of integration in land resource management, disregards the interdependence of various biophysical processes, and over-reliance on fast-growing non-native species, which can lead to excessive water consumption (Zhang and Schwärzel, 2017). This excessive water use causes increased water stress in semi-humid and arid areas, leads to soil drying, and contributes to higher tree mortality (Zhang and Schwärzel, 2017). Therefore, it is crucial to address these issues by adopting a more holistic and sustainable approach to land resource management, especially water resources management, which considers local water conditions, the complex relationships between different ecological processes, and promoting the conservation of native vegetation.

In general, it is possible to achieve sustainable use and management of land resources through an integrated approach that includes land, water, and vegetation management. An integrated approach to land resource management is a comprehensive and holistic approach that considers the complex interactions of natural, human, cultural and historical aspects of the landscape to achieve sustainable land use practices that address environmental and socio-economic challenges (Izakovičová et al., 2018). By considering the interrelated nature of these elements, an integrated land resources management system can be implemented to promote more comprehensive and effective resource management.

IWM (Figure 9) is a comprehensive and systems management framework that strives to achieve a balance of ecological, economic, cultural, and social conditions within a given watershed (Wang et al., 2016). The primary goal of IWM is to integrate land and water planning by considering groundwater and surface water flows, including recognizing, and planning for the intricate interactions between water, plants, animals, and human land uses within the physical boundaries of the watershed (Wang et al., 2016). In addition, IWM recognizes that actions taken in one part of a watershed can have far-reaching impacts elsewhere. By emphasizing interconnections, IWM helps to identify and address potential impacts and interdependencies among the parts, such as land use, water availability, biodiversity, and human activities. In the 1990s, the Integrated Water Resources Management (IWRM) approach was adopted in rural northwest China to respond to water and ecosystem degradation problems (Mao et al., 2020). Despite the complexities and challenges associated with the top-down decision-making process characteristic of IWRM projects in the region in achieving effective water resources management, this approach has had positive results in addressing the key issues of desertification, water scarcity, and ecological degradation (Mao et al., 2020).

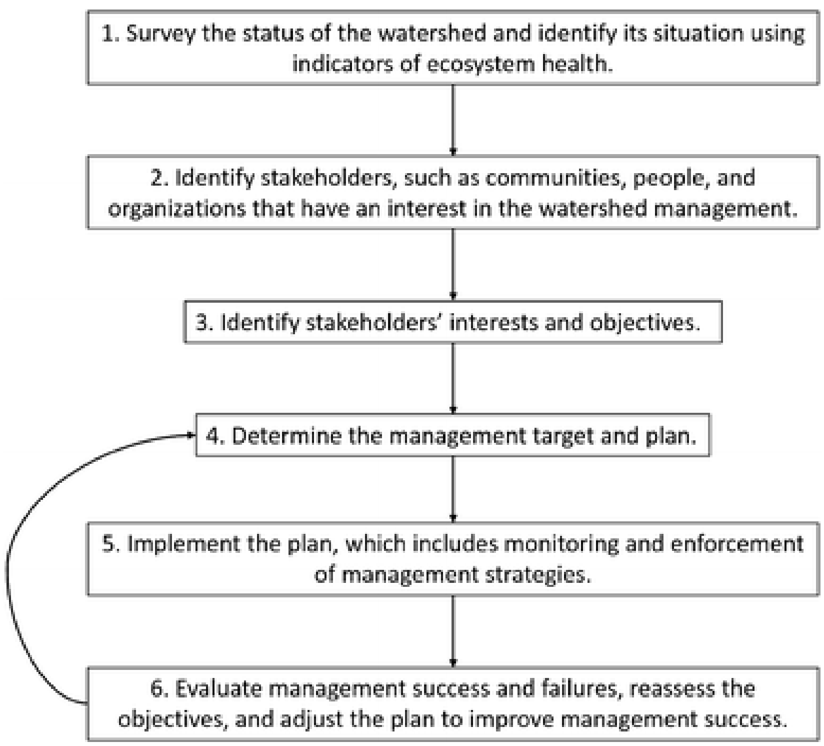

Figure 9 The process of integrated watershed management (Wang et al., 2016)

Increase groundwater recharge and availability

IWM plays a key role in maximizing water resource potential while ensuring its sustainability by proposing soil and water conservation measures, pond catchment and groundwater recharge to enhance water resource potential (Tang and Adesina, 2022). A study conducted by Pathak et al. (2017) in southeastern Rajasthan, India, examined the effects of an integrated watershed management program, and found that one of the main positive impacts of the project was an increase in groundwater recharge and availability. The average annual precipitation in the project implementation area is highly variable, ranging from 240 mm in 1998 to 605 mm in 2001 between 1996 and 2008 (Pathak et al., 2017). Given the challenges of rain-fed agriculture with low and variable rainfall, the focus of the watershed program at the study site is primarily on achieving increased water availability and mitigating soil erosion through the implementation of various catchment and groundwater recharge structures, such as check dams and percolation tanks (Pathak et al., 2017). Figure 10 illustrates the significant influence of the recharging structure on groundwater levels throughout the study period from 2002 to 2008. The treated areas consistently exhibit higher groundwater levels compared to the untreated areas, even in years of low rainfall, such as 2003 and 2005.

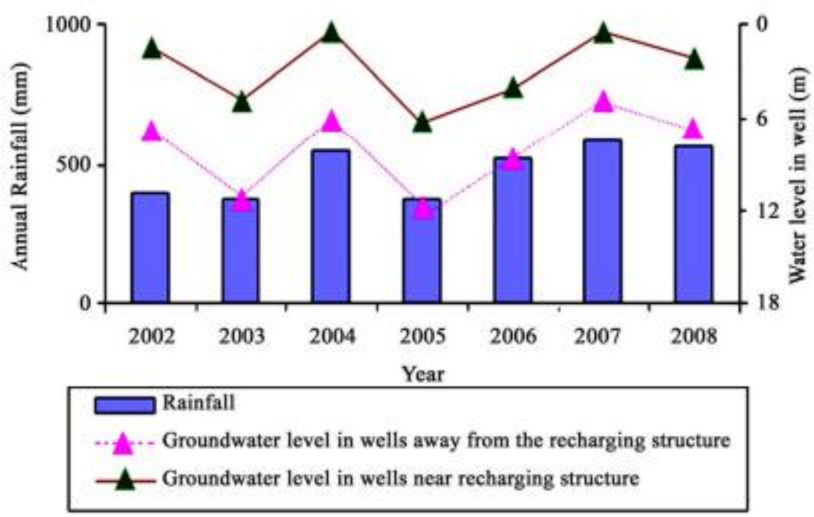

Figure 10 Variation in mean groundwater levels in open wells caused by groundwater recharge structure from 2002 to 2008 (Pathak et al., 2017)

In addition to maximizing the potential of water resources, the social context surrounding water management strategies needs to be considered to ensure their effectiveness. Recognizing the importance of the social context, IWM considers the complexity of governance and stakeholder dynamics. For example, conflicting interests between different levels of government, including central and local governments, can directly lead to a lack of integration of surface and groundwater management at the local and county levels (Mao et al., 2020). Therefore, an inclusive and collaborative governance framework that actively engages all relevant stakeholders is essential to promote an integrated approach that is consistent with the natural and social context.

Conclusion

In conclusion, afforestation can be a promising tool for addressing environmental challenges such as desertification, soil erosion and climate change. However, the implementation of afforestation requires careful consideration of local conditions and potential impacts on water resources. While afforestation has been successful in increasing forest cover and carbon sequestration, it must be recognized that its impact on water availability can be complex and region specific. Integrated watershed management (IWM) is a systems framework for managing the intricate interactions between afforestation, water resources, and ecosystem restoration. By incorporating IWM principles into afforestation projects, it is possible to strike a balance between increasing forest cover and ensuring sustainable water management. Understanding the lessons learned from afforestation projects, particularly in the Loess Plateau region of China, provides valuable insights for planning and implementing afforestation projects in other regions facing similar challenges.

Recommendations

1. **Conduct a comprehensive analysis of local factor conditions:** A comprehensive analysis of local hydrologic conditions is essential before implementing the afforestation projects. The analysis should consider local factors such as precipitation patterns, groundwater availability, and streamflow dynamics.
2. **Planting species selection:** The choice of tree species to plant is a key factor in ensuring that afforestation is compatible with local ecosystems. It is essential to consider the water requirements of the selected species, such as the potential impact of deep-rooted tree species on water resources. Select shallow-rooted native species that are well

adapted to local hydrological conditions can help maintain groundwater availability and minimize water competition between trees and other water consumers.

3. **Local communities and stakeholders involvement:** It is critical to involve local communities and stakeholders to promote the success and long-term sustainability of afforestation projects. By incorporating the perspectives and expertise of local stakeholders, project planners can obtain valuable insights into local ecosystem and hydrologic dynamics.
4. **Monitoring and assessment:** Ongoing monitoring and evaluation of afforestation projects is essential to assess their effectiveness and ensure that the desired outcomes are achieved.

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Appendix

Afforestation in China: The Role of Integrated Watershed Management (IWM)

Afforestation, though promoted as a remedial process for degraded land, does not always have a positive impact on water supply. Therefore, implementing IWM is essential to mitigate the water impact of afforestation and balance forest and water demands.

Afforestation and Problems in China

- **Afforestation:** forests on previously unforested lands
- **Reforestation:** forests on previously forested land
- **Problems:** Soil erosion, desertification, and the impoverishment of farmers' livelihood

However...

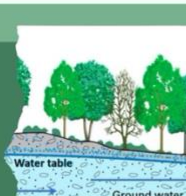
Despite significant investment in afforestation, the anticipated outcomes **were not achieved**

Why?

The **lack of considerations** for tree species, planting density, and local hydrological conditions

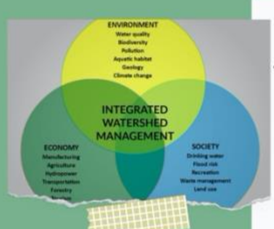
Impacts

- Impacts on **groundwater level, regional water supply balance, water consumption, and deeper soil moisture**



What is IWM?

- A **comprehensive approach** to balance environment, economy, and society within a watershed
- **Consider** how water moves underground and on the surface, and **understand** how nature and land use are connected



Why IWM?

Afforestation with IWM: Moving Ahead

- **Select** appropriate tree species
- **Consider** local hydrological conditions
- **Engage** local communities and stakeholders
- **Continue** monitoring and assessment

UBC Master of Land and Water Systems
Learn more: (Liu, 2023)