Soil salinity patterns reveal changes in the water cycle of inland river basins in arid zones

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Abstract: Soil salinization caused by irrational water resource use seriously affects the agricultural development and ecological construction of inland river basins in arid zones, so clarifying the water cycle mechanism of salinization in inland river basins in arid zones is crucial for the ecological environment management of the basins and the rational use of water resources. Based on remote sensing and observation data, this study quantitatively analyzed the changes in soil salinization in the Shiyang River Basin, an arid region in Northwest China, from 2002 to 2022. It also explored the impact of hydraulic engineering and farmland irrigation on soil salinization. The results indicated that: (1) The lower reaches of the Shiyang River are the areas with more severe salinization, and the severity of salinization has been increasing, the middle and upper reaches of the river are at lesser risk of salinization; (2) The main causes of soil salinization are the rising groundwater levels around the reservoir, evaporation in farmland, and ecological water delivery downstream. Human activities have become a decisive factor in changing the salinization pattern of inland river basins, and the rational use and management of water resources have great potential to improve soil salinization.

Keywords: arid zones; soil salinization; reservoirs; water transfer projects

1. Introduction

Land is an essential natural resource for human beings with economic, social, and ecological benefits in various production activities (Lambin and Meyfroidt, 2011). Soil is the basis of natural ecosystems. Material and energy can cycle within the system and interact with the biosphere, hydrosphere, atmosphere, and so on (Seneviratne et al., 2010; Smith et al., 2015). Soils can promote plant growth and coordinate the watershed water cycle by regulating infiltration and distribution of precipitation. The purification capacity of soils breaks down potential pollutants, preventing water and air pollution to some extent (Bünemann et al., 2018; Banwater et al., 2019). At the same time, water bodies also impact soil quality, mainly through irrigation and precipitation, which influence changes in soil composition. Once soil quality decreases or degrades, it will cause irreversible damage and directly affect human life (Reynolds et al., 2007; Abu Hammad and Tumeizi, 2012). Soil salinization is critical to land degradation (Daliakopoulos et al., 2016). It specifically means that water is lost after groundwater rises to the surface through evaporation from soil pores to the atmosphere under high temperatures. At the same time, heavy masses of salts remain at the surface as they precipitate. Long-term accumulation of salts at the soil surface affects the growth of all types of crops, which can lead to negative consequences such as reduced yields (Qadir and Oster, 2004; Folberth et al., 2016). Soil salinization can be divided into primary and secondary salinization according to the cause of its formation. Primary salinization is mainly influenced by natural factors such as physical or chemical interaction of rocks during the water cycle, sea level rise leading to erosion of coastal land, infiltration of sedimentary brine, evaporation from sea level, changes in the composition of the soil colony, and atmospheric precipitation, all of which increase the salt concentration in the groundwater, resulting in widespread soil salinization (Kaushal et al., 2005; Zhuang et al., 2021; Perri et al., 2022).

The problem of secondary salinization of soil triggered by human activities and incredibly irrational agricultural irrigation has increased the risk of elevated salt concentrations in groundwater (Sharma and Minhas, 2005). It has become a challenge in areas such as hydrology and agriculture. Artificial water transfer projects have significantly altered the connectivity between groundwater and soil water, and the trend of salt enrichment to the surface through evaporation has become more pronounced. Seasonal storage in reservoirs also affects soil water salinity in watersheds. The global area of saline soils is estimated to have exceeded 833 million hectares (Food and Agriculture Organization of the United Nations). Globally, about 20 percent of agricultural land and 33 percent of irrigated agricultural land is saline (Xiao et al., 2023), which is expected to worsen (Hassani et al., 2021). In the inland river basins of the arid zone, the climate is exceptionally arid, the intensity of evaporation from soils and plants is high, and the water table is high. Soil salinization in arid and semi-arid regions is more severe and more extensive, with salinized cultivated land in the inland northwest accounting for nearly one-fifth of the total cultivated land in China; therefore, the study of soil salinization in inland river basins in the arid zone is conducive to the understanding of water cycle processes and mechanisms in the basins and is of great significance in irrigated agriculture and water resource management (Wei et al., 2020).

Remote sensing technology has been widely used to assess soil salinization, and feature spectral characteristics are essential markers for identifying saline soils (Konstantin et al., 2019). There is a significant difference in reflectance between various soil salinity levels in the visible light and near-infrared bands. Saline soils exhibit higher reflectance compared to non-saline soils and show absorption peaks in the visible light band. There is a positive correlation between soil reflectance and soil salinization. (Metternicht et al., 2003; Farifteh et al., 2007; Abderrazak et al., 2016; Zhang and Huang, 2019; Lotfollahi et al., 2023). Saline soils show absorption peaks in the visible band, and there is a positive correlation between their soil reflectance and soil salinity. In world-scale soil salinity studies, researchers have used machine learning methods to monitor the dynamics of soil surface salinity over the past four decades (Hassani et al., 2020) and ML algorithms to predict soil salinity in the 21st century in the context of global climate change (Hassani et al., 2021). It was found that the salt-affected areas were mainly distributed in arid and semi-arid regions, significantly more severe in northwestern China (Li et al., 2014). The risk challenge of soil salinization is further increased in arid and semi-arid regions of China due to their special climatic conditions, which are influenced by irrigation, drainage, and ecological water transport (Wang et al., 2012; Miguel et al., 2013). The temporal and spatial relationship between soil salinization and groundwater decline exacerbates the regional water-salt imbalance. Irrigated agriculture carries salts into the groundwater layers, leading to increased groundwater salinity and resulting in soil salinization in irrigation areas (Foster et al., 2018). Furthermore, as more land is converted to farmland, increased irrigation leads to salt accumulation. The overexploitation of land resources has had a significant and lasting impact on soil salinization (Wang et al., 2013; Yin et al., 2021).

The Shiyang River Basin, located in the arid region of Northwest China, is a typical inland river basin where soil salinization is a prominent issue closely linked to factors such as hydraulic engineering and irrigation activities. Therefore, assessing the distribution of soil salinization in this basin is crucial for understanding how natural and human activities impact soil salinization in arid areas. In this study, we aim to address the following questions: (1) Quantitatively analyze the degree of salinization in the Shiyang River Basin and reveal its spatial and temporal distribution characteristics; (2) analyze the impacts of water cycle changes on salinization. The study's results will help clarify the impact of the water cycle on soil salinization in the inland river basin and provide a scientific basis for agricultural development, ecological construction, and water resource use planning in the arid zone.

2. Materials and Methods

2.1 The Background Conditions of the Study Area

The Shiyang River Basin is located in northwestern China, at the eastern end of the Hexi Corridor. It consists of eight major tributaries: the Dajing River, the Gulang River, the Huangyang River, the Zaomu River, the Jinta River, and the Xiyang River (Fig. 1). Lakes and wetlands in the whole region mainly exist in reservoirs, with 15 reservoirs built with a more than 1 million cubic meters capacity. Water storage in reservoirs helps to adjust the distribution of river water and improve the ecological environment in the northwest. The study area is characterized by a continental temperate arid climate, with strong radiation, low precipitation, intense evaporation, and large diurnal temperature variations. The topography slopes from the southwest to the northeast and is divided into three units. The bedrock of the southern Qilian Mountains consists of metamorphosed sandstones and volcanic rocks, with soil types including Cryosols, Leptosols, and Phaeozems. The land is primarily forest and grassland, with annual precipitation of 300-600mm, evaporation rates of 700-1200mm, and the groundwater level is 50-200 meters below the surface. The central corridor plain features bedrock composed of schist and slate, with soil types including Gypsisols, Calcisols, and Solonchaks. The land use is primarily agricultural, with annual precipitation of 150-300mm, evaporation rates of 1300-2000mm, and the groundwater level is 50 meters below the surface. The northern low hills and deserts have predominantly igneous bedrock, and soils consisting of Arenosols, Leptosols, and Solonchaks. The landscape is barren, with annual precipitation below 150mm, evaporation rates of 2000-3000mm, and the groundwater level is 30 meters below the surface. The three geomorphological units show distinct differences, with increasing aridity from south to north.

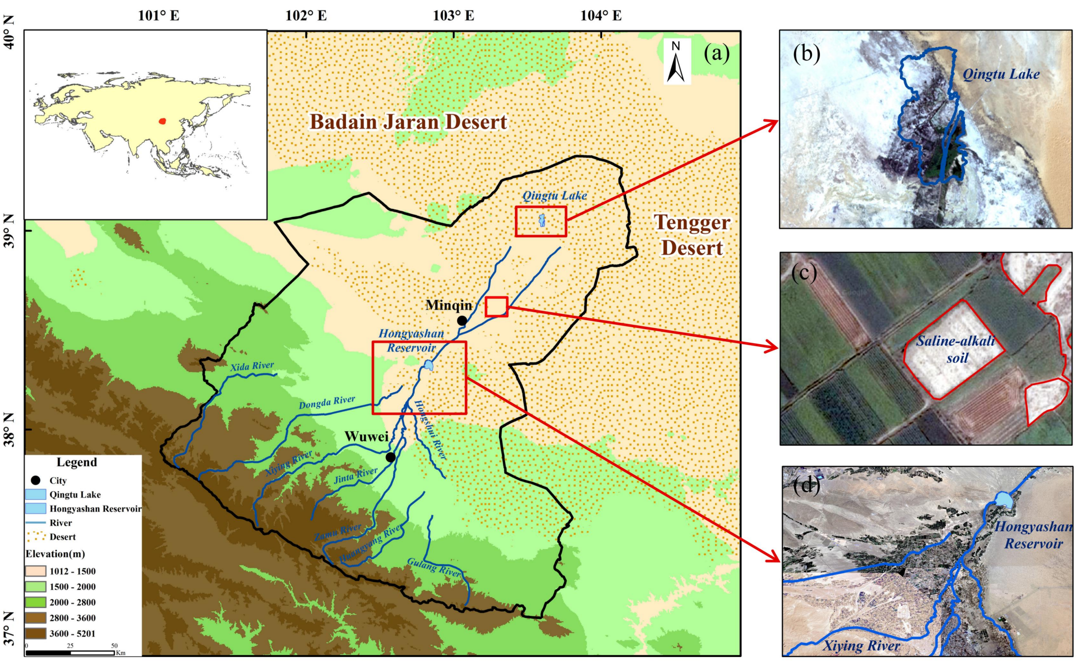

Figure 1. Overview map of the study area (a: Qingtu Lake (from USGS); b: Saline soils in

agricultural land (from Google Maps); c: Distribution of water systems in the Shiyang River Basin (from USGS))

2.2 Data Sources

2.2.1 Landsat Data

The Landsat series from the United States is jointly managed by the National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS). It is a series of Earth observation satellite systems used by the U.S. for monitoring Earth's resources and environment. Landsat is mainly used to investigate ocean resources and groundwater resources and to assist in regulating the rational use of water resources (National Research Council, 1997). Landsat data is available from the Earth Explorer service (https://earthexplorer.usgs.gov), which provides surface reflectance every 16 days with a spatial resolution of 30 meters. This article uses satellite data from Landsat-5, Landsat-7, Landsat-8, and Landsat-9. Landsat-5 was launched in March 1984, carrying the Multispectral Scanner (MSS) and Thematic Mapper (TM), and provided nearly 29 years of Earth imaging data. Landsat-7 was launched in April 1999, carrying the Enhanced Thematic Mapper Plus (ETM+) and the SLC sensor. Since June 2003, this sensor has collected and transmitted data with gaps caused by the failure of the scan line corrector (SLC), providing better radiometric and geometric data. Landsat-8, launched in February 2013, carries the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), ensuring the continuity of land data reception and availability. Its data is consistent with existing standard Landsat data products. The OLI sensor is used to capture remote sensing images in the visible, near-infrared, and shortwave infrared spectral ranges and is designed with a push-broom configuration, providing better level and stability and resulting in higher quality images. The OLI-2 sensor on Landsat-9 has a higher radiometric resolution, enabling finer detection in areas such as water bodies and dense forests.

2.2.2 Land Use Data

This article obtained the 30m land use data product for the Shiyang River Basin from 2002 to 2022, which is available in the public domain athttps://doi.org/10.5281/zenodo.4417810(Yang and Huang, 2022). This data calls upon 335,709 Landsat images on Google Earth Engine to construct the first Landsat-based annual land cover product of China from 1985 to 2019 (CLCD). It uses the CLUD dataset and multi-source sample collection training data to obtain classification results through a random forest classifier, and it improves spatiotemporal consistency through spatiotemporal filtering and logical reasoning.

2.2.3 Digital Elevation Model

The Digital Elevation Model (DEM) data is ASTER GDEM data jointly developed by Japan's METI and the U.S. NASA, distributed to the public for free with a resolution of 30m. This data can be downloaded athttp://reverb.echo.nasa.gov/reverb/. Slope data is calculated from the DEM data.

2.3 Data preparation and processing

This article selects the years 2002, 2007, 2012, 2017, and 2022 as the study periods, with four satellite remote sensing images chosen for each period to cover the entire study area. Preference is given to downloading high-quality satellite remote sensing images from the summer of each year, with cloud cover less than 1%, as this is more conducive to identifying the salinity and alkalinity levels of the soil (Allbed & Kumar, 2013). For the subsequent remote sensing inversion of salinity and alkalinity, preliminary preprocessing of the images in ENVI5.3 software is necessary (Source: https://www.l3harrisgeospatial.com/Software-Technology/ENVI), including steps such as radiometric calibration, atmospheric correction, image fusion, image mosaicking, and image clipping. Based on the natural attributes of the soil in the study area, auxiliary data, and field survey conditions, we use high-resolution images from Google Maps to select interpretation markers for mild, moderate, and severe saline-alkaline land and other land types. Next, we adjust the band combination of satellite remote sensing images to be most suitable for extracting saline-alkaline land (Khan et al., 2005; Jia et al., 2024). Using the Normalized Difference Salinity Index (NDSI), slope data, and texture features as references, we employ a Support Vector Machine (SVM) algorithm for supervised classification to identify the distribution of saline-alkaline land in the study area. The formula is as follows:

$$\min_{w,b,\xi_i}\left(\frac{1}{2}\|w\|^2+C\sum_{i=1}^{n}\xi_i\right) \quad (1)$$

$$y_i(w\cdot x_i)\geq 1-\xi_i,\xi_i\geq 0,i=1,\ldots,n \quad (2)$$

In the formula,wrepresents the weight vector, which defines the direction of the hyperplane;bis the bias term, defining the offset of the hyperplane;ξ_i is the slack variable, which increases the robustness of the model;Cis the regularization parameter, balancing the model complexity and training error; y_i is the label of data pointi, commonly used to define a hyperplane.

Finally, the accuracy of the supervised classification results is evaluated using the confusion matrix method, including overall classification accuracy, Kappa coefficient, etc. The data processing flow is shown in Figure 2.

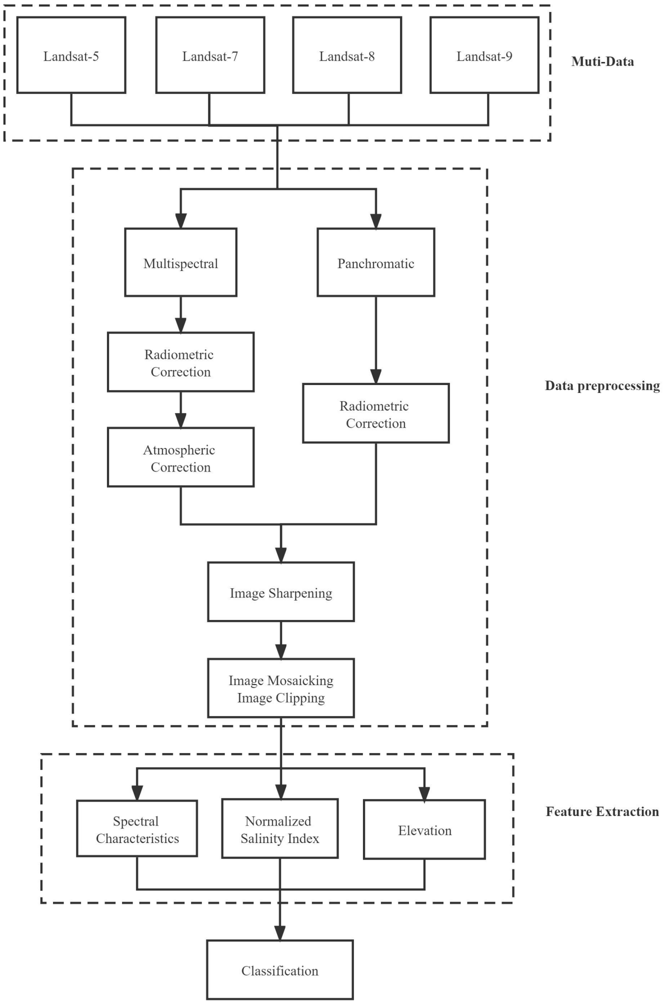

Figure 2. Flow chart of data processing

3. Results

3.1 Spatial distribution of soil salinization

Remote sensing inversion of salinization in the Shiyang River Basin from 2002 to 2022 was carried out based on the selected samples of mild, moderate, and severe soil salinization (Fig. 3). The results showed that the salinization of the basin gradually increased from upstream to downstream, especially in the downstream of the basin near Qingtu Lake, where the salinization of the soil was the most serious. From the perspective of natural landform division, the salt-accumulating areas of the Shiyang River Basin are widely distributed across the central corridor plains, northern low mountains, hills, and desert areas. In the central corridor plains, soil salinization is mainly characterized by mild and moderate salinization. Moderate saline soils are primarily concentrated in the oasis farmland irrigation areas on both sides of the river, with a few plots transforming into severe saline soils. The area of moderate saline land expanded significantly in 2012, with growth areas located in the central part of the plains. Mild saline lands are scattered and cover a smaller area. In 2012, a large number of new mildly saline plots emerged in the western part of the central corridor plains, and the area of mild saline land increased in the southeast. By 2022, mild salinization in these areas had improved to some extent. In the northern low mountains, hills, and desert areas, soil salinization is mainly characterized by moderate and severe salinization, with the area and extent far exceeding those of the central corridor plains. Moderate saline lands are mostly located in semi-desert areas and outside irrigation zones, especially at the end of the Shiyang River Basin, where downstream salt accumulation is prevalent, resulting in a concentration of heavily saline lands. In contrast, mildly saline lands are less common and scattered.

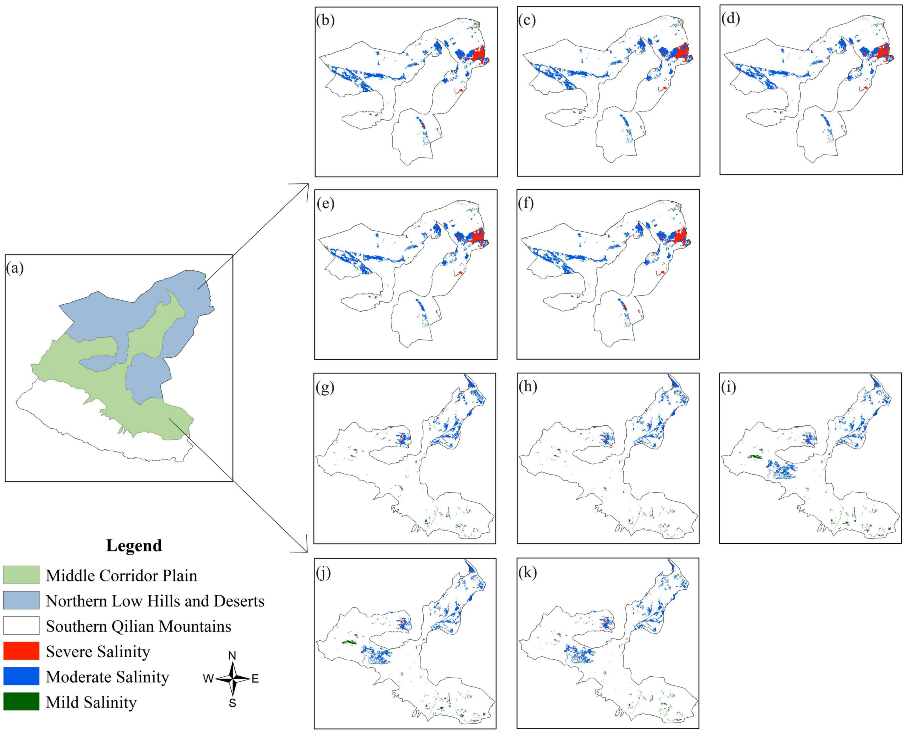

Figure 3. Spatial distribution of salinization in the Shiyang River Basin (a: Natural Landform Unit Division of the Shiyang River Basin; b-f: Distribution of Soil Salinization in the Northern Low Hills and Deserts for the Years 2002, 2007, 2012, 2017, 2022; g-k: Distribution of Soil Salinization in the Central Corridor Plain for the Years 2002, 2007, 2012, 2017, 2022)

3.2 Temporal changes in soil salinisation

The study area is divided into three parts based on natural landform units. The Southern Qilian mountain area did not exhibit soil salinization, so the focus is on the temporal changes in soil salinization area in the central corridor plains and the northern low hills and deserts (Fig. 4). Over the 21 years, the change in the area of soil salinization in the basin was not substantial. Specifically, the area decreased from 2002 to 2007, increased from 2007 to 2012, and decreased again from 2017 to 2022. In the central corridor plains, although the soil salinization area reached a historic low in 2007, overall, it shows an increasing trend. Compared to 2002, the area of soil salinization in 2022 increased by over 18%. The mild salinization area reached its maximum in 2017 and returned to the 2002 level by 2022. The increase in moderate salinization area is the most notable, while the area of severe salinization changed little. In the northern low mountains, hills, and desert areas, the soil salinization area showed an overall decreasing trend, with an average annual reduction rate of 38.19

km². The area of mild salinization changed little, with a slight increase in 2022 compared to 2002. The area of moderate salinization consistently decreased, especially significantly from 2002 to 2007. The area of severe salinization slowly decreased from 2002 to 2017 but increased from 2017 to 2022. Overall, the reduction in the soil salinization area in the northern low mountains and desert areas was significant, although the increase in the central corridor plains' soil salinization area was slightly less than the decrease in the northern areas.

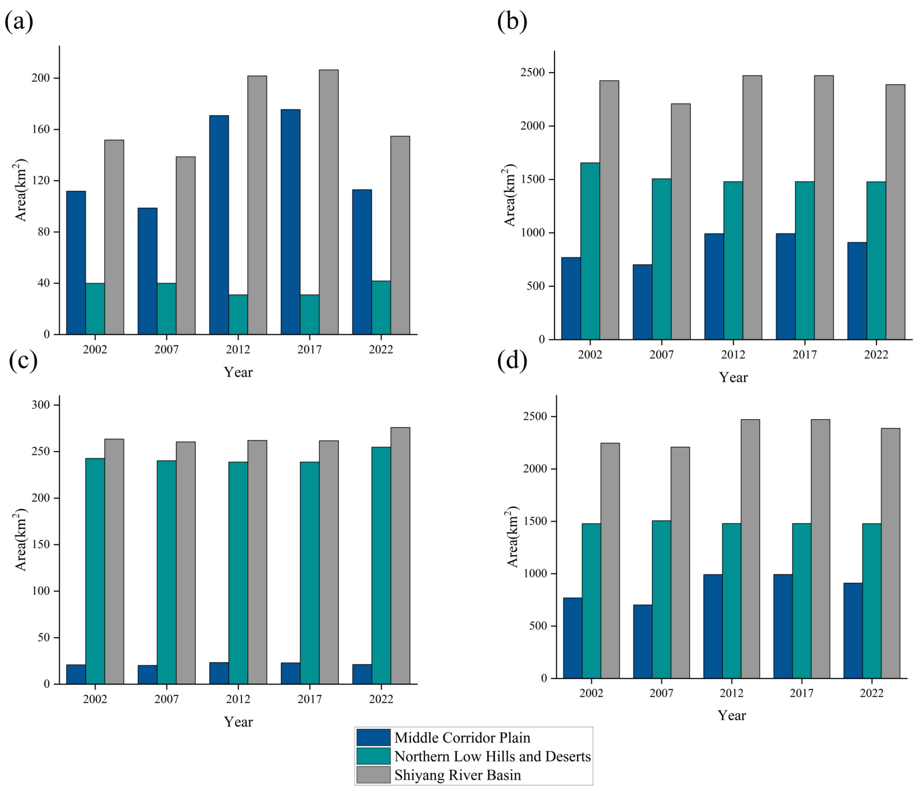

Figure 4. Changes in soil salinization area in the Shiyang River Basin (a: Changes in Mild Soil Salinization Area; b: Changes in Moderate Soil Salinization Area; c: Changes in Severe Soil Salinization Area; d: Changes in Soil Salinization Area in the Shiyang River Basin)

4 Discussion

4.1 Soil salinization and basin water conservancy project

With the advancement of the water transfer project and the increase of water transfer, the amount of farmland irrigation water is bound to increase substantially, and the input of external water will inevitably break the equilibrium state between regional soil, vegetation, and climate, so it is necessary to pay attention to the salinization problem brought about by farmland irrigation (Abbas et al., 2013; Thorslund et al., 2021). In the long term, secondary salinization is a major potential obstacle to the sustainability of inter-basin water transfers. The negative effects are reflected in both the evaporation processes that are altered by the transfer of water for irrigation and the rise in the water table caused by the foreign water (Duan et al., 2022). The connectivity between groundwater and soil water increases, and the trend of salt enrichment to the surface through evaporation becomes more obvious. Low rainfall and high evapotranspiration in arid areas will lead to the accumulation of large amounts of salts dissolved in water on the soil surface to form salinization (Aboelsound et al., 2023).

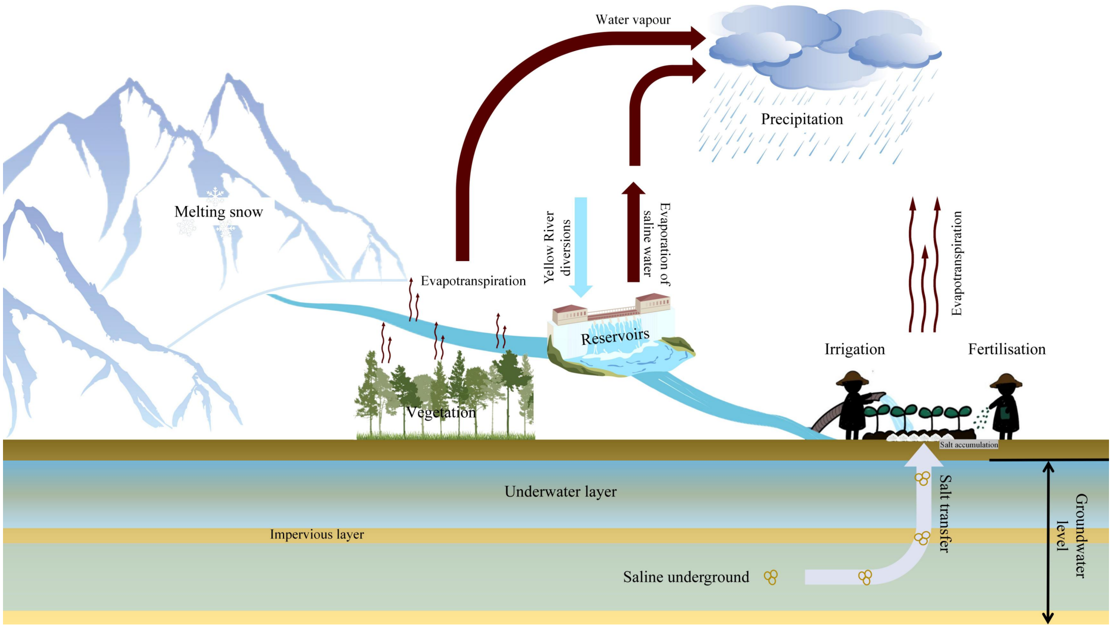

Figure 5. Conceptual diagram of the salinization cycle in arid zones

In the upper reaches of the Shiyang River Basin, natural water sources such as precipitation and snowmelt water are introduced into the irrigation area; in the middle reaches, the construction of reservoirs and canals is used to improve the supply of water resources in the irrigation area; in the lower reaches primarily rely on water from the upper reaches of the Shiyang River and ecological water transfer. Ecological water transfer mainly refers to the Jingdian water transfer (i.e., water diversion from the Yellow River), which regulates the irrigation water use pattern by transferring water to Qingtuhu Lake through the Hongya Mountain Reservoir (Fig. 5). The Xiyang River has been transferring water to Minqin since 2006. The Jingdian II water transfer project has transferred water from the Yellow River to the Minqin area for 12 consecutive years since 2011. These projects have considerably eased the pressure on Minqin's water resources. Meanwhile, from the trend of soil salinization area change in the Minqin area in the past 21 years, the salinized area in the Minqin area is gradually decreasing. In 2012, the salinized area of the Minqin area in the salinized area of Shiyang River Basin showed a sharp decline in the percentage of the area. Then, it has been kept in a stable state related to the basin water transfer. This is because the water transfer project slows down the rate of decline of the groundwater table and improves the surface water utilization rate. When the groundwater level falls, the salts in the soil are usually adsorbed on the soil surface and not easily washed away by the water body, which will cause the accumulation of salts. However, at the same time, too much water transfer or irrational irrigation will also lead to excessive water accumulation on the soil surface, coupled with the intense evaporation in the Minqin area, the evaporation on the soil surface will increase, and the salts will further accumulate on the soil surface. Hence, the proportion of severe salinity in the Minqin area shows a rising trend. When the surface water use efficiency is low, the irrigation water cannot fully penetrate the deep soil layer but only stays on the soil surface. Then, the salts will stay on the soil surface through evaporation, which will aggravate the degree of soil salinization (Yin et al., 2022). Although the water transfer project is designed to improve the ecological and water shortage status of inland river basins in arid areas, it also aggravates salinization in Minqin (Yang et al., 2020).

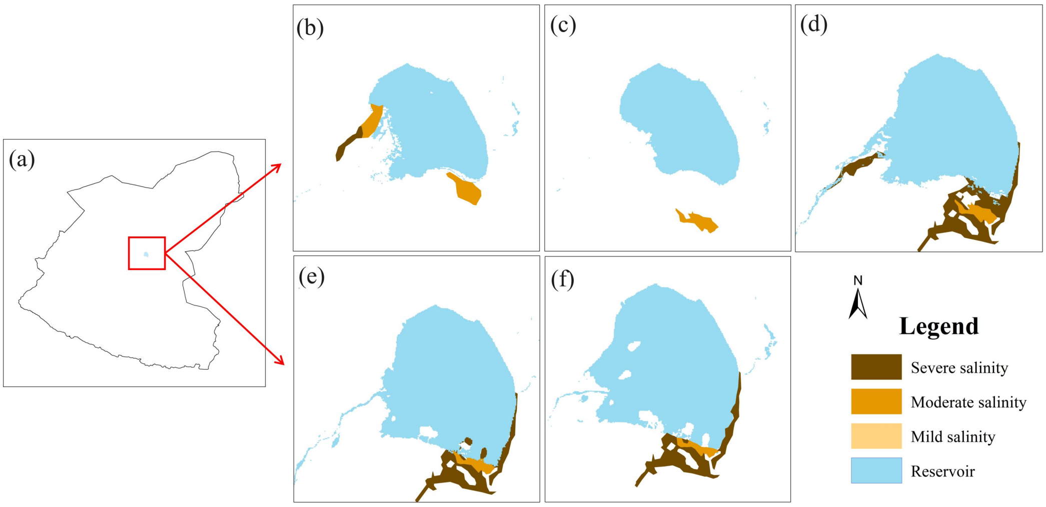

Figure 6. Changes in water body area and salinity in Red Bluff Mountain Reservoir (a: Shiyang River Basin; b: 2002; c: 2007; d: 2012; e: 2017; f: 2022)

Irrigation around the reservoir is a significant cause of increased soil salinity (Wu et al., 2019). The Hongyashan Reservoir is located in the middle of the desert, and its western side is built on the Hongya Mountain, while the other sides are manufactured. The Hongyashan Reservoir is intended to improve the downstream ecological water shortage, but as the reservoir area increases, the downstream terrestrial water storage is decreasing. The conductivity of groundwater is an essential indicator for assessing its salinity. By measuring the EC value of groundwater in Hongyashan Reservoir from 2017-2019, it was found that the EC value of groundwater in Hongyashan Reservoir remained above 500 μs/cm, beyond the range of low-salinity water. There was a slight upward trend in recent years, with an increase of 14.119 μs/cm from 2017 to 2023. From 2002 to 2022, as the area of Hongyashan Reservoir expanded, the salinization of the soil around it gradually increased (Fig. 6). In 2002, the area of the reservoir was relatively small, and the soil along the foot of Hongyashan Mountain at the west was heavily and moderately salinized. Part of moderately salinized land also appeared in the southeast. In 2007, water storage in the western part of the reservoir increased. The salinized area in the southeast shifted southward. In 2012, soil salinization in the southern part of the reservoir increased dramatically to severe salinity and, in the south-western corner near the Shiyang River area, severe salinization also occurred. From 2012 to 2022, with the raising and expansion of the reservoir, the soil salinization has remained the same, and the salinization area around the reservoir has further expanded. Moreover, the reservoir's water level is raised, coupled with an arid climate and low rainfall, which will intensify soil surface water's evaporation, leading to the accumulation of salts in the surface soil and a gradual increase in the degree of soil salinization.

4.2 Soil salinization and irrigation

The development of irrigated agriculture is necessary to meet the growing food needs of the global population (Jägermeyr et al., 2017). In the Shiyang River Basin, the saline-alkali land converted from farmland accounted for 3.07% of the saline-alkali land area in 2022. The conversion from grassland accounted for 6.23%, and the wasteland conversion rate was the highest, reaching 11.27%. These data indicate a significant risk of salinization occurring in farmland, grassland, and wasteland. Salinization and irrigation are two common but often neglected issues in agricultural production. It is essential to clarify the relationship between salinization and irrigation and provide possible solutions. There are 27 irrigation districts in the Shiyang River Basin (Fig. 7), the largest of which is the Hongyashan Irrigation District, with an area of 1619.45 km^2. Among the irrigation districts with more serious soil salinization are the Hongyashan Irrigation District, the Changning Irrigation District, the Dongdaha Irrigation District, the Nanhu Irrigation District, the Donghe Irrigation District, the Xiyinghe Irrigation District, and the Qinghe Irrigation District, with most of them having a medium degree of salinization. A small portion of them were mildly salinized, among which the Dongdaha Irrigation District was moderate from 2007 to 2012. Irrigation District in 2007-2012, soil salinization was more serious, and the salinized area increased substantially. In the Gulang River Irrigation District, Wujiajing Irrigation District, Huangyang River Irrigation District, Huangyan Irrigation District, Qiduntai Irrigation District, Jingdian Irrigation District, Dajing River Irrigation District, Qingyuanjing Irrigation District, Zaomu River Irrigation District, Jinta River Irrigation District, Jinyangjingyuan Irrigation District, Yongchang Irrigation District, Xiehe Irrigation District, Siba Irrigation District, and Jincheon

Irrigation District, the degree of soil salinization was mild. The area of salinization was relatively small. Regarding spatial distribution, irrigation areas with severe salinization are in the middle and lower reaches of the watershed, and those with lesser or no salinization are in the upper regions. This is closely related to evaporation in arid regions, a vital salinization driver. The evapotranspiration in the Shiyang River basin has apparent vertical and regional zonation. The upstream is located in the alpine semi-arid humid zone of the Qilian Mountains, with an altitude of 2000-5000 m. The annual evaporation is 700-1200 mm, the annual evaporation in the middle reaches 1300-2000 mm, and in the downstream, it is as high as 2000-3000 mm. Evaporation gradually increases from the upstream to the downstream, and salinization is gradually aggravated. Among them, the area of soil salinization in Gulang River and Wujiajing irrigation areas increased continuously from 2002 to 2017, while the area decreased from 2017 to 2022, and the area of soil salinization within other irrigation areas did not change much.

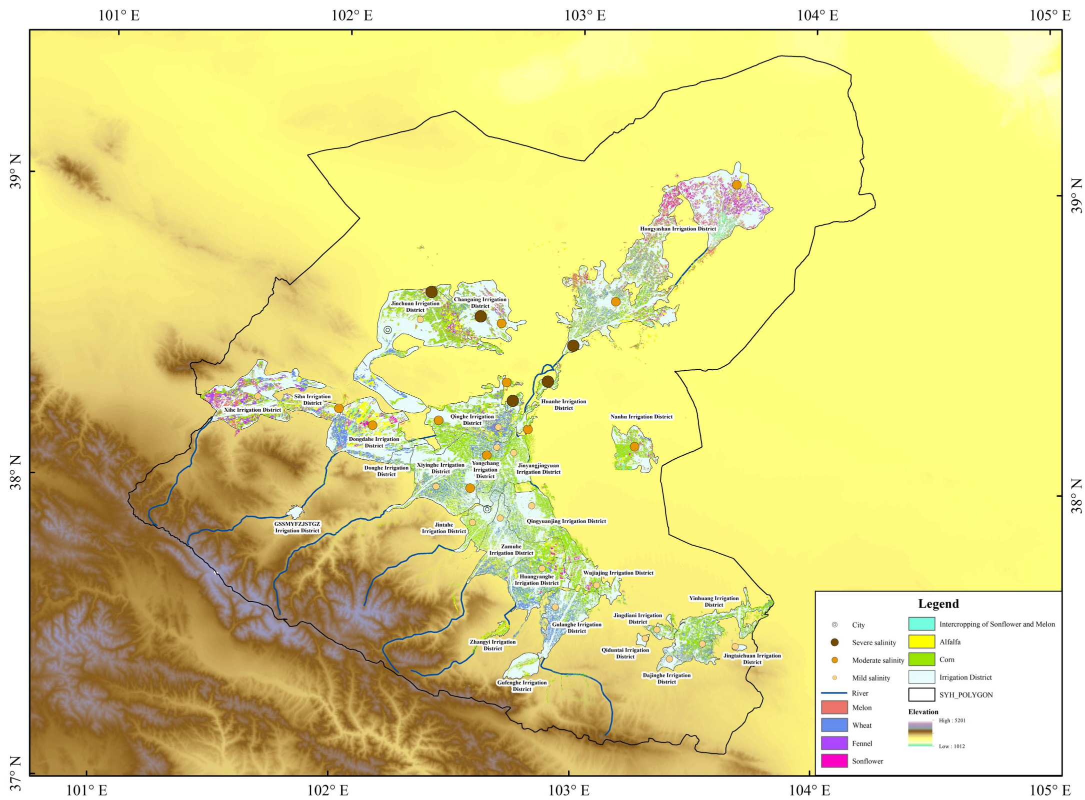

Figure 7. Distribution of irrigation areas in the Shiyang River Basin

Most soil salinization in the Shiyang River Basin is found in irrigated areas. In irrigated areas, problems such as long-term over-irrigation and poor drainage often occur, accumulating salts and alkaline substances in the soil, thus causing soil salinization (Minhas et al., 2020). In addition, the monoculture of land within irrigated areas, where only one or a few crops are often grown, also tends to lead to excessive accumulation of certain elements in the soil, thus aggravating soil salinization. For example, in the midstream region of the basin, cropping patterns are adjusted according to variations in topography, climate, and land use methods. In contrast, the downstream cropping patterns are more singular, primarily focusing on the cultivation of fennel, melon, and corn. This can, to some extent, affect soil salinization. The relationship between salinization and irrigation is evident: excessive irrigation can lead to an increase in soil salt concentration, thereby triggering salinization issues. Furthermore, soils with high salt content can compromise the quality of irrigation water, which adversely affects plant growth and yield (Singh, 2022).

4.3 Uncertainty in research.

This study analyzed soil salinization in the Shiyang River Basin using Landsat satellite data. However, due to the inherent uncertainties of satellite data, the results may have certain limitations. Although satellites can provide multispectral data, the spectral resolution is relatively low, and atmospheric correction issues may also affect data accuracy, posing challenges for identifying soil salinization (Vicente-Serrano et al., 2008; Vanonckelen et al., 2013). Landsat has a revisit cycle of 16 days, which can be further extended by climatic effects during certain seasons, significantly limiting seasonal monitoring of the region. To improve the temporal resolution of the data, future research could use the ESTARFM model for optimization (Zhu et al., 2010). Additionally, the selection and quantity of training data directly affect the accuracy of supervised classification. An accuracy assessment of the supervised classification results revealed classification accuracies of 89.40%, 88.37%, 89.80%, 99.52%, and 96.83% for the years 2002, 2007, 2012, 2017, and 2022, respectively, with kappa coefficients of 0.82, 0.81, 0.82, 0.99, and 0.95. However, due to the limitations of sampling size and satellite data, the identification of mildly saline-alkaline land is slightly less effective compared to other types of land, which requires further improvement in future work. To further enhance the precision and scope of soil salinization identification, future research will attempt to use deep learning models for image classification and feature extraction and establish an integrated multi-source database that includes field measurement data, meteorological data, irrigation data, etc., to improve the application of soil salinization inversion results in hydrological and soil research.

5 Conclusion

This study utilized high-resolution remote sensing data to quantify changes in soil salinization in the inland river basin of arid regions from 2002 to 2022 and its impact on the water cycle mechanism. The area of salinization in the basin has generally remained stable, but the degree of salinization has gradually intensified from the southwest to the northeast. The area of moderate salinization in the central corridor plain has expanded, while the area of severe salinization in the northern low mountains, hills, and desert areas has increased. Farmland, grassland, and wasteland are at the highest risk of converting into saline-alkaline land, which poses a challenge for farmland management. Additionally, addressing salinization requires a balanced focus on both water bodies and soil. Human activities have significantly altered the soil quality in the basin, further affecting the water cycle and water resource conditions. This study will provide more scientific evidence for agricultural and water resource management in the basin.

Conflict of Interest Statement

The authors declare no conflicts of interest.

Author contributions statement

Gaojia Meng and Guofeng Zhu conceived the idea of the study; Yinying Jiao, Dongdong Qiu and Yuhao Wang analyzed the data; Rui Li, Longhu Chen and Qinqin Wang participated in the drawing; Gaojia Meng wrote the paper; Siyu Lu, Enwei Huang, Jiawei Liu and Wentong Li checked and edited language. All authors discussed the results and revised the manuscript.

Acknowledgements

This research was financially supported by the National Natural Science Foundation of China(42371040, 41971036), Key Natural Science Foundation of Gansu Province(23JRRA698), Key Research and Development Program of Gansu Province(22YF7NA122), Cultivation Program of Major key projects of Northwest Normal University(NWNU-LKZD-202302), Oasis Scientific Research achievements Breakthrough Action Plan Project of Northwest normal University(NWNU-LZKX-202303).

Data Availability Statement

The 30m land use classification data for the Shiyang River Basin used in this study are available in the public domain (https://doi.org/10.5281/zenodo.4417810); Landsat series data were obtained from Earth Explorer service (https://earthxplorer.usgs.gov).

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