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Land Cover Change and Groundwater Depletion: The Impact of Poppy Cultivation in the Northern Districts of Helmand

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Abstract: In recent decades, significant land-cover change has occurred in many areas of Helmand province, which has led to an unprecedented decline in groundwater levels. Poppy cultivation is considered one of the fundamental drivers of this land-cover change. This study analyzes the relationship between poppy cultivation and the depletion of groundwater in four northern districts (Nowzad, Kajaki, Musa Qala, and Washir). Using the ENVI 5.6 software, land-cover change from 2000 to 2023 was calculated. The results show that, compared to the year 2000 when the cultivated area was 285 km², this area increased to 1,036 km² by the end of 2014. However, in the beginning 2018, a decline in agricultural land started and by 2023 the cultivated area had decreased to 650 km². In addition, data collected through a survey of 81 local residents indicate that water scarcity has become a serious problem. The lack of water for drinking and agricultural activities has created widespread challenges, and the intensive use of deep wells is causing severe damage to groundwater resources. Climate change and the drop in groundwater levels have been identified as the main causes for the reduction of agricultural land and activities in this region. Finally, the study emphasizes the need for proper water resource management and the adoption of alternative agricultural practices instead of poppy cultivation.

Keywords: Land cover, groundwater level, poppy cultivation

1. Introduction

Helmand is one of Afghanistan's provinces that holds particular importance due to its large area, flat plains and extensive agricultural lands. However, in recent years, poppy cultivation has created numerous challenges in the region. After the year 2000, local residents, in order to cultivate poppy crops securely, brought large areas of desert land under cultivation and began to extract groundwater to irrigate these newly cultivated lands. This marked the beginning of rapid land-cover change in Helmand. Over the past two decades, this transformation has gone through two phases. In the early years, the area of agricultural land devoted to poppy cultivation expanded, but after a short delay, drought and a decline in groundwater levels caused some farmland to revert back into barren and desert land.

Climate change has created another concern for Afghanistan. In particular, the reduction in precipitation, which is one of the adverse effects of climate change, has severely affected many areas of the country. Due to the lowering of groundwater levels, not only has agricultural land been affected, but in many regions access to drinking water has also become a challenge for the local population.

Because of the presence of flat desert lands, Helmand Province has played a major role in poppy cultivation. According to reports from the United Nations Office on Drugs and Crime (UNODC, 2021), Afghanistan produces more than 80 percent of the world's opium. Research based on satellite images and modern technologies from 1990 to 2020 shows that vast expanses of desert land have been converted into agricultural land. The expansion of agricultural activities in Helmand Province is considered one of the main factors behind the dramatic decline in groundwater levels. Reports indicate that groundwater was used in an unprecedented and unregulated manner to irrigate large poppy fields, leading to a shortage of groundwater in many parts of the province (UNODC, 2021; IWA, 2021).

The impacts of climate change have further exacerbated these conditions in Helmand Province. Studies show that climate change, particularly in areas with limited water resources, has created major challenges for agriculture (Hassan et al.,

2022). The continuous over-extraction of water resources has also contributed to the intensification of climate change (Zeiler et al., 2023). The decline in groundwater levels is a widespread problem in many countries and is largely attributed to climate change, population growth, human activities, and land-cover change. Research in this field indicates that these factors jointly contribute to the depletion of groundwater resources and pose serious challenges to sustainability. A study conducted in Oaxaca, Mexico, shows that climate change and land-cover change are the main drivers of water scarcity and, together with population growth in the region, rapidly reduce groundwater levels (EA Ojeda et al., 2019). Likewise, human activities—particularly agricultural changes—and the effects of climate change have a profound impact on groundwater depletion, which in turn negatively affects the socio-economic conditions of the region (Panda et al., 2021). Similarly, land-cover change also severely disrupts the infiltration of water back into the ground (Siddik et al., 2022). Continuous extraction of water from deep wells lowers groundwater levels and is considered a major threat to sustainability in semi-arid regions (Xia et al., 2019). Likewise, research in Egypt shows that groundwater depletion is a result of climate change and agricultural activities (Moghazy et al., 2020). The expansion of agricultural activities and the effects of climate change have created serious challenges for water resources, leading not only to lower water levels but also deteriorating water quality (Dangar et al., 2015). In semi-arid regions, the relationship between agricultural activity and groundwater salinity has also been examined in various studies, which indicate that increased salinity is the result of intensive agricultural activities and excessive groundwater extraction (Foster et al., 2021). Helmand holds a specific place in the expansion of illegal agricultural activities, as the growth of poppy cultivation has accelerated land-cover change and placed the region's ecosystem under serious threat (Goodhand & Mansfield, 2019). Although poppy cultivation has provided short-term economic benefits to the region, it has, in the long term, exacerbated problems relating to water resource depletion and environmental disturbance (Pain, 2008). The relationship between climate change and land-cover change is an important subject of research in Afghanistan. Studies have shown that climate change and the decline in water resources have made the transformation of desert land increasingly challenging (Turral et al., 2010). Overall, groundwater depletion is a complex issue that is linked to climate change, human activities, and water management. To prevent this problem, it is essential to develop and implement plans for proper water management, the use of modern agricultural technologies, and adaptation to climate change.

Research Rationale and Significance

In the four northern districts of Helmand Kajaki, Musa Qala, Nowzad, and Washir—the combined effects of climate change, the expansion of agricultural land, and particularly the ruthless extraction of groundwater for irrigating poppy fields have led to an unprecedented decline in groundwater levels. This process has not only resulted in reduced agricultural production, but has also made access to clean drinking water increasingly difficult for local communities. The significance of this study lies in its scientific examination of the relationship between land-cover change, the depletion of groundwater resources, and poppy cultivation

Research Objectives The aim of this study is to scientifically analyze the impacts of land-cover change, climate change, and human activities. In addition, it seeks to identify the main causes of groundwater depletion and propose effective solutions to resolve this problem in the long term.

- To analyze the extent of land cover change in four northern districts of Helmand between 2000 and 2023.
- To identify the main drivers of groundwater depletion.
- To evaluate the role of poppy cultivation in groundwater decline.
- To propose effective and sustainable solutions for water resource management and agricultural diversification.

2. Materials and Method

Although land-cover change and groundwater depletion have affected all of Helmand Province, this study focuses, as a case study, on four northern districts—Washir, Nowzad, Musa Qala, and Kajaki—whose residents are facing extremely challenging living conditions. Two main approaches were followed in this research:

First, land-cover change was calculated using satellite images from Landsat 7, Landsat 8, and Landsat 9. Landsat 7 was launched in 1999, Landsat 8 in 2013, and Landsat 9 in 2021; each provides a spatial resolution of 30 meters and is suitable for monitoring changes in agricultural land. Specifically, images from the years 2000, 2007, 2014, 2018, 2020, and 2023 (March and April) were used in this study. These images were obtained from the USGS Earth Explorer and processed using ENVI 5.6 software, which also included atmospheric correction. Helmand has two agricultural seasons; this study evaluated the agricultural areas in the spring season, during which poppy is widely cultivated. Therefore, satellite images captured between March 15 and April 15 were used, as agricultural areas during this period can be clearly distinguished from non-agricultural areas.

Second, a survey containing 29 questions was conducted to better understand the local situation. The questions focused on water scarcity and agriculture, such as: "Has the water level in your area decreased compared to previous years?" "By how many meters has the groundwater level dropped in the last five years?" "Have your crop yields decreased?" and "If the current situation continues, will you have sufficient water for agriculture in the next five years?" The survey was carried out among residents of different villages in the four districts and the relevant data were collected. The obtained

data were entered and analyzed in Excel. Finally, the results obtained from both methods were used to analyze the current situation and assess future conditions.

3. Results

This study examined long-term land-cover changes in agricultural areas in the four northern districts of Helmand (Nowzad, Musa Qala, Kajaki, and Washir). The assessment was based on satellite images for six different years (2000, 2007, 2014, 2018, 2020, and 2023). The evaluation clearly illustrates the influence of both environmental and human factors on the expansion of agricultural activities.

First Phase of Agricultural Expansion (2000–2014): In 2000, the agricultural area in the four northern districts was only 285 km². At that time, traditional irrigation systems such as karezes were widely used, although local communities had only recently begun to rely on deep wells as a major water source. Satellite images show that agricultural land increased to approximately 495 km² in 2007. This expansion of 210 km² over seven years represents an annual increase of nearly 30 km². The widespread adoption of deep wells formed the basis for this growth, enabling farmers to convert desert land into productive agricultural areas. The rapid expansion of agricultural land continued, and by 2014 its total extent had reached approximately 1,036 km². This represents an annual increase of around 77 km² during this period. Large areas of desert were converted into farmland, primarily for poppy cultivation, as these areas allowed farmers to grow poppy without restriction. This period represents an unprecedented phase of agricultural expansion in the four districts. As shown in Figure 1, from 2000 to 2014 agricultural land quadrupled, with the spread of deep wells and the conversion of desert lands being the main driving factors.

Decline of Agricultural Land (2018–2023): In 2018, the total agricultural area in the districts of Kajaki, Musa Qala, Nowzad, and Washir was recorded at 1,023 km², representing a decline of 13 km² compared to 2014. Although this decrease was not significant, it was considered a worrying sign. The decline was mainly due to the combined effects of climate change and intensive use of groundwater, which caused the water table to drop in many areas. In 2020, the agricultural area further declined to 949 km², showing a decrease of 74 km² in only two years. During this period, the impacts of climate change—such as reduced rainfall and increased evaporation—became even more pronounced. The specific requirements of poppy cultivation, particularly the need for continuous and regular irrigation, forced farmers to extract even more groundwater in the absence of precipitation. As a result, groundwater levels declined rapidly in many areas. The period between 2020 and 2023 is referred to as the "severe period," as it saw the greatest reduction in agricultural land cover. In 2023, the total agricultural area in the four districts decreased to only 650 km², representing a loss of 300 km² in three years, as shown in Figure 1. This corresponds to an average annual decline of 100 km². The main causes of this sharp decline were the continuous decrease in groundwater levels and the persistent effects of climate change. This period clearly exemplifies the reduction in agricultural expansion and the increasing environmental pressures that have placed water resources and agricultural activities in the region under serious threat.

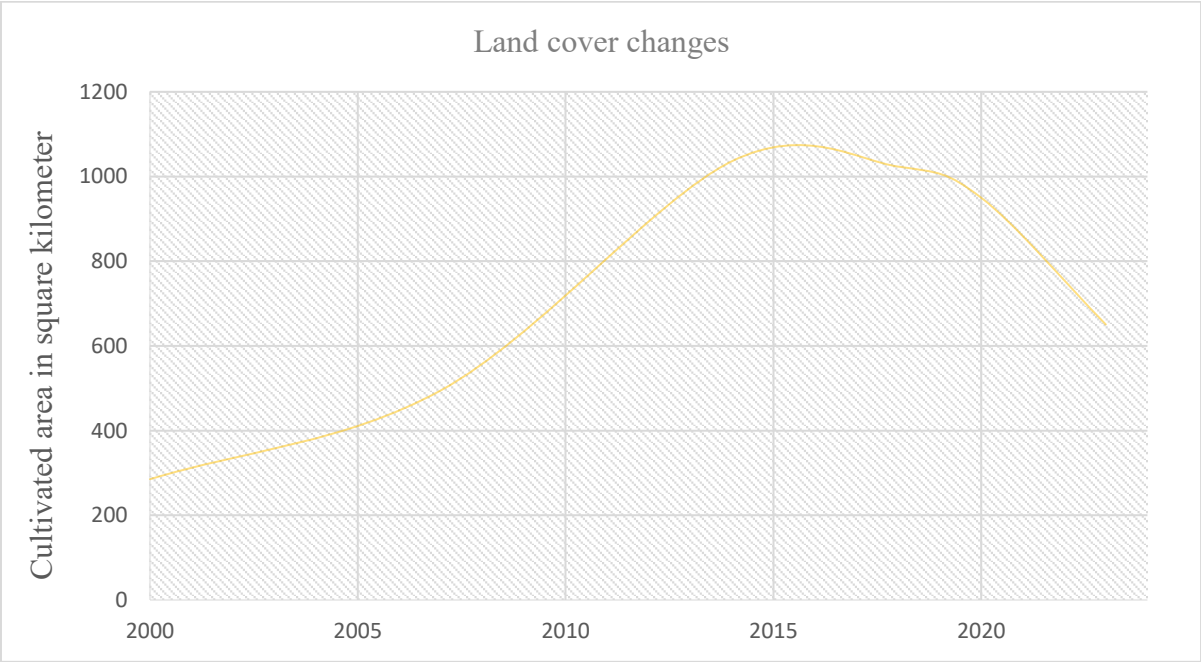

Figure 1: Land cover changes in the North four distracts of Helmand Province

Second Phase of the Research

In this study, a comprehensive survey was conducted with 81 local residents in the four northern districts of Helmand (Nowzad, Washir, Kajaki, and Musa Qala). The survey included 29 detailed questions aimed at collecting information on the decline in groundwater levels, the impacts of climate change, and agricultural practices. Of the 81 respondents, 33 were residents of Nowzad, 25 of Washir, 13 of Kajaki, and 10 of Musa Qala, who shared their experiences and observations regarding water resources and agricultural challenges. Before the year 2000, hundreds of karezes in this region served as the primary source of irrigation, supplying water to many agricultural lands. However, the unprecedented decline in groundwater levels caused these karezes to dry up, forcing local residents to turn to alternative sources of water. Out of the 81 participants, 70 stated that they now rely on deep wells as the main source of irrigation for agriculture. The remaining 11 respondents mentioned canals, though they also confirmed the presence of deep wells on their lands. As shown in Figure 2, many participants indicated that they had constructed several deep wells on their farms in order to secure reliable access to water.

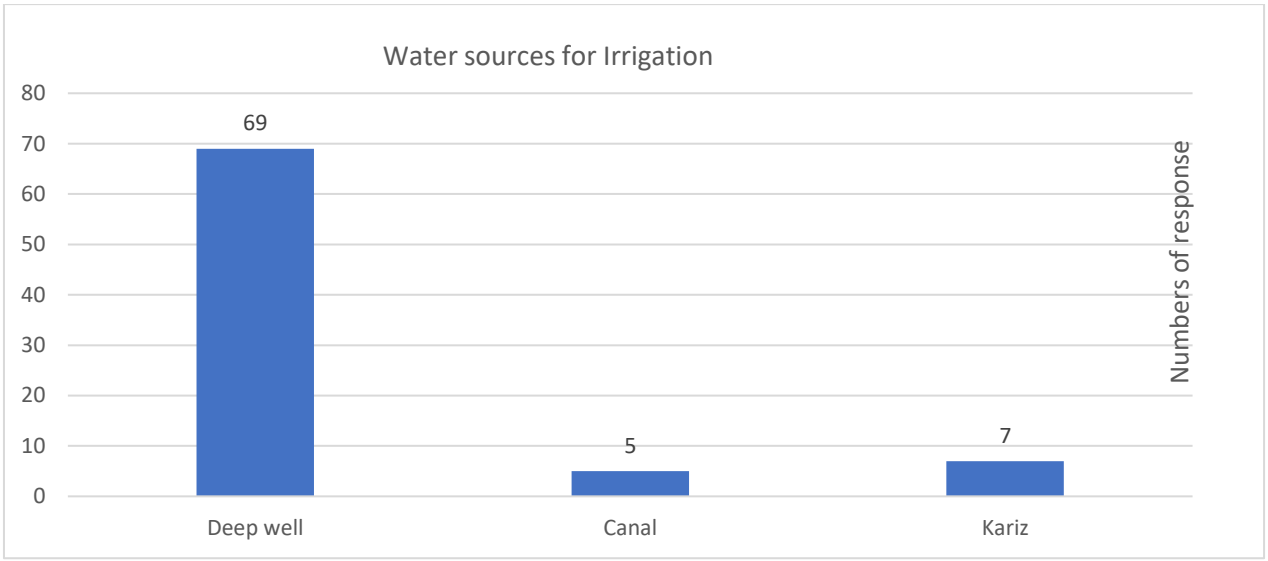

Figure 2: Water sources for irrigation in the North distracts of Helmand province

Based on the interviews with local residents, it became evident that the groundwater level has decreased dramatically, and hundreds of karezes have dried up due to the declining water table. In some areas, the water table has dropped to more than 250 meters. Many respondents stated that they currently obtain water from deep wells at depths of around 150 meters. During the past five years, reduced rainfall has further intensified water scarcity, causing severe damage to both agriculture and the local economy. Information obtained from residents indicates that the groundwater level has fallen by approximately 50 meters over the past five years, and in some areas this decline has reached up to 100 meters. The 2023 land-cover map and the survey results show a significant reduction in agricultural land, with more than 100 km² of agricultural land, on average, being converted into non-agricultural land each year. As shown in Figure 3, the majority of respondents reported a marked decrease in agricultural yields; of the 81 respondents, 65 noted a substantial decline in crop production. If the current situation continues and no appropriate measures are taken to manage rainfall and groundwater resources, the region could face severe challenges in the coming five years.

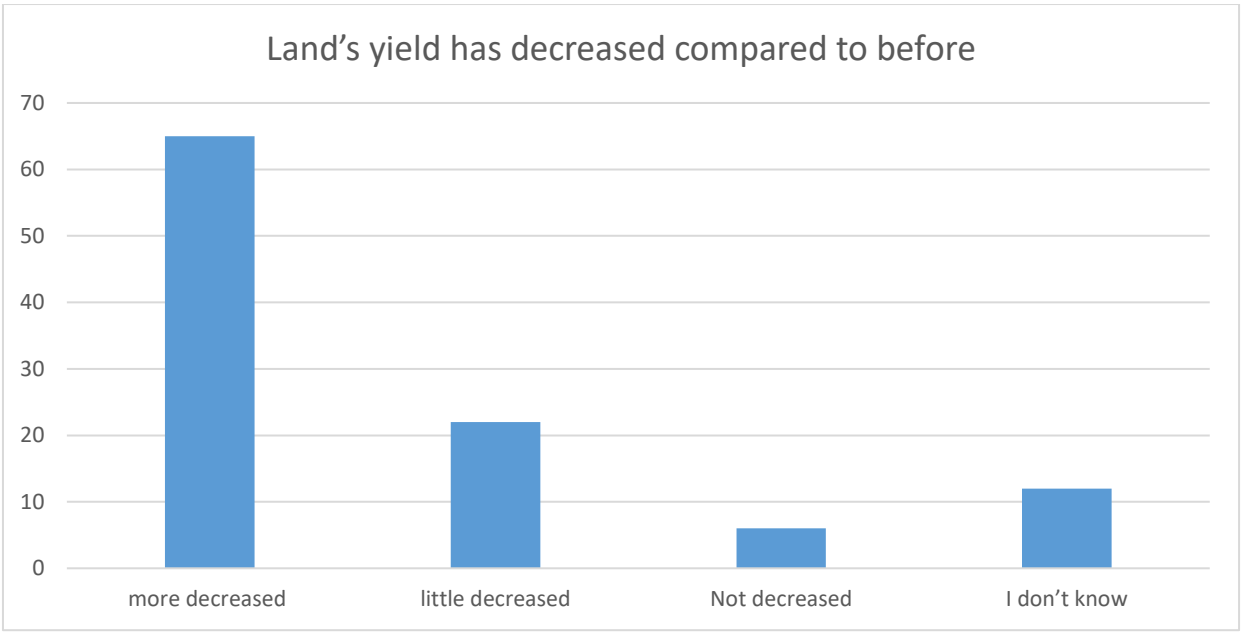

Figure 3: Residential response about the declination of crop production in the north of Helmand province.

Regarding the availability of drinking water, nearly half of the participants expressed deep concern. The survey results show that approximately half of the respondents stated that they either do not have access to clean water or obtain it with great difficulty. Local residents were also worried about continuing to live in the area; only 11 respondents said that they might remain in the region over the next five years. The remaining 70 respondents indicated that, if the current situation persists, they are pessimistic about staying in the area, as shown in Figure 4.

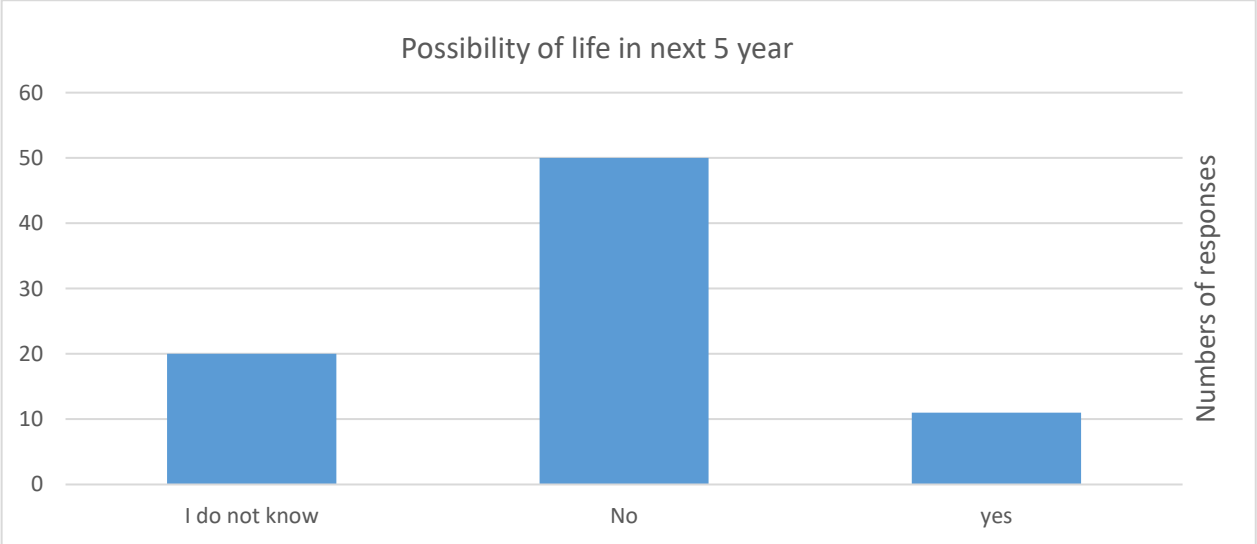

Figure 4: Residential response for possible life in next five years at this region

4. Discussion

The northern districts of Helmand Province have faced serious environmental and economic challenges as a result of poppy cultivation. Over the past two decades, poppy cultivation has played a fundamental role in land-cover change and the decline of groundwater levels. After 2000, farmers gradually began cultivating poppy in remote areas of Helmand, as these areas were outside of government control and farmers could grow poppy freely. As a result, agricultural land in these four districts increased from about 250 km² to 1,036 km², representing a very rapid land-cover transformation in a relatively short period of time. Mansfield (2020) also confirms that, because of the high economic returns from poppy, farmers continued expanding land for poppy cultivation. Since poppy cultivation requires large amounts of water, the number of deep wells increased in the region, and significant quantities of groundwater were used for poppy irrigation. Consequently, the groundwater level declined dramatically. This situation led to the drying up of karezes and a persistent shortage of water for agriculture (FAO, 2019). The expansion of poppy cultivation has contributed to land degradation

and the depletion of natural resources. Groundwater depletion has not only led to a reduction in agricultural land, but has also negatively affected the presence of trees, forests, wildlife and birds in the environment. Poppy cultivation provides short-term economic benefits for the region, but in the long term, the continued decline in groundwater and reduction in agricultural land has damaged people's livelihoods. The northern districts of Helmand are facing serious problems due to the adverse effects of poppy cultivation. Groundwater levels have dropped to dangerous levels and the available resources for agriculture have gradually diminished. Urgent measures are needed to implement sustainable agriculture and effective water management in order to ensure the economic and environmental sustainability of the region.

5. Conclusion

The findings of this study show that poppy cultivation has played a central role in the decline of groundwater levels and land-cover change in the northern districts of Helmand Province. Between 2000 and 2014, agricultural activities expanded rapidly due to the high economic value of poppy, and extensive desert areas were converted into agricultural land. During this period, the agricultural area increased from 285 km² to 1,036 km², which led to the drying up of karezes and encouraged the digging of deep wells due to the unprecedented extraction of groundwater.

After 2018, climate change and the continued depletion of groundwater resources became key factors in the reduction of agricultural activities. By 2023, the agricultural area had decreased to only 650 km², representing an average annual reduction of around 100 km². This situation was the result of poor water resource management and the high water requirements of poppy cultivation, which contributed to the decline in groundwater levels.

The survey of 81 residents of these districts reveals that most local people are facing serious water scarcity problems. Challenges in accessing water for both drinking and agricultural purposes have become widespread, and the extensive use of deep wells is causing damage to groundwater resources.

Overall, this study indicates that, despite the short-term economic benefits of poppy cultivation, it has created significant environmental and climatic problems, highlighting the urgent need for serious action to establish a sustainable agricultural system in the northern districts of Helmand.

Recommendations

In order to reduce water resource depletion and mitigate the negative impacts of poppy cultivation in the northern districts of Helmand, urgent measures are required for proper water management and the implementation of sustainable agricultural practices:

- The expansion of illegal cultivation must be controlled, and crops that require less water should be promoted in the region.
- New and modern irrigation systems should be introduced to prevent water loss.
- To prevent further decline in groundwater levels, the number of deep wells should be reduced and new, effective strategies for groundwater management should be developed.

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