



Impacts of Climate Change and Air Pollution on Agricultural Yield and the Water Cycle in Central Afghanistan

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ABSTRACT

Agricultural livelihoods in Afghanistan's central highlands are highly dependent on snowmelt and seasonal precipitation, rendering them acutely vulnerable to climatic variability and environmental stress. This study examines the combined effects of climate change and rural air pollution on water availability, agricultural productivity, and human capital in the snow- and rain-fed provinces of Daikundi, Bamyan, and Ghor. Existing research largely remains at the national scale and fails to capture how seasonal precipitation shifts interact with rural pollution sources to shape provincial-level agricultural and socio-economic outcomes. To address this gap, the study applies a qualitative synthesis of secondary data, integrating provincial climate indices, national precipitation trend analyses, hydrological observations of springs and kariz systems, agricultural yield studies, food security assessments, and socio-economic evidence within environmental production and human capital frameworks. The findings indicate that timing and variability risks, earlier snowmelt, declining winter–spring precipitation, and longer consecutive dry periods, now rival volumetric rainfall decline in constraining growing seasons, disrupting groundwater recharge, and reducing crop yields. Concurrently, chronic rural air pollution from biomass fuels, coal, and diesel-powered irrigation imposes cumulative burdens on crop photosynthesis, household health, and labor productivity, intensifying food insecurity, distress migration, and educational withdrawal. Together, these interacting pressures undermine environmental, social, and economic sustainability by accelerating groundwater depletion, widening inequality, and eroding human capital, highlighting the necessity of province-level climate governance, sustainable water management, and cleaner rural energy pathways to strengthen long-term resilience in Afghanistan's central highlands.

KEYWORDS: Climate change, Precipitation seasonality, Drought, Snowmelt timing, Springs (kariz), Groundwater depletion, Rural energy emissions, Food security

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1. INTRODUCTION

The Afghan central highlands constitute a tightly coupled climate–water–agriculture system in which even minor variations in temperature and the timing of precipitation can generate disproportionate impacts on local livelihoods. This system is defined by short growing seasons associated with high elevations and a pronounced dependence on winter snowfall and spring rainfall to sustain soil moisture, surface runoff, and the recharge of shallow aquifers. Agricultural practices in the region remain largely calibrated to historical hydrological norms, rendering them highly sensitive to climatic variability (Akhundzadah, 2024). The empirical challenge extends beyond assessing whether precipitation is changing at particular temporal or spatial scales over extended periods; rather, it concerns whether shifts in inter- and intra-seasonal patterns are undermining the viability of planting and irrigation

by eroding the climatic and hydrological conditions that support them. National-level studies consistently report warming trends exceeding the global average and an increasing frequency of drought events; however, such aggregate analyses obscure substantial provincial-level variability. The central highland provinces of Daikundi, Bamyan, and Ghor are characterized by exposure profiles that differ markedly from those of irrigated lowland regions, as snow-dominated hydrological processes constrain water availability, while geographic remoteness and seasonal road closures during winter snowfall severely limit market access (Shokory et al., 2023). As rain during winter–spring reduces, later shortfalls cannot make up for rain increases during summer–autumn since those months are climatologically dry and hydrologically ineffective to replenish aquifers. Further, minimum temperatures increased at a larger rate compared to maximal temperatures at selected provincial records to decrease the

temperature diurnal range and alter crop respiration. These characteristics are a sign that concerned risks are timing risk (earlier melt, later rains) and variance risk (extended dry periods and more variable wet days), and not merely trend risk.

Pollution is traditionally depicted as an urban phenomenon centered on Kabul's winter pollution. That narrative is inadequate to the current research question. At rural provincial scales, household energy and small-scale productive activities (heating, stoves and cooking, off-grid power generation, water lifts) cause particulate and gaseous emissions concentrated by valleys during temperature inversion-dominant months of cold weather. Absolute magnitudes are potentially lower than those at urban basins, but exposure is chronic and concentrated disproportionately indoors. Agriculturally, particulate deposition reduces photosynthetic efficiency by covering stomata and attenuating incident light; acidifying components can alter chemistry over time. From a laborer's standpoint, respiratory illness reduces peak-period work capacity when and where farm time is most valuable. The analytical case here is not some rural pollution that overwhelms revenue outcomes with yields; it is simply a constant, compounding burden upon a climatically sensitive system.

Food insecurity in the highlands exemplifies this connection. Agricultural and grazing shocks spread rapidly to local shortages due to distance and sparse markets. Household adjustments, dissaving, distress sales of animals, transient migration, and dropout of children from school buffer consumption in the short run while reducing future productive capacity. The channel through human capital is of prime importance: when farm wages fall, schooling is the first adjusting margin; health expenditure is postponed until illness is suffered. The result is an intertemporal transfer of climatic and environmental shocks to reduced future adaptive capacity. For already infrastructurally constrained provinces, these intertemporal transfers are tighter binding. The rationale for provincial-level analysis is therefore straightforward. Firstly, aggregation to national scales obfuscates variation in seasonally dominated hydrology and snow-fed hydrology determinative to the central highlands. Secondly, interaction amongst warming, timing of precipitation, groundwater abstractions, and rural domestic pollution has never been adequately evaluated at these provincial levels, while local evidence (summer desiccation of springs by early onset during summer; increased pump reliance; winter smoke exposure indoors) suggests cumulative effects. Thirdly, the institutional environment since 2021 has changed access to data and the potential set of adaptation measures to transfer responsibility further to provincial and community scales. This paper has three purposes.

The first is descriptive: to combine and align provincial data for temperature and precipitation trends and variability, hydrologic lag and timing, and agriculture exposure. The second is analytical: to decompose the interactions among and between climatic variables and source sectors of pollution into tractable pathways—soils and leaf-level photosynthesis; household health and work supply; equity and groundwater pumping—so that observed end states (crops, water disputes, schooling) can consistently be interpreted. The third is practical: to distill from the combination a parsimonious set of policy directions supportive of existing institutional capacity and minimizing timing and variance risk while engendering

neither unsustainable pumping nor extraction.

The paper organization reflects these goals. Section 2 reviews relevant literature with attention to (a) seasonal precipitation variations and extreme indices for Afghanistan, and (b) observed provincial signals for Daikundi, Bamyan, and Ghor; it further places rural air pollution in plant physiological and household health literatures. Section 3 describes the methodology approach with a qualitative combination of secondary sources aggregating and comparing climatic indices, precipitation trend analyses, hydrologic observations of springs and kariz, and socio-economic research. Section 4 shows findings through five interrelated lenses: climatic signals, farm yields, water cycle disturbances, paths to pollution, and socio-economic responses. Section 5 clarifies implications for provincial climatic administration, community water allocation, household and irrigation power, and education-protective safety nets. Section 6 concludes with limitations and priorities for measurement and evaluation.

Two clarifications bracket the scope. Firstly, the analysis neither offers new instrumental data nor synthesizes them synthetically; it combines provincial and national research with local accounts of observations when necessary. Precision is thereby constrained by data quality and granularity. Secondly, when we talk about pollution during this period, we are interested in typical rural sources and pathways for the central highlands and non-city-scale episodes; where there are empirical holes, the argument is limited to being conservative and mechanistic (i.e., deposition and health exposure pathways) and not inferentially expansive.

The reasoning is accordingly orderly: ground → province → system → governance. Ground-level data (e.g., springs running dry earlier; altered planting dates) are first compared with provincial climatic and hydrologic signals; provincial signals are then converted to system outcomes (crop yields and baseflow and household work and schooling); governance implications are finally derived and are feasible with current constraints. This sequence shields from over-generalization and aligns advice with realities actually perceived by farmers, canal user communities, and administrators at the local scale.

2. LITERATURE REVIEW

2.1 Climate Change and Agriculture in Comparative Perspective

Research from different regions shows that agriculture is intricately connected with climatic variability (Zuhara and Isaifan, 2018). The temperature and timing, and frequency of precipitation determine crop quality and yields, and water and erosion cycles. For South Asia, reduced and increasingly unpredictable rainfalls are predicted by the Intergovernmental Panel on Climate Change with enhanced frequency and severity, heatwaves, and drought. For rain-fed smallholders, their main risk is not only decreased total rainfall but volatility added to it. A delayed onset monsoon season or short growing season dry spell can be as damaging as a constant long-term decrease. Research also records indirect circuits: when farm revenues fall, household food and health care expenditure decline further, and education expenditure drops substantially. Thus, while shock to the climate may only damage one growing season's harvest, it can equally damage the long-term ability to sustain humankind.

2.2 Climatic Vulnerability

Afghanistan is climatically one of the world's most vulnerable countries (D'Souza, 2024). The temperature rose by an average of 1.8°C per year from 1950 to 2010, about twice the global average (Aliyar, 2024). The country has suffered consecutive droughts in 1998, 2008, 2018, 2021, and 2023, disrupting agriculture and displacing hundreds of thousands (Nabizada and Köylü, 2025). The Afghanistan Drought Risk

Management Strategy foresees by 2030 increasingly annually recurring droughts and warns of raised frequency and fortification by mid-century and beyond. 80 percent of Afghans rely directly on agriculture, livestock, and natural resources, further heightening exposure. Without crops or with dead animals, there are not enough alternative livelihoods. These national-level observations, although contextualized, are too general to explain how a region with a distinct geography, like the central highlands, is subjected to climatic pressure.

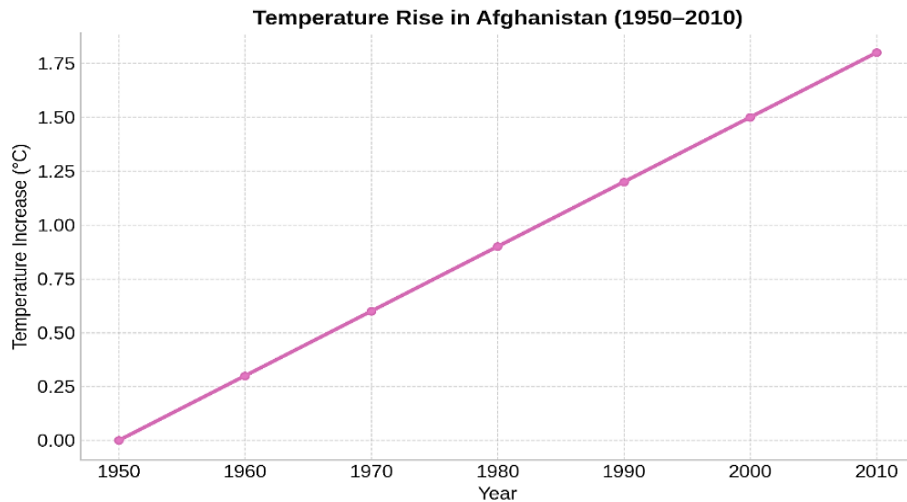


Fig. 1. Increase in average annual temperature in Afghanistan, 1950–2010. Source: UNEP (2017)

2.3 Precipitation Dynamics and Season

Precipitation is central to Afghan hydrology because irrigation is based mainly on snowmelt and rain and not on huge storage dams. National rainfalls are concentrated mainly during winter and spring, when precipitation is roughly 80 percent during those months (Suryavanshi et al., 2022). These months replenish aquifers, supply water to the kariz system, and are valuable for planting crops. There is documented loss of winter–spring precipitation during recent research, whereas summer and autumn see minimal gains (Suryavanshi et al., 2022). Yet, since these are mainly dry seasons themselves, these added volumes do nothing to compensate for losses earlier. Hydrologically, snowpack and prior snowmelt reduce the runoff season duration. Serial Mann–Kendall analyses confirm a reduction in rainfall during spring beginning from the early 1980s, and corresponding to when the large-scale drought peaked (Suryavanshi et al., 2022). Indices of extremes confirm that there is a tendency to dry: an increase in the number of consecutive dry days and a reduction in very wet ones (Suryavanshi et al., 2022). To agriculture, it means shortened growing seasons and later planting and crop failure with growing frequency.

2.4 Provincial Level Evidence: Daikundi, Bamyan, and Ghor

At the provincial level, research is limited but valuable. For Daikundi, analysis of climatic indices from 1986 to 2019 shows continuous warming. The minimum temperatures showed a higher rate of increase compared to the maximum temperatures and therefore reduced the diurnal range (Aliyar and Eltfs, 2021). This produces increased night-time plant respiration and reduces net photosynthesis. The precipitation showed local variability: some districts revealed constant levels while others illustrated constant reduction, like Kariz. The

farmers verify that springs lasting until summer are already drying up as early as June.

Bamyan is similar. Potato cultivation, being a main livelihood activity, is subject to diminished rainy seasons and an unreliable supply of water (Hasani and Shrestha, 2023). Minimized snowfall during winter decreases aquifer recharge, and rivers dry up earlier. Ghor is less studied but appears to show the highest variability with abrupt peaks during autumn rain (Suryavanshi et al., 2022). The autumn rains are, however, uniquely distributed in heavy pulses and thus induce floods and are not useful for recharge. In all three provinces, evidence points to diminished growing seasons, erratic irrigation, and shifts from valley-wide communal supply to individual extraction from groundwater.

2.5 Food Security and Socio-Economic Impacts

The food situation in Afghanistan has become critical. The Integrated Food Security Phase Classification has approximated that a third of Afghans suffered from acute food deficiencies during 2023 (Islam et al., 2022). Isolation and scarce infrastructure in central provinces complicate recovery further. The road closures during the winter months interrupt food transportation, and thus, if local crops fail, markets are not easily able to compensate.

The evidence links food insecurity to household allocation decisions about expenditure. The literature suggests that expenditure is reduced first on education when farm income falls, oftentimes by de-enrolling children to save on fees or to access labor (Mohammadinia, 2023). Health expenditure is reduced later, only when illness is severe. This strategy is destructive to long-term capacity. Malnutrition reduces work productivity, weakens immune systems, and increases health

demands. This evidence thus suggests a reinforcing cycle: climatic shocks reduce food and income, reducing education and health, and thus reduce adaptational capacity in the future.

2.6 Rural Pollution Sources

Most of the literature on Afghan air pollution is focused on Kabul and other cities, with apparent smog being produced by the combustion of coal, traffic jams, and industry. However, rural areas are not excluded. In Daikundi, Bamyán, and Ghor states, residential sectors are significant consumers of biomass fuels such as wood, dung, and crop residues, and coal and kerosene are being consumed as well. Power generation using diesel generators and water-pumping are common practices. Small brick kilns are also present in some districts. These practices emit fine particulates, Sulphur dioxide, nitrogen oxide emissions, and black carbon emissions (Islam et al., 2022).

Even with sparse data, likely effects are apparent from studies in similar circumstances. The particulate matter falls upon leaves and reduces photosynthesis. The acidic deposition can change the soil's chemistry. Smoke exposure is a leading threat to respiratory disease inside buildings, and it is especially true for women and children who are inside for a larger proportion of time when stoves are burning. Health outcomes reduce work productivity during the growing season and increase medical bills. Animals exposed to the same air show compromised health and productivity. The research literature has yet to rigorously analyze rural Afghan pollution.

2.7 Climate and Disease

Another research area is evaluating how climate change alters disease risk. Warmer temperatures and varied rainfalls enlarge the range of vectors, such as mosquitoes and ticks (Samadi, 2024). Malaria and leishmaniasis, diseases once restricted to lowlands, are being discovered in highland areas. Other illnesses, such as Rift Valley fever and lumpy skin disease among cattle, are equally vulnerable to hotter and rainier temperatures. These health stresses are coupled with malnutrition and pollution exposure to contribute to vulnerability in rural states with scarce clinics and veterinary services.

2.8 Governance and Institutional Context

Environmental stresses are present amidst a weak governance system. National climate institutions, such as the National Water Affairs Regulation Authority, established during the 2021 political change, were dismantled (D'Souza, 2024). The global community left Afghanistan out of international climate finance and left it out of United Nations climate process membership. The technical staff left, and the remaining agencies lost resources and authority. At the provincial level, community institutions such as shuras still manage water allocation but struggle to adapt to situations of scarcity. Disputes over springs and kariz are growing increasingly frequent, and customary regulations based on ordinary flows are hard to adapt to sporadic supply. Donor-driven initiatives exist, but with restricted coverage and consistency.

2.9 Research Gaps

The published work provides a reasonable base for describing Afghan vulnerability to its climate, but it has two main omissions. Firstly, all but a very few are national or provincial-level studies. They define composite-scale warming

and drying, but never break out Daikundi's, Bamyán's, and Ghor's distinct seasonal and hydrological regimes. Secondly, whilst there is general acknowledgement of air pollution as a key health issue all over urban Afghanistan, there is hardly any empirical investigation of rural sources and their hydrological and agricultural implications. The combined implication of pollution and climate stress at the rural highland provincial scale is virtually missing from published research.

This study aspires to bridge those gaps. Centered on main provinces, it integrates climate indices, precipitation trend analyses, hydro-social studies, and socio-economic evidence to synthesize a provincial profile. The intention is neither to generalize nor to promote but to elucidate the exact mechanism through which warming, seasonally altering precipitation, and rural pollution affect agriculture, water supply, and human capital individually and cumulatively.

3. METHODOLOGY

3.1 Research Design

This research is premised on a qualitative synthesis of secondary data. In the absence of granular direct field data from Daikundi, Bamyán, and Ghor, a range of types of sources are assembled to form a holistic picture of the combined effects of climate and pollution. Instead of making the new measurements, the goal is to bring the various studies that have been conducted into a comparable accord with one another so that climatic signals, hydrological implications, agricultural impacts, and social responses can all be analyzed comparatively. The approach thus becomes case-intensive: the provinces are considered case sites of the intersection of large-scale climatic phenomena and locally specific socio-economic and environmental conditions.

The methodology is, by design, integrative. Hydro-social examinations of springs, kariz, and precipitation trends and climate indices are presented side-by-side with hydrological assessments and food security analysis. These are further interwoven with socio-economic assessments of household health, education, and income. By interweaving these, the approach is trying to work from household-level outcomes back to their source in variables like pollution and climate.

3.2 Data Sources

This study draws on five interrelated categories of data. Climatic and precipitation data include provincial climate indices for Daikundi covering the period 1986–2019, national precipitation trends from 1979 to 2013 with provincial disaggregation, and peer-reviewed analyses of extreme climate indicators such as consecutive dry days and rainfall intensity. Hydrological observations are derived from studies documenting the loss of springs and kariz systems in Daikundi Province, research on groundwater abstraction using diesel- and solar-powered pumps, and national water resource assessments with provincial-level observations. Agricultural and food security analyses rely on Integrated Phase Classification (IPC) reports, peer-reviewed drought studies on wheat, potato, and orchard productivity, and assessments of animal health and pasture degradation during drought years. Socio-economic and human capital evidence includes studies examining interactions between farm income and household expenditure on education and healthcare, migration and coping responses to climatic shocks, and analyses of malnutrition and its impacts on health and labor capacity.

Finally, governance and institutional evaluations draw on post-2021 institutional reform records, including the dissolution of the National Water Affairs Regulation Authority, alongside studies of community-based water management structures (*shura*) and provincial evaluations of non-governmental and donor interventions. Together, these sources enable a multidimensional synthesis, where provincial data are unavailable, national-level evidence is used cautiously, with underlying assumptions stated explicitly.

3.3 Analytical

The Theory of Change supporting the system presents a chain of causations, where:

Climatic Factors (temp, precipitation, extremes) → Hydrological Alteration (snowpack, runoff, groundwater recharge) → Agricultural Impacts (crop yields, livestock, soils) → Socio-Economic Impacts (food security, education, migration, health).

It also includes pollution as a cross-cutting stressor with agricultural and human health consequences:

Sources of Pollution (biomass, diesel, coal, kilns) → Ecological Impacts (leaf fall, chemistry of soils, water pollution) → Human Health (pulmonary disease, reduced work productivity).

The work is rooted in two traditions of theoretical work:

Environmental Production Theory, by virtue of which temperature, rainfall, and the quality of soils are linked with the yields of crops. This forms a basis for the linkage of climatic variables to farm outcomes.

Human Capital Theory explains why income shocks affect household investment in education and health. This serves to discuss how agricultural decline has implications for long-term capacity loss. Theoretical application is pragmatic. It provides structure to bring in supporting evidence, but it is never a substitute for empirical detail.

3.4 Scope and Limitations

The methodology has three main drawbacks: Primarily, it is limited to secondary data. No new field work was undertaken, so analysis depends on the quality of past research. There is scant data at the provincial levels and national means, which tend to obscure local differences. The synthesis is diligent about noting this shortfall and is cautious about asserting anything beyond evidence at hand.

Second, data for rural Afghan pollution are scarce. Direct measurements for particulate matter and deposition are essentially nonexistent for Daikundi, Bamyān, and Ghor. As a result, the discussion is based on wider data for biomass and diesel emissions and similar studies elsewhere. The discussion is wary in its conclusions and describes probable pathways without hyperbole.

Third, institutional and governance processes are fluid. Since 2021, formal institutions have changed quickly, and information access has reduced. NGOs' reports and research at community levels are thus relied upon to supplement official records.

3.5 Ethical

As this study does not involve primary field research with human participants, ethical considerations focus on the responsible representation of issues affecting vulnerable

populations. Evidence management is guided by two core principles: transparency and responsibility. Transparency requires that data limitations be explicitly acknowledged to avoid overstating the conclusiveness of findings. Responsibility entails framing interpretations and conclusions with careful consideration of the lived realities of rural households, while avoiding normative or externally imposed judgments.

4. FINDINGS AND DISCUSSION

The findings are organized into five thematic sections: climate signals, agricultural yields, water cycle disruptions, pollution processes, and socio-economic consequences. Each section begins with evidence at the provincial level and subsequently examines its implications for institutional responses and household-level outcomes. The discussion emphasizes convergence across multiple data sources while explicitly acknowledging areas where measurement constraints limit the strength of inference.

4.1 Climatic

4.1.1 Rising Temperatures and Narrowing Diurnal

Temperature records from Daikundi indicate a positive temperature trend from 1986 to 2019. Notably, minimum (night) temperatures are warming up faster than the maximum ones, and hence narrowing the diurnal range (Aliyar 2024; Aliyar and Eltfs 2021). It is not just a technicality; warmer nights increase plant respiration and thereby reduce net energy available to boost growth. At those higher elevation areas where crops already have limited growing periods, it further compresses productivity.

National data support this trend and have also identified an increase in the extremes of hot spells. The interior high plateaus continue to see fewer extremely warm days than desert zones by a shrinking margin. The warming trend, however, is increasing evapotranspiration and promoting earlier onset of drying soils and higher irrigation demand.

4.1.2 Decreasing Precipitation

Afghanistan receives 300 mm of precipitation annually, with the winter and spring months accounting for about 80%, vital for snow-pack building and spring run-off (Suryavanshi et al., 2022). However, records indicate that there has been a consistent decline during winter and autumn at Daikundi and Bamyān, whereas at Ghor, it has shown a more variable trend (Suryavanshi et al., 2022). Summer and autumn months contribute little to no rain, and it is primarily a season with very little precipitation, so it makes a marginal contribution to groundwater recharge.

Climate indices corroborate this trend: the number of consecutive dry days is increasing, and the occurrence of extremely wet days is decreasing (Suryavanshi et al., 2022). For farmers, this translates to progressively less reliable planting windows and ever greater uncertainty over when they can harvest.

4.1.3 Earlier Snowmelt and Decreased Runoff

Observations from the central high country indicate earlier timing of snowmelt and shorter periods of runoff throughout the year (Hunt et al., 2025). Springs that used to run during parts of the late summer are drying up by early June. This not only shrinks the water supply during peak irrigating season but also further truncates the already-constrained growing season.

Fast snowmelt further increases the risk of flash floods when heavy precipitation coincides with accelerated snowmelt.

Implication:

The challenge is not adequately captured by changes in average precipitation alone, as total rainfall in key regions has not exhibited uniform or monotonic decline. Rather, the primary concern lies in shifts in precipitation timing and increased variability. Delayed snowmelt and autumn rainfall generate seasonal water deficits, disrupt established cropping calendars, and undermine the stability and predictability of agricultural yields.

4.2 Agricultural Outcomes

4.2.1 Wheat and Staple

Wheat remains the region’s principal staple crop. During drought years, notably 2018 and 2021, national wheat production declined by approximately 20–30%, with substantially larger yield reductions observed in high-altitude provinces (Nabizada and Köylü 2025). In Daikundi Province, reduced frequency of spring rainfall adversely affected crop

germination, resulting in lower overall yields. Additionally, a shortened growing season compelled farmers to harvest earlier than optimal, further exacerbating yield losses.

4.2.2 Potatoes and Horticulture

Potato growing is predominant at rural livelihood levels in Bamyan province. The crops rely greatly on consistent spring rain and hot summers. However, erratic rainfalls and hot summers have compromised yields (Hasani and Shrestha 2023). The farmers bemoan smaller potatoes and decreasing market prices. The fruit orchards, particularly apple and apricot, also face increasing threats. Early flowering with later frosts has brought perennial losses during recent years.

4.2.3 Soil Degradation and Erosion

Dried-out vegetation covers leaves soils vulnerable to erosion. The loss of topsoil reduces fertility, limits water intake, and accelerates run-off. In Daikundi, it has paralleled diminishing spring run-off water. To make up for it, some farmers have further added similarly vulnerable marginal lands to cultivation, unwittingly increasing erosion risks yet further.

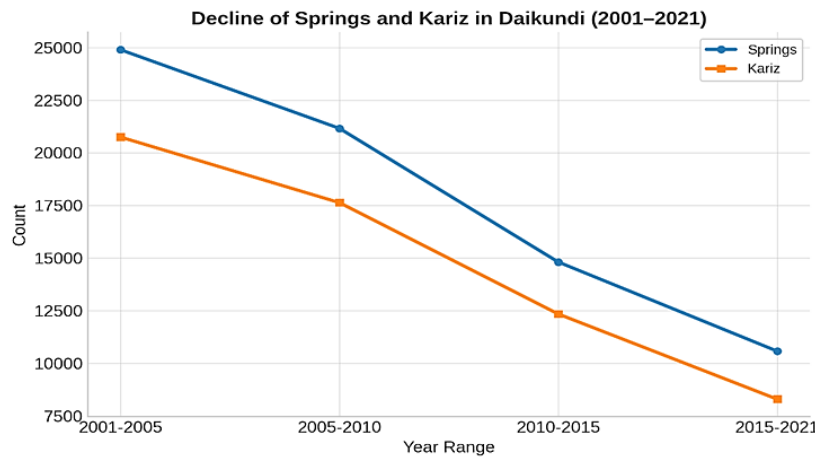


Fig. 2. Decline in the number of active springs and kariz systems in Daikundi, 2001–2021. (Heinrich Böll Foundation, October 2023)

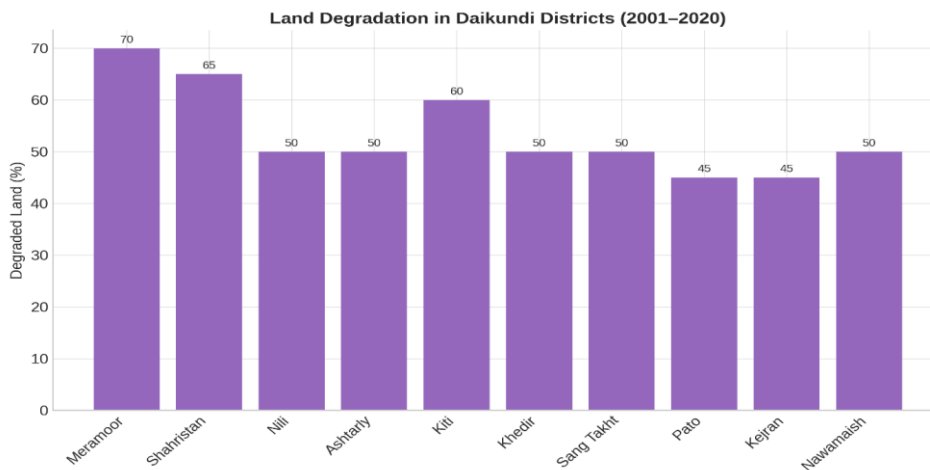


Fig. 3. Percentage of degraded land across Daikundi districts, 2001–2020. Source: Department of Agriculture, Daikundi (2020)

4.2.4 Animals and Livestock

These are crucial household assets that bring food and income to families. As drought reduces pastureland, animals earn less and die at increasing rates. For most families, losing livestock is

a fall into further poverty because animals are nutritional and a financial cushion all at once. As well, global warming has brought vector-borne diseases to new regions, and this puts further strain on animal health (Samadi, 2024). The rural sector

in the central provinces faces multiple, mutually reinforcing risks. Short planting windows, limited irrigation infrastructure, and a high dependence on rainfall collectively heighten systemic vulnerability. Climate change exacerbates this exposure by reducing agricultural yields both directly, through diminished and less reliable precipitation, and indirectly, through the degradation of pastures and marginal lands. As a result, rural livelihoods are increasingly subject to cumulative and compounding shocks.

4.3 Water Cycle Disruptions

4.3.1 Springs

For conventional water distributions, springs and kariz, recharge is through slow snowmelt and rainwater. As rainfall is getting smaller and snowmelt occurs earlier in the year, these

distributions are running out earlier. The majority of its kariz fail by early summer when communities are already using alternative water sources.

4.3.2 Groundwater Extraction

With diminishing shallow sources, societies are increasingly dependent upon groundwater pumps. Both diesel and solar sets are being increasingly used. They are only temporary but never sustainable relief measures. Deep aquifers are expensive and slow to replenish. Pumping is only affordable by richer families, while being out of reach for poor ones, with a resultant unequal access to water (Aliyar et al., 2024). Inaction cumulatively reduces baseflow to rivers and prolongs water shortage further.

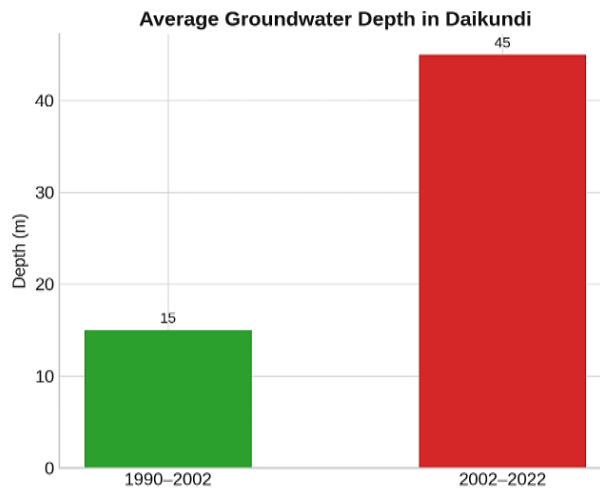


Fig. 4. Average depth of groundwater access in Daikundi, showing depletion trends. (Heinrich Böll Foundation, October 2023)

4.3.3 Irrigation Infrastructure

Only one-third of the irrigable land is actually being utilized, primarily owing to insufficient infrastructure. For Ghor and Bamyan, irrigation is mainly through the surface system, but with significant loss through seepage and evaporation. Limited investment is made towards newer techniques, so irrigation is still wasteful, aggravating the consequences of diminished rainfall.

4.3.4 Conflict and Social Stress

Water tensions are commonly escalated during midsummer when flows are at a minimum. Allocation schemes at initial stages were designed during spells of relative abundance and not scarcity. As water scarcities are further ingrained, disputes intensify and at times turn violent. Children and women, commonly entrusted with water fetching, are worse affected by this pressure and are often made to walk further to find water. Changed hydrology has weakened communal arrangements and pushed water access towards individual solutions. Unless collective management can be revived, inequity and groundwater depletion will likely worsen.

4.4 Pollution Dynamics

4.4.1 Household Energy and Generators

Biomass, coal, and kerosene are the most common rural fuels for space heating and cooking, while diesel generators are used for lights and to power water pumps. These dirty fuels emit

particulates and carbon monoxide when burned and are therefore implicated in both environmental and air degradation.

4.4.2 Effects on Crops and Soil

These particles drop onto crop leaves to block light and reduce photosynthesis. At the same time, acidic particles alter soil chemistry. Though there are no exact data for Afghanistan, studies from similar circumstances confirm significant losses of crop yields. Even marginal losses can greatly impact small-scale farmers with thin margins.

4.4.3 Effects on Health and Labor

Indoor smoke is a major cause of respiratory disease, and it disproportionately harms women and children who are closer to and spend more time around the cooking fires. The illnesses reduce work availability during peak farm seasons for households and increase healthcare costs. Animals are equally affected as they inhale the same fumes, and it harms their performance. Pollution is an ever-present chronic strain on farm livelihoods and household well-being. Though it is less dramatic than a drought, it always erodes resilience and limits communities and families' ability to adapt.

4.5 Socioeconomic Impacts

4.5.1 Food Insecurity

Ongoing dry spells and withering crops have increased hunger.

From 2021 until 2023, when the situation became less severe, a third of Afghans endured acute deficiencies. Isolation alone worsens this situation in central highland states. The winter road closures limit access to the marketplace and render homesteads reliant upon whatever is locally farmable by them.

4.5.2 Migration

To manage, families export members to Iran or Pakistan to work during the seasons. The migrants earn and remit money back home, but at a cost of separation and less availability to work at home. Sanctions and tighter border restrictions further render remittances unreliable. Within the country, migration puts a further burden on host communities and taxes their already scarce resources.

4.5.3 Education and Human Capital

As agricultural incomes fall, households start by cutting education spending before health. Children leave school, either to save money or to give a helping hand at home. Human capital is eroded, undermining the long-term resilience of the community to future shocks.

4.5.4 Health Burdens

Pollution and climate change also increase disease risk (Isaifan 2023; Isaifan and Al-Thani 2024; Mahmoud et al., 2023). Vector-transmitted diseases like malaria and leishmaniasis are expanding their range out of areas that were once too cold to support them. This is also compounded by malnutrition and respiratory diseases, which all impact productivity and deepen poverty traps.

Implication:

The most direct effect of pollution and climate change happens at the household level - through food insecurity, lost income, illness, and missed schooling. The result is not only immediate impoverishment, but also a longer-term erosion of families' ability to recover and adapt.

4.6 Governance and Institutional Capacity

The fall of the Republic in 2021 significantly weakened Afghanistan's national climate institutions. International climate finance and technical support are no longer accessible. Provincial-level governments do not have the financial means to compensate, and NGOs are tightly controlled. Local water distribution is still organized by community shuras, but the increasing scarcity has been stretching their capacity. Traditional coping mechanisms are hard to uphold despite being resilient in the past, as situations are changing more rapidly now.

Policy interventions have traditionally centered only on municipal policy and metropolitan pollution, neglecting rural areas. That neglect has widened the urban-rural divide and exacerbated the vulnerability of rural regions. Governance has emerged as the most constrained resource. Adaptation to climate change cannot be scaled effectively without localized planning, reliable data collection, and community support.

5. DISCUSSION

The evidence suggests a double burden in the central highlands. The impact of climate change, and less water when it is needed most, conspicuously coincides with the impact of pollution when families are depending on energy resources to light and heat their homes. One stress compounds the other.

For instance, earlier snowmelts translate into less water, which leads families to use diesel-fueled pumps. This means more pollution in the atmosphere. A return to biomass in winter for burning to heat homes may be welcomed, but it is unhealthy and decreases productivity. Each coping mechanism is a trade-off, alleviating one stress, even as it deepens another.

What is striking in the data is this: variability and seasonality matter as much as aggregate reduction. Runoff and late rains are sophisticated; they cause seasonal gaps in water availability that can't be offset by more pumping without over-exploiting groundwater reserves over time. Pollution is no substitute for climate stress; it multiplies it, reducing farm and work productivity. And when education is affected and health compromised, it is a long-term loss of human potential, paid for by future generations.

6. POLICY RECOMMENDATIONS

The high central provinces (Daikundi, Bamyan, and Ghor) share two problems that overlap: rural pollution and climate change. Solutions to both can be designed based on provincial experience, commensurate with existing institutional capacity, and grounded at the provincial level. The following are not exhaustive or prescriptive but highlight operational evidence-based entry points for change.

6.1 Improving Provincial-level Climate Governance

National water and climate agencies' capacities have dramatically reduced since 2021. This adjustment makes provincial governance more imperative than ever before. Having miniature functional units for water and climate at provincial levels would facilitate coordinating planning at local levels with data collection and information dissemination.

Even small-scale, localized observations of rain, temperature, and groundwater would assist. Regular bulletins, seasoned to suit the growing calendar, would inform farmers about prospects for future water and planting and maintain well-informed decisions.

6.2 Community-Led Water

The previous allocation regimes presupposed sound hydrology, a situation increasingly contestable. These statutorily based regulations are now subject to reappraisal.

Community shuras can be helped to adopt rotational access, water allocation measures, and rural processes for conflict resolution to reflect the scarcity of today. Efficiencies can be achieved with minimal investment in lined canals, water storage ponds, and moisture retention in soil. Restoration of the kariz water supply by collective maintenance can permit cheap irrigation, especially for poor farmers.

6.3 Reducing Pollution and Improving Energy Efficiency

Though rural families will still rely on biomass and coal, selective improvement can significantly reduce harm. Promoting proper ventilation, using proper insulation, and keeping clean cookstoves would significantly reduce atmospheric pollution indoors (Al-Qahtani, Koç, and Isaifan 2023). For agriculture, enhanced water scheduling and drip irrigation can reduce excessive pumping.

To prevent over-extraction of groundwater, with the adoption of solar-powered pumps, community ordinances or regulations are needed (Hassab et al., 2025; Melhim and Isaifan,

2025). Village-level cooperatives or energy programs can help spread out expenses and reduce dependency on diesel generators as well.

6.4 Health Protection and Education Support

The provincial health infrastructure is weak, yet it still can benefit from small-scale targeted initiatives. Health facilities at local levels can be equipped with minimal protocols to manage respiratory disease and health risks posed by pollution. Information campaigns through schools or community organizations can educate families regarding ventilation, cleaner fuels, and safe drinking water practices.

Above all else, social protection initiatives need to secure children's education during times of crisis. Conditional cash transfer schemes or community employment initiatives retaining children at school amidst farm sector losses would avoid long-term losses of human capital.

6.5 Filling Data and Evidence Gaps

Climate change adaptation plans are limited by a lack of reliable data. Investment in cheap, non-high-tech rain, air-quality, and groundwater sensors can provide the requisite information. But data should not remain centralized; there has to be open sharing at community and district-level offices and at community events in user-friendly formats. Local university and non-government organization collaborations can further help provincial capacity to interpret and make effective use of data. Without trustworthy information, policy will never be proactive but only reactive.

7. CONCLUSION

The Afghan central highlands are controlled by the snow and spring rain cycle. The cycle is unreliable today. Warming has shortened growing seasons, cracked snowpack, and altered runoff at earlier points in the season. Air pollution is less perceptible at rural locations compared to Kabul, but quietly reduces crop yields and damages household health. These combined drivers undermine Daikundi, Bamyan, and Ghor agriculture, water security, and human capital. The evidence reveals three enduring trends. Firstly, timing is as crucial as volume. The snowmelt advance and rain delay allow holes to lie mostly intact to an extent that no average precipitation can fill. Secondly, extraction is a stopgap at a long-run cost. Pumps

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secure one crop but reduce groundwater and increase inequality amongst families. Thirdly, pollution is a steady tax. It reduces farm productivity by a marginal quantity, reduces labor productivity, and increases health costs disproportionately, especially for women and children. These trends meet at the household level. As a result of crop failure, food insecurity grows. The household responds by cutting education first and health second, and by allowing household members to migrate. The effect is an actual shortage and long-term loss of human capital. In the long term, it reduces household and community capacity to absorb subsequent shocks. The problem is environmental as well as social and institutional.

The capacity for governance is the most restricted resource today. National institutions are worn thin, and access to international finance has narrowed. Provincial governments and community organizations are indeed mainly responsible. The task is difficult but not impossible. Incremental steps – improved monitoring, less profligate irrigation, cleaner household energy, and insulation of schools in dry periods – can make a difference. They would not eliminate vulnerability nor fundamentally shift priorities, but can slow capacity erosion and protect the future. The input to research is in recasting the problem at a provincial scale. The national level masks the varied pressures on the central high plateaus. The novel combination of climate indices, precipitation studies, hydrological data, and socio-economic information here is used to uncover how the provinces of Daikundi, Bamyan, and Ghor experience the interaction between climate and pollution. The analysis is constrained by data gaps, particularly around rural pollution levels and groundwater trends. The pointers to future research are to gather local data that can help inform adaptation actions with greater precision. The provincial capitals are thus far from peripheral. They are the places that mirror the rural Afghan reality in which livelihoods are still based on agriculture and natural watersheds. It is thus vital to any national and international effort to build resilience to have an understanding of the climatic and pollution pressures they face. There is evidence to report that adaptation is still possible if the provincial administration, community management, and basic services are strengthened. Without those efforts, the combined effect of climate change and pollution will further erode agriculture, further deepen food insecurity, and devastate human capital over later generations.

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