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Irrigation Water Stress, Gender Roles and Migration in Khageri Irrigation System, Chitwan, Nepal

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Abstract

Irrigation water stress, climate variability, migration, and gender transformation are increasingly shaping rural agricultural systems in Nepal. This paper analyzed the relationships between irrigation water stress, household migration and the changing gender roles in Khageri Irrigation system of Chitwan, Nepal. The study employs interdisciplinary methodology that uses Cropwat8.0 to quantify irrigation water stress in khageri irrigation command area and SPSS for statistical analysis. A household survey of 210 agricultural households was used to gather primary data, which was supported by 6 KIIs and 7 FGD. The Secondary data, including records from the Department of Hydrology and Meteorology and irrigation projects, were used to assess the hydroclimatic trends and irrigation performance. The analysis of quantitative data was performed with descriptive statistics, paired sample t -tests, chi-square analysis, and correlation analysis in SPSS, whereas the qualitative data were interpreted with the help of the thematic analysis. The findings indicate major hydro-climatic shifts in the research site. The water level in canal drops to zero during critical crop growth period in dry seasons and this indicates an increased irrigation stress and agricultural vulnerability in study area. Deterioration in farm earnings is also experienced over time, which is a result of growing economic strains on the farming families. Migration is usually common but statistical analysis reveals that there is no significant direct relation between irrigation failure and migration decisions. Rather, migration is primarily driven by broader economic factors such as employment opportunities. The study also finds significant transformation in gender roles after male migration. Male out-migration has increased the labor burden to women's, leading to the feminization of agriculture. The results of the research show that climate- resilient irrigation management, gender-inclusive water governance, and livelihood diversification strategies need to be employed to increase rural resilience in response to environmental change and socio-economic change.

Keywords: *Irrigation water stress, Irrigation Water Requirement, Migration, Gendered Role*

Introduction

Agricultural productivity depends more on irrigation particularly in country like Nepal where water management is very critical to the food security. Climate variability poses a significant challenge to Nepal's agricultural sector, particularly in places like Chitwan, where farming households rely heavily on consistent irrigation for crop production. Irregular rainfall patterns and shortened monsoon seasons have intensified irrigation water stress, leading to declining yields and shifts from traditional rice-wheat cropping systems toward more diversified patterns such as rice-vegetable-maize (Kandel et al., 2023; Solomon et al., 2024). Crop yields are lowered by hydrologic stressors which causes more men to migrate abroad in quest of better employment opportunities. As a result, even while total farm output is still falling, women are left to take on a greater portion of agricultural duties. This trend causes women to take on a greater share of agricultural responsibilities, extending their working hours and greatly increasing their overall workload (Gautam, 2017; Arslan et al., 2021). This study addresses these gaps by integrating climate data, validated irrigation assessments, and gender-focused analyses to develop climate-resilient water governance strategies that promote socio-economic stability, gender inclusive water governance and align with Sustainable Development Goal 5 on gender equality (Bhadra and Neupane, 2021; Kandel et al., 2023).

Literature Review

Table 1: Literature Review

Author (Year)	Study Area & Data	Methodology	Key Findings	Relevance to This Research
Bista et al. (2024)	Small cities, Nepal; household water deficit survey	Econometric welfare analysis	Water stress significantly reduces household welfare, increases coping burden	Provides empirical evidence that water scarcity directly affects livelihoods, justifying irrigation migration linkage
Solomon et al. (2024)	Nepal, India, Bangladesh; panel household data	Econometric modeling	Climate risks trigger circular migration as a risk-management strategy	Supports your argument that migration is an adaptation to climate and irrigation stress
Kandel et al. (2023)	Nepal agro-ecological zones	Multivariate regression	Social groups and agro-ecology determine climate resilience	Supports differentiated vulnerability across caste, gender, and geography
Arslan et al. (2021)	Nepal; national climate & migration data	Structural econometric model	Climate shocks reduce agricultural income and increase migration	Confirms irrigation failure → income shock → migration pathway
Baral (2025)	Nepal; time-series climate data	ARDL econometric model	Rainfall and temperature shocks significantly raise out-migration	Supports your climate-driven migration hypothesis
Epstein et al. (2022)	Chitwan & Terai Nepal	Longitudinal demographic data	Drought increases male temporary migration	Directly validates the Khageri-region drought–migration relationship
Maharjan et al. (2020)	Gandaki Basin, Nepal	GIS + land-use modeling	Out-migration leads to land abandonment and farming decline	Supports migration impacts on agricultural systems
Southard & Randell (2022)	South Asia	Feminization of agriculture analysis	Male migration increases women's farm labor and stress	Provides theoretical basis for feminization of agriculture in Khageri
Paudyal et al. (2019)	Nepal national policies	Policy analysis	Gender poorly integrated into climate & agriculture policy	Justifies need for gender responsive irrigation governance
Shrestha et al. (2024)	Khageri system	Benchmarking study	Canal capacity exists but service delivery is weak and unequal	Provides technical validation for irrigation stress in Khageri

Methodology

Study Area

The study area comprised selected branch canals of khageri irrigation system in Chitwan, Nepal i.e. Branch Canal 1, Branch Canal 6 and Branch Canal 8. Khageri irrigation system is one of the oldest gravity irrigation systems, serving about 3,900 ha of agricultural land. Despite its importance for agricultural production, the system faces challenges related to infrastructure, management, and equitable water distribution (Bhatta et al., 2006). The location map and network of canals are shown in Figure 1.

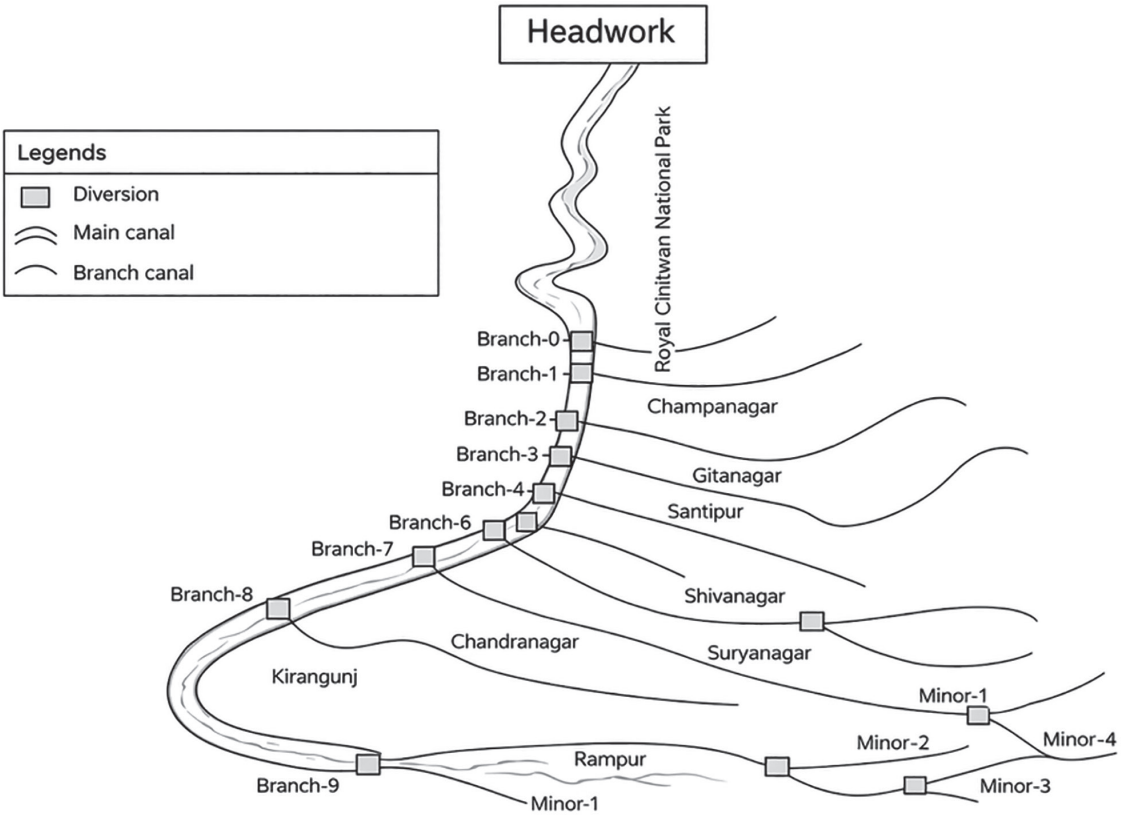

Figure 1: Schematic Diagram of an Irrigation Canal Network

Research Methodology

A mixed method approach was adopted to examine the relationship among irrigation water stress, migration and gender roles

QUANTATIVE COMPONENT
Analysis of irrigation water availability, crop water requirement, and households-level socio-economics and gender roles

QUALITATIVE COMPONENT
Exploration of lived experiences, institutional perspectives and gendered impacts through interview and focus group discussion

INTEGRATED APPROACH
Provide a comprehensive understanding of both biophysical (water, climate, crop) and social (institutional, gender, migration) dimension of irrigation related stress

DATA SOURCES AND COLLECTION METHODS	
PRIMARY DATA	**SECONDARY DATA**
Household Survey (n=210) Semi-structured questionnaire on Irrigation access, crop production, migration status, income sources, and gender roles	Department of Hydrology and Meteorology (DHM), Nepal Climate data: Rainfall, temperature, wind speed, humidity, sunshine hours
Key Informant Interviews (n=6) Officials from Khageri WUA and irrigation authorities on Institutional arrangements, water distribution, and governance challenges	Central Bureau of Statistics (CBS), Nepal Socio-economics and demographics data
Focus Group Discussion (n=7) Farmers (men and women) in head and tail sections of the canal system irrigation reliability, labor division, migration impacts, and adaptation	Khageri Irrigation Project and Water Users Association Records Irrigation records, water distribution data, project documents
Field observation Observed canal conditions, cropping patterns, irrigation practices, and visible gender roles in agricultural activities	Published Articles, Reports and Literature Studies on irrigation, climate change, gender, and migration in Nepal

DATA ANALYSIS		
QUANATATIVE ANALYSIS Software: SPSS	**CROP WATER ANALYSIS** Used to estimate crop water requirements and irrigation demands	**QUALAITATIVE ANALYSIS** Data from KIIs and FGDs were analyzed using thematic analysis:
Descriptive statistics (mean, frequency, percentage, standerdeviation)	FAO Penman-Monteith method for reference evapotranspiration (ET_o)	Irrigation water scarcity and distribution inequality
Paired sample t-test (changes in gender roles and workload before and after male migration)	Crop Evapotranspiration (ET_c) $ET_c = K_c * ET_o$	Migration drivers and livelihood adaptation
Chi-square tests (association between irrigation water stress and migration decisions)	Irrigation Water Requirement (IWR) IWR = ET_c-Effective Rainfall (Pe)	Changes in gender roles and feminization of agriculture
Correlation analysis (relationship among irrigation reliability, income, and migration)	Climate inputs, rainfall, temperature, humidity, wind speed, sunshine hours	Institutional and governance challenges in irrigation management
	Outputs: seasonal and monthly irrigation deficits	

Sample Size

A semi-structured household questionnaire survey was conducted to measure the socio-economic impacts of irrigation. The survey included both closed-ended and open-ended questions. The sample size for this study was determined using the following formulas:

$$n_o = \frac{Z^2 * p * q}{e^2} \quad (1)$$

Where, z = 1.96 (Corresponding to a 95% confidence level), p = 0.5 (Estimated proportion of the population), q = 1 - p = 0.5, e = 0.05 (Margin of error at 5%).

Table 2: Sample Size Distribution on Each Branches

Branches	Household Size	Sample Size
Branch 1	483 (Shrestha, Awasthi and Bohara, 2024)	122
Branch 6(W)	365 KII	92
Branch 8	296 (Shrestha, Awasthi and Bohara, 2024)	75
Total	1144	289

Result and Discussion

Rainfall Trend Analysis

Rainfall trend analysis of Jhuwani station between the years 1995-2025 reveals that there is moderate inter-annual variation in the annual precipitation. The Mann-Kendall statistic indicates that there is negative trend ($\tau = -0.209$) with Sen slope of -13.40 mm/year and this indicates that there is a mild declining trend in annual rainfall which is shown in Figure 2. This result is consistent with(Basnet et al., n.d.)findings in Kaski District and other regions in Nepal, where researchers have reported that there is reduced yearly precipitation alongside significant seasonal fluctuation. The seasonal analysis reveals that rainfall in the study region is highly monsoon-dominated, where the monsoon months (June-September) receive about 80.7% of the annual precipitation, which is in agreement (Karki et al., 2017)who said that the weather patterns of precipitation extremes in Nepal are predominantly monsoon driven with much of the yearly precipitation recorded in the monsoon months. Analysis of extreme rainfall revealed that 2007 was the only year when the highest rainfall was recorded (2938.7 mm) and 2023 was the only year when rainfall was the lowest (1421.05 mm) indicating that there were considerable inter-annual differences in rainfalls. These changes could have a significant impact on irrigation management, agricultural output, and water resource planning in the region.

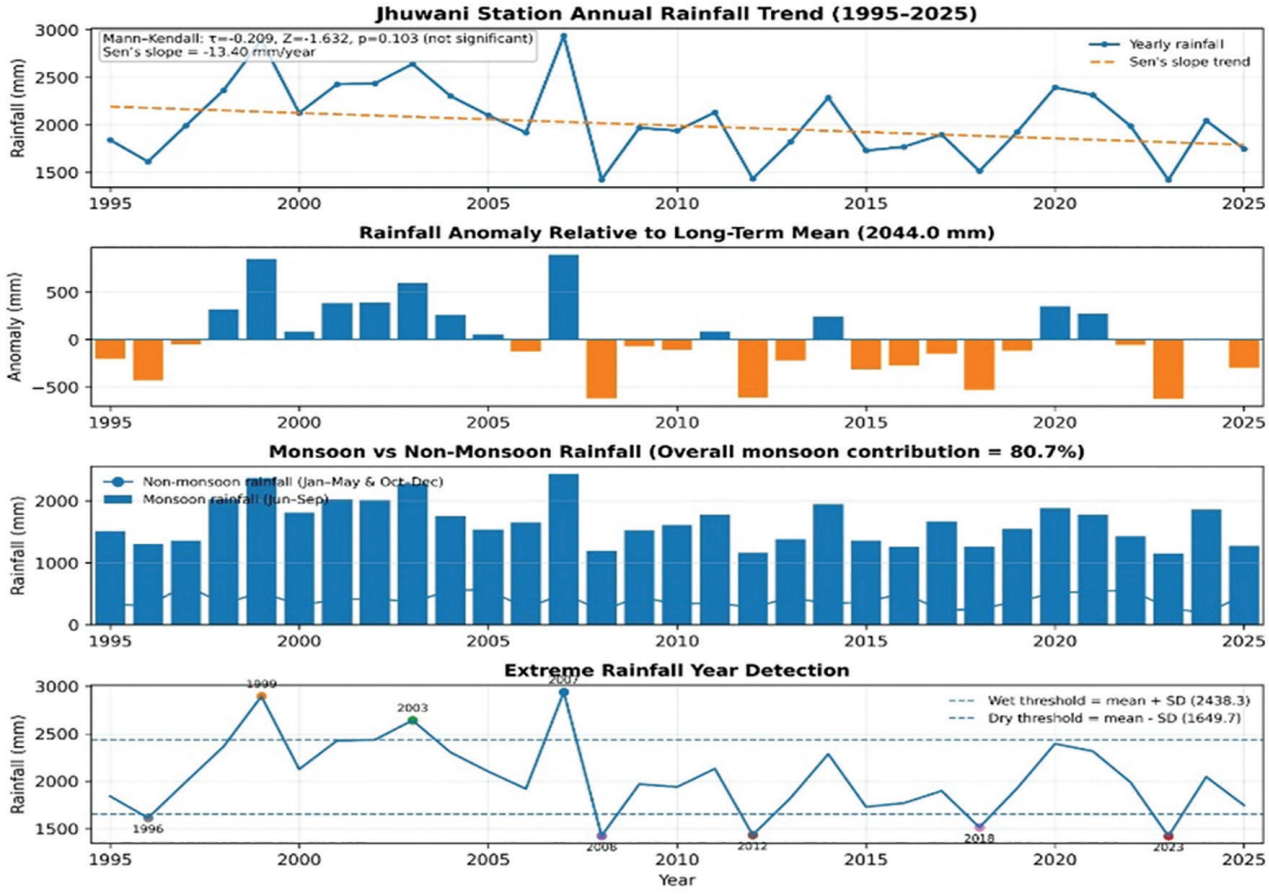

Figure 2: Annual Rainfall Trend

Estimated Irrigation Water Requirement (IWR)

The CROPWAT 8.0 simulation result estimated the seasonal crop water requirements of the major crops cultivated within the Khageri Irrigation System command area. This model results indicate that the total gross irrigation requirement for the entire command area (3,900 ha) is approx. 10.231 million cubic meters per year as shown in Figure 3. Albeit the area receives high annual rainfall of about 3090.66 mm, only around 1331.32 mm is effective for crop use. This shows that there is a clear mismatch between water availability and crop water demand in the study area. This is due to a large portion of rainfall is lost through runoff, deep percolation, and evaporation. Similar observations have been reported in previous studies, which emphasize that effective rainfall is often much lower than total rainfall and plays a crucial role in determining actual irrigation requirements (Solangi et al., 2022). In addition, rainfall is not evenly distributed throughout the year, as most of it occurs during the monsoon season, while very little rainfall is received during the winter months, leaving the winter month relatively dry. This aligns with earlier watershed-level findings in Chitwan, where water availability has been reported as increasingly seasonal and unreliable (Shrestha et al., 2020).

Among the major crops grown in the study area, wheat requires the highest irrigation water, followed by rice and mustard. Rice, which has the highest crop evapotranspiration demand 655.22 mm as shown in Figure 4, requires minimal irrigation 53.67mm because it is cultivated during the monsoon period when rainfall is abundant. In contrast, wheat, with a lower crop evapotranspiration demand 404.19 mm, shows the highest

irrigation requirement 303.70 mm due to its cultivation during the dry winter season. Similarly, mustard has a relatively low evapotranspiration of 175.38 mm but still requires moderate irrigation 133.11 mm because of limited rainfall during its growing period. Similar conclusions were drawn by (Pradhan, 2017),who reported that Khageri canal performance is highly sensitive to seasonal flow variability, leading to structural deficits during non-monsoon months. These findings show that irrigation demand is influenced more by the timing of rainfall than by total annual precipitation. This distribution is largely influenced by the seasonal availability of rainfall in Nepal.

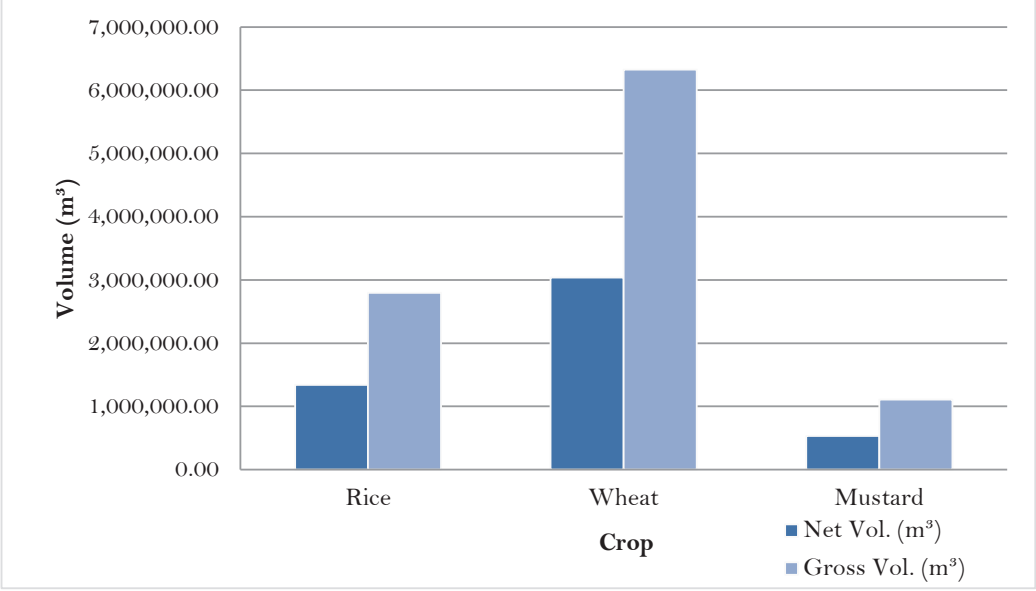

Figure 3: Seasonal Net and Gross Volume by Crop

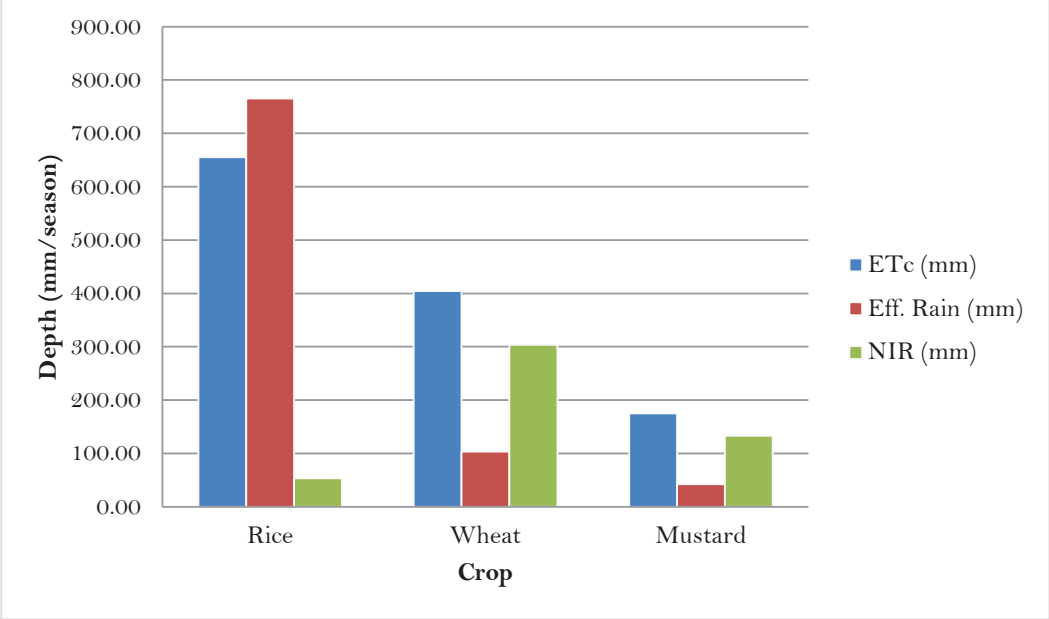

Figure 4: Seasonal ET_c, Effective Rainfall, and NIR by Crop

Monthly Distribution of irrigation Demand

The analysis of monthly Gross Water Demand shows that water requirements are majorly concentrated during specific months rather than being evenly distributed throughout the year. The highest irrigation demand occurred in March as shown in Figure 6, which was identified as the peak demand month. During this period, wheat is in its late growth stage and requires significant water for grain filling and maturity. At the same time, rainfall remains minimal and evapotranspiration demand is increasing due to rising temperatures as shown in Figure 5. Solangi et al., (2022)have also shown that crop water requirements vary across growth stages and are highest during the development and late growth stages. This creates the importance of timely irrigation supplies rather than only focusing on total water availability. Conversely, irrigation demand during the monsoon months June to September is very low because rainfall is sufficient to meet most crop water requirements. However, actual field visit further reveals a critical gap between crop water requirements and actual water availability in the Khageri Irrigation System. Although crop water demand is highest during the winter season, field observations and practical evidence indicate that canal discharge is often zero during this period. Likewise, Shrestha et al., (2020) also indicates a similar result in khageri, farmers facing irrigation water stress in the dry season and farmers are found shifting toward drought tolerant crops during dry season leaving the traditional crops. This shows that the irrigation system is unable to supply water when it is most needed. The Khageri canal provides sufficient water only during the monsoon season, when rainfall is already abundant and irrigation demand is relatively low. Similar findings from irrigation system performance studies indicate that estimating crop water requirements alone is not sufficient unless supported by effective water delivery and management systems (Shrestha, Awasthi and Bohara, 2024).

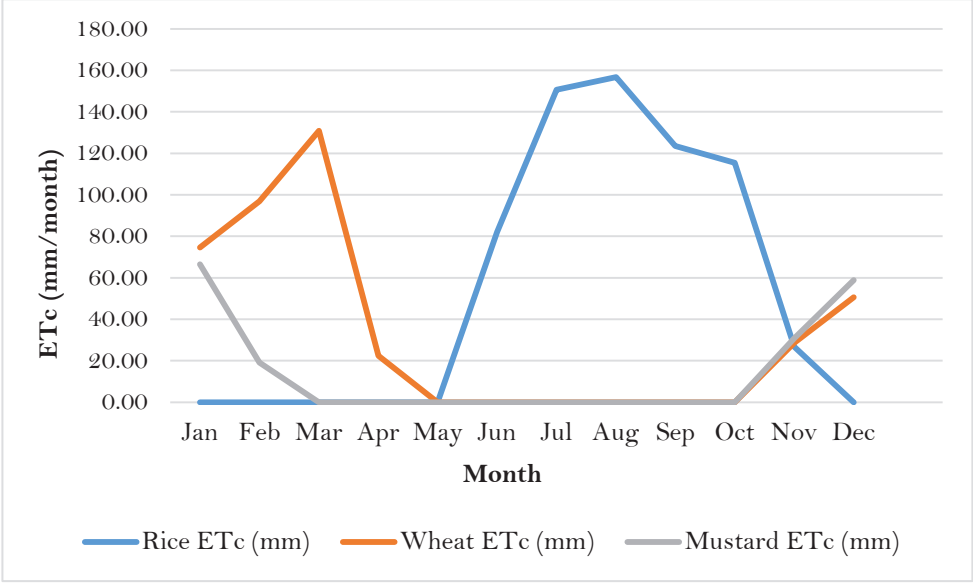

Figure 5: Monthly Crop Evapotranspiration (ETc)

Figure 6: Monthly Gross Water Demand

This evidence clearly indicates a serious problem of irrigation water stress in the khageri irrigation system command area. The system fails to support dry season crops, which are highly dependent on irrigation, thereby increasing the vulnerability of farmers and affecting agricultural productivity. Overall, the results focus on the urgency towards improvement of water availability and management in the Khageri Irrigation System to ensure reliable irrigation during critical crop growth periods. This imbalance between supply and demand illustrates a typical problem in monsoon-dominated irrigation systems, where water availability does not correspond to crop needs. As a result, dry season crops like wheat and mustard face severe water stress, reducing agricultural production and farmers livelihood. Overall, this research finding emphasizes that enhancing irrigation effectiveness in the Khageri Irrigation System needs both better water management and more timely water supply as indicated by (Shrestha, Awasthi and Bohara, 2024).

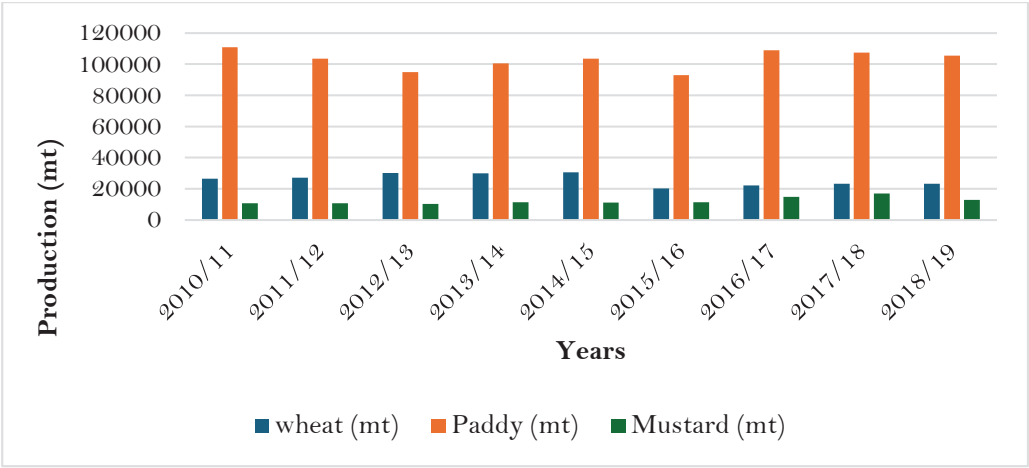

Figure 7: Major Crop Production Trend in Chitwan

The production trends of primary crops in Chitwan fluctuated significantly between 2010/11 to 2018/19. Wheat and paddy production fluctuated during the research period, but mustard production gradually grew until dropping in 2018/19 as shown in Figure 7. These variations show that agricultural productivity is unstable, which may have decreased household income and livelihood security. Consistent with the findings of (Khatri and Timsina, 2023), declining and variable agricultural productivity probably indirectly contributes to outmigration by limiting local livelihood opportunities, even though migration in the Khageri Irrigation Project area is primarily driven by broader economic factors rather than irrigation water stress. The observed fluctuation in agricultural production, combined with broader economic constraints, has had an impact on household livelihood alternatives such as migration. Migration is common among surveyed households. Among 210 respondents, 113 hhs (53.8%) reported that there is at least one household member who has migrated to work. The primary cause of household migration is found employment. Out of the 113 responses, 83 respondents (73.7%) said employment was the main reason why they migrated to another country and the next highest reason was education (15.8%). This implies that most of the migration is as a result of seeking better employment opportunities and amenities beyond the home locality. The finding is consistent with the past research by (Singh Kunwar, 2015)that labor migration is on the rise in Nepal because of the lack of employment opportunities in the country. Household survey show that a significant proportion of the household members have gone abroad in the quest to seek employment especially the Gulf countries like Saudi Arabia, Qatar and Dubai and Malta that reflect the national trend of labor migration. This trend highlights the scarcity of local employment opportunities, which has pushed many individuals to migrate abroad in search of better economic prospects.

But the chi-square test results show that there is no statistically significant relationship between household migration and the influence of irrigation stress on migration decisions in the study area as shown in Table 2. Even irrigation stress exists in the study area people prefer to stay here due to various infrastructural and livelihood opportunities. Overall, the findings suggest that although migration is common among households, irrigation water stress alone does not significantly determine migration decisions, implying that other socio-economic factors may be more influential. Nepalese empirical research shows a more complex link. While Maharjan et al., (2020) showed that migration results depend on socio-economic and ecological circumstances, (Epstein et al., 2022)discovered that drought conditions can also affect migration patterns, particularly temporary labor migration. However, according to (Joshi and Dongol, 2018)findings, environmental factors such as drought and water scarcity continue to have an indirect impact on migration. Their research found that prolonged drought, drying of water supplies, and falling agricultural production exacerbated seasonal and, in some cases, permanent migration by threatening local livelihoods. In contrast, the current study finds that, while irrigation water pressure occurs, it is not the key motivator for migration.

Table 3: Chi-Square Test Showing the Association Between Irrigation Stress and Household Migration

Chi-Square Tests					
	Value	**df**	**Asymptotic Significance (2-sided)**	**Exact Sig. (2-sided)**	**Exact Sig. (1-sided)**
Pearson Chi-Square	1.733[a]	1	.188		
Continuity Correction[b]	.365	1	.546		
Likelihood Ratio	2.495	1	.114		
Fisher's Exact Test				.501	.288
Linear-by-Linear Association	1.725	1	.189		
N of Valid Cases	210				
a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is .92.					
b. Computed only for a 2x2 table					

Women's Workload After Male Migration

As women performed both fieldwork and household work after male migration there is significant increase in workload of women's after male migration as women's median daily work hour has increased from about 8 hours to 9 to 10 hours after male migration as shown in Figure 6. Therefore, male migration led to longer working hours for women, reflecting increased labor burdens to women. These findings highlight the growing feminization of agricultural as women are actively involved in labor and decision-making roles in khageri households. This finding is consistent with Southard and Randell, (2022) research, which found that male migration, frequently motivated by climate stress or livelihood issues, shifts agricultural tasks to women increasing the workload to the women. Women's growing involvement demonstrates not only more participation, but also a shift in traditional gender roles within a rural household. However, this shift is mostly motivated by necessity rather than empowerment, as women frequently have limited access to alternative livelihood opportunities and resources. As a result, while feminization is increasing, it might additionally indicate increased workload and vulnerability for women. These findings highlight the need for gender-sensitive policies, improved access to training, and institutional support in ensuring that increasing involvement leads to actual empowerment.

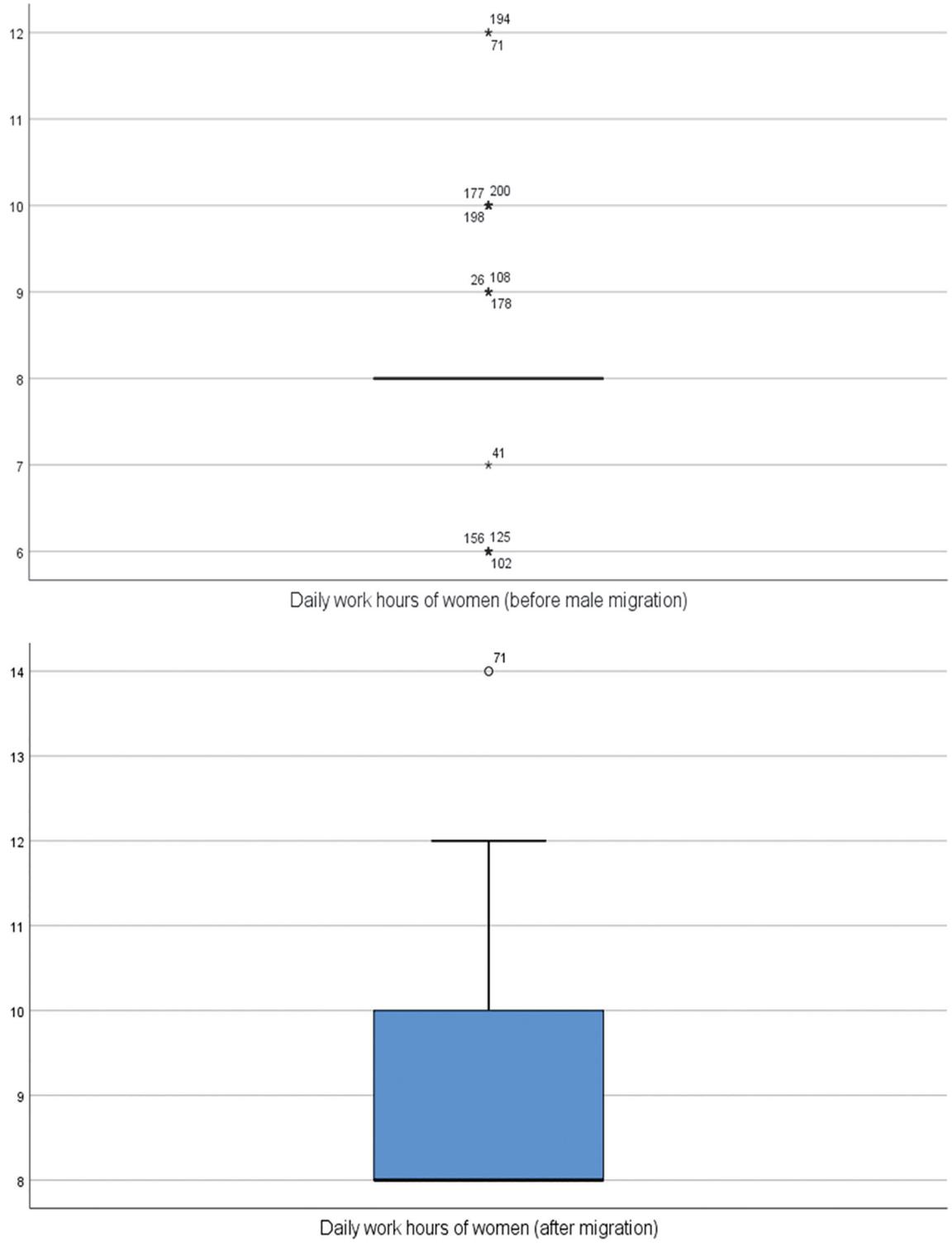

Figure 8: Workload of women Before and after migration

Conclusion

This study demonstrates that irrigation water stress, climate variability, migration, and gender transformation are closely related processes that determine livelihoods within the Khageri irrigation command area. The threat of decreasing water supply, monsoon dominate rainfall increasing pressures on agricultural production systems especially during dry seasons. Such environmental transformations lead to reduced agricultural earnings and high livelihood insecurities. Migration has now grown into a significant livelihood approach among most families though it is not only irrigation stress that causes it but mainly economic factors. Out-migration of males has also changed the family labor dynamics and primarily led to the growing feminization of agriculture. Women currently increasingly participate in agricultural production and irrigation management, but the expansion of their duties is usually accompanied by an increase in the workload and a decrease in institutional representation. Enhancing gender-inclusive irrigation governance is thus vital as a way of boosting water management and sustaining a viable agricultural livelihood. The research also emphasizes the fact that there is the necessity of a combined policy that ensures that the environmental and social aspects of irrigation systems are considered. The issue of sustainable irrigation management should be integrated with enhanced infrastructure, proper institutional governance, gender, and climate-resilient agriculture.

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