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RESEARCH ARTICLE

Inequality of access in irrigation systems of the mid-hills of Nepal

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ABSTRACT
Access to, and control over, water for irrigation is one of the most important factors for increasing agricultural productivity, thereby affecting household food security and levels of poverty in developing countries. However, investments in the irrigation sector have often failed to consider equity aspects of irrigation interventions. Using data from 199 households from three irrigation systems in the mid-hills of Nepal, we analyse access and control of water in different levels of socio-economic heterogeneities. The results demonstrate that efforts to improve livelihoods of the rural poor should give due consideration to the distributional aspects of irrigation interventions, with authority for allocating the level of access to irrigation water given to the farmers throughout the system.

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KEYWORDS
Spatial inequality, socio-economic heterogeneity, access to water, irrigation, poverty, Nepal

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摘要
尼泊尔中部山地灌溉系统使用权的不平等性. *Area Development and Policy*. 能够使用和控制灌溉用水是提高农业生产率最重要的因素之一，从而对发展中国家的家庭粮食安全和贫困水平有影响作用。然而，对灌溉行业的投资往往忽视了灌溉干预的公平性。基于尼泊尔中部山地三大灌溉系统 199 户家庭的数据，本研究对不同社会经济异质性水平上水的使用权和控制权进行了分析。结果显示，改善农村贫困人口的生活水平应充分考虑灌溉干预的分配因素，将分配灌溉用水使用权水平的权力交到整个系统中的农民手里

关键词
空间不均衡性, 社会经济异质性, 水的使用权, 灌溉, 贫困, 尼泊尔

RESUMEN
Desigualdad del acceso a los sistemas de irrigación en las colinas medias de Nepal. *Area Development and Policy*. El control y el acceso al agua de irrigación es uno de los factores más importantes para aumentar la

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productividad agrícola, afectando a la seguridad alimentaria de los hogares y los niveles de pobreza en los países en desarrollo. Sin embargo, muchas veces las inversiones en el sector de la irrigación no han sabido considerar los aspectos de equidad en los programas de irrigación. A partir de datos de 199 hogares de tres sistemas de irrigación en las colinas medias de Nepal, analizamos el acceso y el control del agua en diferentes niveles de heterogeneidades socioeconómicas. Los resultados demuestran que en los esfuerzos por mejorar los medios de vida de zonas rurales pobres deberán tenerse en cuenta los aspectos distributivos de los programas de irrigación con autoridad para asignar qué nivel de acceso al agua de irrigación se proporciona a los agricultores en todo el sistema.

PALABRAS CLAVE

Desigualdad espacial, heterogeneidad socioeconómica, acceso al agua, irrigación, pobreza, Nepal

АННОТАЦИЯ

Неравенство доступа к ирригационным системам Мид-Хилс Непала. *Area Development and Policy*. Доступ к воде для орошения и контроль над ней являются одним из важнейших факторов повышения производительности сельского хозяйства, которые влияют на продовольственную безопасность домашних хозяйств и уровень бедности в развивающихся странах. Однако инвестиции в ирригационный сектор часто не учитывали аспект справедливости подобных вмешательств. Используя данные 199 домашних хозяйств из трех ирригационных систем Мид-Хилс Непала, мы анализируем доступ и контроль над водой на различных уровнях социально-экономической гетерогенности. Результаты показывают, что усилия по улучшению жизнедеятельности сельской бедноты должны учитывать распределительные аспекты ирригационных вмешательств, с предоставлением полномочий по назначению уровня доступа к ирригационной воде во всей системе фермера

КЛЮЧЕВЫЕ СЛОВА

Пространственное неравенство, социально-экономическая неоднородность, доступность воды, орошение, бедность, Непал

INTRODUCTION

Once they have arisen, social inequalities can be very persistent, even if the law guarantees equality irrespective of characteristics such as gender or cultural heritage. Structural spatial inequalities are particularly difficult to address because once people are physically positioned with respect to access to natural, social or economic resources, then tenure laws protect their location (Kanpur & Venables, 2005; Kanpur & Zhang, 2005). Three lines of argument are prominent in the literature on the causes of spatial inequalities. First, a 'structures' perspective argues that spatial inequalities can be attributed to the structural factors such as ethnicity (Anderson & Pomfret, 2003), institutional diversity (Davies & Hammack, 2005), lack of credit markets (Galor & Zeira, 1993), variations in household borrowing and repayment capacity (Hare & West, 1999), social networking (Munshi & Rosenzweig, 2005) and access to natural resources (Shackleton & Shackleton, 2006). Second, 'status-quoism' attributes spatial inequality to initial conditions such as initial regional endowment (Alesina & Rodrik, 1994), income distribution (Chakravorty, 2003), land distribution (Knight & Song, 1993) and other asset holdings (Fujita, Krugman, & Venables, 1999). Third, 'economic opportunism' maintains that spatial inequalities arise as a consequence of the presence or absence of the economic opportunity that space provides (Banerji & Jain, 2003). The proponents of this argument suggest that spatial inequality can be attributed to market thickness, as areas with greater market opportunities attract investment, settlement and consumption (Fujita, 2008; Liu, Dunford, Song, & Chen, 2016). They argue that economic space matters in determining the magnitude of spatial inequalities (Nel & Rogerson, 2009).

Access to and control over natural resources such as irrigation water is a common and interesting example of spatial inequality. Irrigation is often considered critical for farmer livelihoods, especially in developing countries (Hussain, 2007; Jodha, 1990). Policy interventions to ensure farmers' access to natural resources, whilst partially successful (Campbell et al., 2001), continue to face challenges. A growing body of theoretical and empirical literature argues that the existence of heterogeneities (socio-economic, cultural, spatial, interests, power relations etc.) contribute towards the non-realization of the full potential of policy interventions in both developing and developed countries (Bardhan & Dayton-Johnson, 2002; Vedeld, 2000). In many developing countries the distribution of irrigation water is based on land ownership, which makes irrigation development inherently biased against the landless and land poor. Case studies from India found that both inter-farm and interregional inequalities widened in almost one-third of the irrigation systems (Freebairn, 1995). Economic factors, such as access to market, provide obvious advantages to owners of large tracts of land; social factors, such as caste, influence the level of benefits obtained by farmers. For example, in India there were significant differences in the benefits accruing to households from higher social strata as compared with those from lower caste affiliations (Banik et al., 2003). Consequently, measures of sustainable resource use must also include success in promoting social goals such as equitable distribution of benefits and social security (Bardhan, 2000; Smith, 2004).

Differences imposed on farmers' abilities to extract benefits from irrigation resources are likely to give rise to recurrent distributional conflicts and create factionalism (Fresson, 1979; Johnson & Libecap, 1982). Head to tail (upstream–downstream) inequity in irrigation systems has been well documented (Hussain & Hanjra, 2004). For example, farmers at the tail end of irrigation canals have high transaction costs for negotiating water access due to spatial disadvantages in deriving benefits from the canal system. A systematic difference in the level of incentives for engaging in collective action was observed between head- and tail-end farmers (Bardhan & Dayton-Johnson, 2002; Meinzen-Dick, Raju, & Gulati, 2002). These differences often translate into differences in land values: land with easy access to irrigation has a higher value than that with limited accessibility to irrigation, thereby reinforcing existing wealth inequalities (Chakravorty, 2016; Ostrom, 1990).

The significant body of literature on the performance of irrigation systems (Oad & Sampath, 1995; Renault & Vehmeyer, 1999) is mostly technical in nature without the consideration of farmers' perspectives. Previous studies in Nepal have mostly focused on comparative analysis of irrigation systems governed by different property management regimes and associated institutional arrangements (Shivakoti, 1991; Lam, 1996, 1998; Maskey, Weber, & Loof, 1994; Hill, Pant, & Thapa, 2008; Regmi, 2007; Pradhan, 1989). From a management perspective, Nepalese irrigation systems can be broadly divided into three categories: government-managed irrigation systems (AMISs); farmer-managed irrigation systems (FMISs); and jointly managed irrigation systems (JMISs). The devolution of irrigation systems and resultant co-management structure is the product of a policy shift in the early 1990s when there was a gradual retrenchment of government involvement in the construction, maintenance and operation of irrigation systems, with increasing irrigation management roles for users (Department of Irrigation (DoI), 1992).

Some previous studies on the performance of irrigation systems considered the perspectives of irrigation managers, but did not fully represent the perspectives of the farmers who use the irrigation resources (Bottrall, 1981; Lethem & Ng, 1983; Levine & Coward, 1986). This study explores the distributional implications of irrigation development at the household level using users' perspectives. Farmers are organized through water user's associations (WUAs) for managing irrigation systems in many developing countries. First, the paper investigates spatial inequalities in irrigation water distribution across different landholdings within the canal command area. Second, variables associated with socio-economic heterogeneities and their influences on farmer access to irrigation water are identified.

The paper is structured as follows. The next section discusses the research methodology including study sites, data collection and modelling techniques. The third and fourth sections present the findings of the distributive aspects of irrigation development through both descriptive statistics and logistic regression. Conclusions are drawn and policy recommendations are made in the fifth section.

RESEARCH METHODS: STUDY SITE AND DATA COLLECTION

Study site

The criteria used for selecting case study sites included different management regimes, rural settings in the mid-hills region with comparable climate (rainfall and temperature), similarity in cropping pattern, and the existence of socially heterogeneous communities. The southward sloping mid-hills comprise almost 70% of the total land area in Nepal, sandwiched between the low laying Gangetic plains (*terai*) in the south and high Himalayan mountains in the north (Figure 1). Rainfall varies with season, with winter and spring being drier than the monsoon, when 80% of the rain falls. Agriculture in the mid-hills is primarily subsistence farming with cultivation on terraced landscapes. Elevation in the mid-hills ranges from 70 masl in the river valleys to more than 3000 masl in the mountains (HMGN/MPFS, 1988). High topographic variation makes the construction and maintenance of irrigation systems difficult. In consequence, irrigation systems are mostly medium to small scale, and are maintained by local farmers who require irrigation water for crop cultivation. In Nepal, irrigation systems are classified based on the command area (the area irrigated) they serve: < 500 ha (small irrigation systems); > 500 < 2000 ha (medium irrigation systems); and > 2000 ha (large irrigation systems).

The research was undertaken in three districts, Lamjung, Kaski and Parbat in the mid-hills region of Western Nepal, where the Rainastar, Phalebas and Begnas irrigation systems are located respectively. The Begnas irrigation system represents an AMIS, designed and constructed on the basis of engineering and agronomy, with consideration to cropping patterns, irrigation efficiency and effective rainfall (Pradhan, 2005). They are primarily funded and maintained by the government of Nepal through its auxiliary body, the Department of Irrigation (DoI). The Phalebas irrigation system is an example of an FMIS, initiated, constructed and maintained by communal efforts. The Rainastar irrigation system represents the JMIS, and was constructed and managed by the government through the DoI in the first stage of development, and transferred to local communities after communal capacity building. Irrigation systems under JMIS management regimes are co-managed systems with technical inputs from government, while responsibilities for operation and maintenance (O&M) activities and lower-level decision-making is transferred to the beneficiary farmers.

The characteristics of each irrigation system investigated are presented in Table 1. The Phalebas irrigation system has a relatively small command area, while both the Begnas and the Rainastar irrigation systems are medium scale. The Begnas system is managed by government through the DoI, while the Rainastar system is jointly managed by government and local farmers.

Data collection

Data were gathered using a household survey, focus group discussions and key-informant interviews. In addition to questions about the current irrigation system situation, respondents were also asked about their long-term concerns. Respondents were explicitly asked not to base

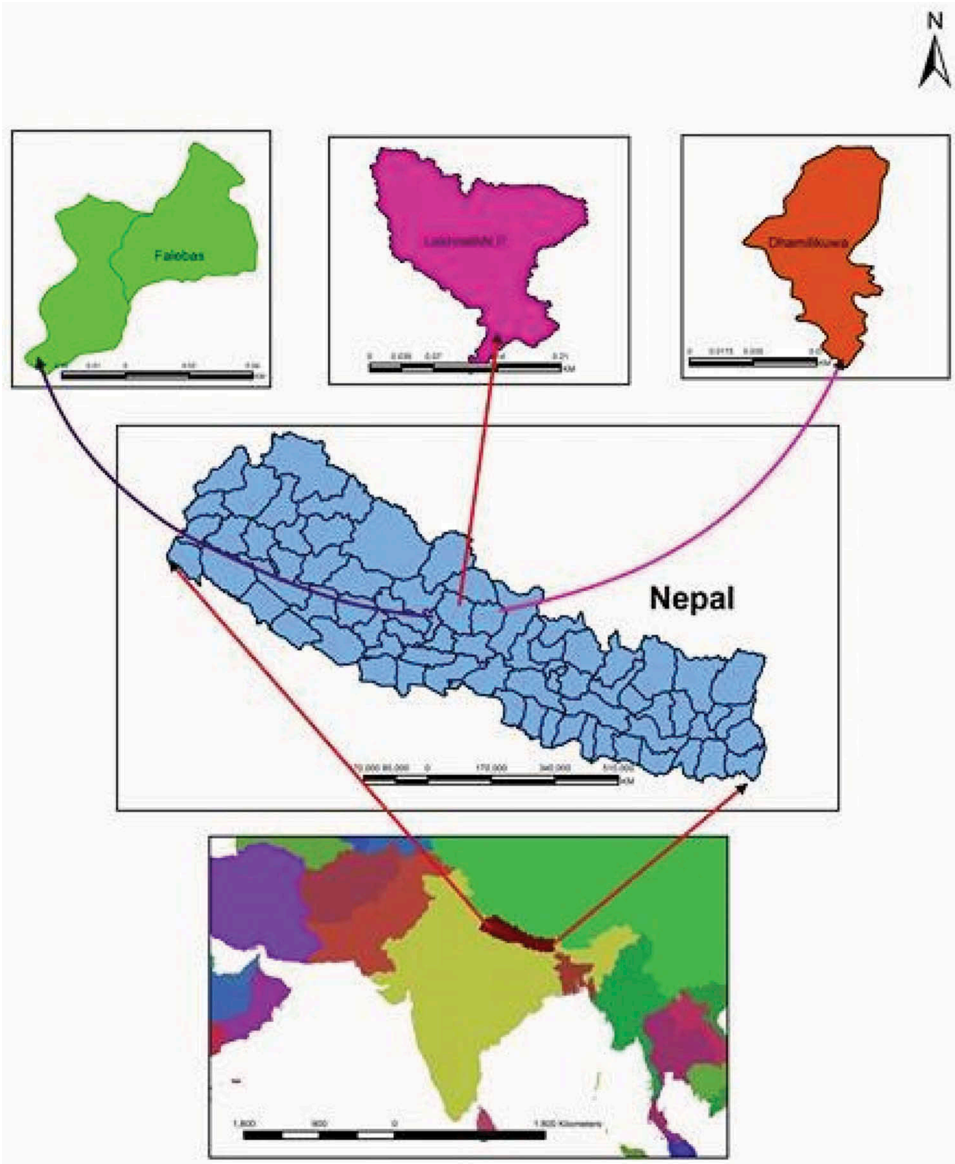

Figure 1. Study sites in Nepal.

their response on one sporadic event, but to take the overall performance of the irrigation system into account while answering questions.

In order to capture spatial and caste/ethnic hierarchy, households were randomly selected on a proportional basis from different locations, landholdings and castes from each ward of the village development committee (VDC) served by the irrigation canals. All the sample households held private landholdings. There were no leasehold lands in the research sites, but share cropping was a common practice amongst the farmers. The amount and type of private land reflects the economic and socio-political status of the households. Households had access to two types of land called *khet* and *pakho*. *Khet* is irrigated lowland, whilst *pakho* is upland,

Table 1. Characteristics of the three irrigation systems.

Irrigation system	Water source and system characteristics	Command area (ha)	Year built	Management type	Water user's associations' (WUAs) duration
Phalebas irrigation system (PIS)	Fed by a local seasonal stream. Mostly non-cement-lined earthen canal with a temporary headwork	341	1931	Farmer-managed irrigation system (FMIS)	3 years
Begnas irrigation system (BIS)	Fed by a lake. A modern system with a sophisticated infrastructure; a cement-lined and permanent headwork	580	1988	Government-managed irrigation system (AMIS)	3 years, but not renewed
Rainstar irrigation system (RIS)	Fed by a perennial river. Semi-modern with a permanent headwork	850	1994	Jointly managed irrigation system (JMIS)	3 years

usually but not always non-irrigated. It is common for households in rural villages to undertake some farming activities outside the canal command area. For example, households reside in hamlets in an elevated areas called *gau* (village) with some non-irrigated farming; and have landholdings at lower elevations, which are more fertile and have access to water called *besi* (farmland).

The Nepal Living Standard Survey categorizes landholding into three categories with holdings < 0.5 ha classified as small landholdings, whilst holdings > 2 ha are large landholdings. Households with larger landholdings are respected, have greater authority and often act in village judicial arbitration. Households were categorized into three landholding groups: small, medium and large landholders (Richards, Kanel, Maharjan, & Davies, 1999) using a participatory rural appraisal (PRA) process.

In this study, local farmers defined landholdings < 0.45 ha as 'small', while those with landholdings between 0.45 and 0.96 ha were considered as 'medium' landholdings. Farmers with landholdings > 0.96 ha were 'large' landholders. A total of 201 households were selected using a stratified random sampling procedure. The survey was administered to household heads. Whilst the authors are aware of the limitations of this questionnaire method, this decision was made primarily because in rural Nepal the head of household generally holds land disposal rights, controls the household's income/expenditure and makes decisions on the behalf of family members. The household heads also take part in meetings and village-level discussions of public interest, and are more likely to be aware of, and have knowledge about, irrigation issues. Most households are headed by men, although some are headed by widows or women whose husbands have left in search of employment in other countries. In the latter case, where the man is not present, women carry out almost all the work customarily assigned to men. In the absence of the father and mother, the households are headed by the eldest son in the family, and he performs all the responsibilities usually performed by his parents. It is least likely that the households will be headed by the eldest daughter. We expected that female-headed households to provide insights into the equity of irrigation interventions. Jazairy, Alamgir, and Panuccio (1992) maintain that female-headed households suffer a triple disadvantage: poverty, gender discrimination and an absence of support in their role. Female-headed households are characterized by lower average earnings, fewer assets, less access to remunerative occupations and productive resources such as land, capital and technology, low education and restricted access to land and credit from banks and local cooperatives (Agarwal, 1994).

The model

Three aspects of access were considered when constructing a model of the system: reliability, equity and adequacy. The variables for adequacy and reliability capture system characteristics enabling the delivery of adequate and reliable water to the farmers. Equity represents institutional mechanisms for water distribution. The importance of water to the farming households varies over the agricultural year, so different weightings were given to responses in different seasons. The weightings were derived by asking farmers to give marks out of 100 for their level of dependency on the canal for irrigation during different cropping seasons. The average marks given by the farmers were 15%, 35% and 50% for monsoon, winter and spring respectively. The dichotomous (binary) responses for the three variables, i.e., reliability, adequacy and equity, in all three cropping seasons (monsoon, winter and spring) were weighted and added together to compute a continuous variable ranging from 0 to 3.

The quantitative data were derived from a relatively small sample so data were aggregated to enable maximum analysis with minimum loss of information (Searle, 2005). The dependent variable was divided into categories: households having strong access to water and those having weak access, reflecting the farmers' experience. The distribution of the weighted access score is presented in Figure 2.

The next stage was to reduce the individual scores into manageable groups, bearing in mind that the choice of boundaries in aggregated data is arbitrary (Bryman & Cramer, 1994, p. 178) and that care needs to be taken when creating cut-off points for dichotomous dependent variables (Searle, 2005). The dependent variable, level of access, was created by dividing households into two categories: strong access (access score > 1.735) and weak access (access score ≤ 1.734). This decision was informed by two considerations. First, the distribution of the weighted access score (Figure 2) is skewed on both sides of 1.73, indicating water availability that is considered to be enough for cultivating two crops in a year. Second, the majority of farmers say that if they have a good water supply throughout the year on all three measures of access defined in this research, they are able to grow up to three crops a year, whereas if they do not have good access to irrigation water, then they could only cultivate one

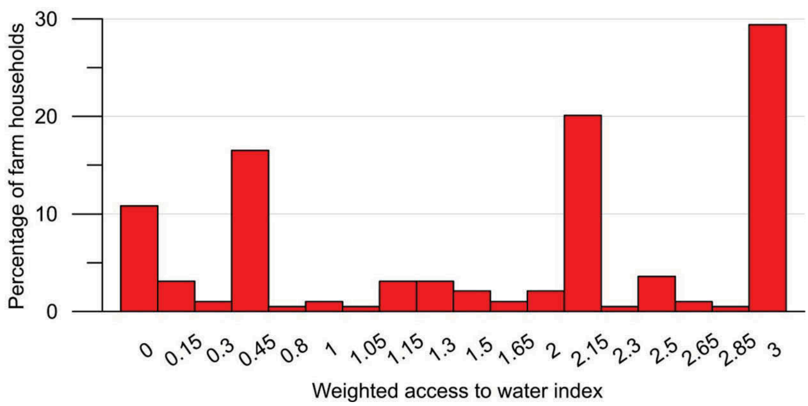

Figure 2. Distributions of access score in the sample.

Table 2. Definition of explanatory variables.

Variables	Explanations	Expected sign of the relationship
RUGOVS	Dummy for simplicity of irrigation-governing rules (1 = simple, 0 = otherwise)	+
LEVTRUH	Dummy for a higher level of trust (1 = higher, 0 = otherwise)	+
LEVTRUL	Dummy for a lower level of trust (1 = lower, 0 = otherwise)	–
CASTE	Dummy for caste (1 = Dalits, 0 = otherwise)	–
HHSEXD	Dummy for gender (1 = male, 0 = otherwise)	+
LOCMCH	Dummy for landholding location at the head end of the canal (1 = head end, 0 = otherwise)	+
LOCMCT	Dummy for landholding location at the tail end of the canal (1 = tail end, 0 = otherwise)	–
AGROKN	Dummy for a farmer's agricultural knowledge used as a proxy for water user's association (WUA) engagement in educating farmers regarding water application (1 = knowing crop-water requirement, 0 = otherwise)	+
PHYCOND	Dummy for the physical condition of the canal (1 = cement lined, 0 = non-cement lined)	+
FARTYPL	Dummy for a large landholding (1 = large, 0 = otherwise)	+
FARTYPS	Dummy for a small landholding (1 = small, 0 = otherwise)	–
NSCLYR	Continuous variable measuring educational level (number of years of schooling)	?
WATFED	Dummy for the source feeding the irrigation system (1 = perennial river, 0 = otherwise)	+
SHAPE	Dummy for the shape of the canal (1 = elongated with multiple outlets, 0 = otherwise)	–
GRAD	Dummy for the gradient of the canal (1 = north–south direction, 0 = east to west or west to east direction	–

crop in a year. Furthermore, there was a common consensus amongst farmers that they should have at least an average access score for them to grow two crops a year, which is critical for household food security. Therefore, an overall mean access score was taken as the boundary for the strong–weak division.

Logistic regression analysis was used to predict the probability of strong access to irrigation water by farmers in households with different socio-economic characteristics. The analysis assumes that access to irrigation water is a function of both socio-economic and physical characteristics of the resource base. Definitions of the explanatory variables are presented in Table 2.

The following model was estimated:

$$
\begin{aligned}
\mathrm{XCESS} = {} & \beta_0 + \beta_1\mathrm{PHYCOND} + \beta_2\mathrm{RULES} + \beta_3\mathrm{TRUSTH} + \beta_4\mathrm{TRUSTL} + \beta_5\mathrm{CASTE} \\
& + \beta_6\mathrm{HHSEX} + \beta_7\mathrm{LOCH} + \beta_8\mathrm{LOCT} + \beta_9\mathrm{AGROKN} + \beta_{10}\mathrm{FARL} + \beta_{11}\mathrm{FARS} \\
& + \beta_{12}\mathrm{NSGRAD} + \beta_{13}\mathrm{WATFED} + \beta_{14}\mathrm{SHAPE} + \mathrm{e}
\end{aligned}
$$

Tests using correlation and heteroskedasticity consistent standard errors (SEs) and White's SEs indicated that for multicollinearity (tolerance > 0.1), variance inflation factor (VIF) < 10) was not a concern. In order to avoid variable omission bias, the 'household number of school years' and 'amount irrigable landholding' (continuous variables) were introduced into the model, after checking that they did not introduce unacceptable multicollinearity.

RESULTS AND OBSERVATIONS

Household sample

A total of 201 households were surveyed, with 199 valid responses used in the final analysis as two questionnaires were discarded for being incomplete. A higher proportion of 'small' landholders (51.3%) compared with 'medium' landholders (23.1%) and 'larger' landholders (25.6%) are characteristic of agriculture in the mid-hills of Nepal, where landholdings are small and often fragmented. Livelihoods are agriculture-based and often only for subsistence cultivation. Although some large landholdings exist, commercial farming is rarely practised; instead farmers with large landholdings allow farmers with small holdings to cultivate their lands on a crop sharing basis. Similarly, the higher proportion of non-Dalit higher castes (86.4%) compared with Dalit castes (13.6%) in the sample (derived using proportional stratification) was representative of the population (CBS, 2011). Historically, Dalits were ascribed a low status within the Hindu caste system and remain one of the most economically marginalized, politically excluded and socio-culturally oppressed communities in Nepal (Berreman, 1973; Pariyar & Lovett, 2016).

As expected, a high proportion (78.4%) of households were headed by men. The remaining 21.6% households were headed by women. Generally, household members followed traditional family roles with women undertaking household activities and men involved in non-household activities including irrigation issues. The number of female-headed households, particularly amongst the Dalit castes, is increasing as many men from the Dalit communities are away, working as labourers in India and Middle Eastern countries (Gyawali, 2007). The majority (51.8%) were in the middle section of the canal with 20.1% at the head and 28.1% at the tail end, partly because the middle section is larger than the head and tail sections. Furthermore, interview data suggest that households prefer to farm in the middle section of the canal mainly because the water supply is good and the area is less likely to become water logged than the head end of the canal.

Household endowment, labour allocation and resource use pattern

The socio-economic inequalities in terms of sample household costs and benefits of involvement in irrigation management are presented in Table 3. Households in the large landholding categories have higher amounts of better-quality productive *khet* land, which is more accessible to irrigation facilities compared with their 'small' landholder counterparts.

A similarly skewed land distribution can be observed between male- and female-headed households with the former having almost double the size of landholdings. In Dalit households, neither the male nor the female headed had double the size of the average landholdings compared with the average landholdings for female-headed households. Statistically, the average landholding of Dalit households (0.34 ha) was significantly less than that of female-headed households from higher castes (0.38 ha). Although statistically not significant, there was also a gender disparity in landholding within Dalit communities with male-headed Dalit households having larger landholdings (0.39 ha) than female-headed households (0.3 ha).

It is also clear (Table 3) that there is a noticeably skewed distribution of types of landholdings among different caste groups with landholders from higher castes having access to more productive *khet* (more than double) than Dalit households, whilst Dalit households have

Table 3. Household characteristics, costs and benefits of irrigation by landholding, gender, location, and caste.

	Land (ha)				Share cropping (%)		Time spent annually (average days)		Costs (Nepalese rupees)		Seasonal total irrigation time (h)				
Landholding categories	*Khet*	*Pakho*	Overall	School years	Share in	Share out	O&M activities/ha	WUA meetings	Total	Cost/ha	Monsoon	Winter	Spring	Overall	Average access score
Large (n = 51)	0.82 (0.50)	0.46 (0.48)	1.28 (0.73)	8 (5.1)	2	35.3	3.6 (2.54)	4.08 (4.23)	368.43 (207.14)	348.16 (242.03)	846 (868.69)	365 (691.16)	415 (692.14)	1627 (2034.78)	6.60 (2.91)
Medium (n = 46)	0.16 (0.17)	0.47 (0.19)	0.63 (0.13)	7 (4.8)	8.7	22.2	6.9 (3.56)	3.02 (3.48)	367.83 (193.33)	596.82 (305.39)	467 (762.10)	133 (378.42)	178 (647.32)	758 (1684.82)	5.65 (3.58)
Small (n = 102)	0.18 (0.11)	0.04 (0.07)	0.22 (0.11)	5 (4.6)	34.3	2	23.5 (20.39)	2.24 (2.67)	364.12 (244.30)	2104.50	437 (660.27)	112 (399.77)	152 (497.15)	703 (1369.11)	5.36 (2.90)
Male head of household (n = 156)	0.45 (0.41)	0.19 (0.33)	0.64 (0.63)	7 (4.9)	19.2	14.9	13.1 (16.2)	2.80 (11.9)	355.83 (121.44)	1195.75 (1738.2)	596 (791.41)	191 (511.60)	248 (629.22)	1031 (1734.43)	5.84 (3.10)
Female head of household (n = 43)	0.26 (0.2)	0.12 (0.23)	0.38 (0.29)	5 (5.1)	23.3	16.3	19.0 (20.81)	2.91 (3.67)	403.26 (257.5)	1884.85 (2271.40)	377 (599.48)	148 (444.02)	146 (444.55)	672 (1412.10)	5.36 (3.12)
Head end (n = 40)	0.42 (0.38)	0.14 (0.21)	0.56 (0.46)	6 (5.0)	15	7.7	13.9 (16.33)	3.23 (4.12)	327.25 (166.10)	1300.65 (1417.55)	979 (819.46)	530 (794.55)	508 (781.31)	2017 (2180.73)	7.33 (2.40)
Middle end (n = 103)	0.43 (0.41)	0.18 (0.26)	0.61 (0.58)	3 (4.9)	23.3	14.7	13.7 (18.61)	3.11 (3.60)	365.83 (241.28)	1253.04 (1593.65)	501 (724.13)	119 (362.59)	171 (461.99)	783 (1362.03)	6.14 (2.78)
Tail end (n = 56)	0.19 (0.43)	0.38 (0.35)	0.57 (0.66)	6 (5.0)	17.9	21.4	16.0 (16.19)	2.25 (2.35)	394.29 (223.10)	1647.49 (1929.10)	327 (654.48)	43 (268.92)	121 (597.42)	491 (1444.35)	3.81 (3.22)
Dalit head of household (n = 27)	0.20 (0.22)	0.13 (0.19)	0.34 (0.28)	3 (4.0)	55.6	0	24.6 (24.27)	3.07 (3.65)	382.97 (232.10)	3506.7 (3758.30)	377 (681.60)	112 (400.82)	95 (393.63)	586 (1270.61)	5.66 (3.12)
Higher castes (n = 172)	0.44 (0.40)	0.18 (0.33)	0.62 (0.61)	7 (4.9)	14.5	17.6	12.8 (15.63)	2.9 (3.37)	363.43 (222.24)	1154.96 (1307.97)	575 (767.75)	193 (510.40)	246 (618.31)	1010 (1723.10)	6.23 (3.01)
Over all (n = 199)	0.41 (0.39)	0.17 (0.31)	0.58 (0.58)	6 (4.9)	20.1	15.2	14.4 (17.46)	2.89 (3.4)	366.08 (223.10)	1305.88 (1482.86)	549 (758.19)	182 (496.96)	226 (594.59)	953 (1673.10)	5.74 (3.10)

Note: O&M, operations and maintenance; WUA, water user's association access to more unproductive and non-irrigable *pakho* lands. Overall, farmers from higher caste groups had access to larger amounts of land (mean = 0.63, SE = 0.05, N = 172) compared with farmers from lower castes (mean = 0.33, SE = 0.05, N = 27). This difference was significant [t (71.527) = −4.22, p < 0.05], and, according to Cohen's effect size value (d = 0.85), large. Whilst the number of female-headed households have increased recently due to male out-migration, out-migrants are mostly from Dalit caste groups who have left mainly due to poverty, lack of land and employment opportunities.

Household labour allocation and the associated total transaction costs for irrigation management are presented in Table 3. The larger, medium and small landholders respectively contributed 3.6, 6.9 and 23.5 man-days labour per hectare of irrigable land in O&M activities annually. These differences are statistically significant [F(2,196) = 39.903, p < 0.01], while Cohen's effect size (d = 0.29) is moderate. Similarly the average person-days spent annually in WUA meetings by the large, medium and small landholders were 4.08, 3.02 and 2.24 respectively. The differences were statistically significant [F(2,196) = 5.251, p < 0.01], but Cohen's effect size (d = 0.05) was small. Small households contribute more labour per hectare (person-day per year) but participate less in WUA meetings than their medium and larger landholding counterparts (Table 3).

Table 3 also reveals that statistically female-headed households (mean = 19.02, SE = 3.17, N = 43) spent significantly [t(197) = 1.956, p < 0.05] more time per hectare of irrigable land in O&M activities compared with male-headed households (mean = 13.1, SE = 1.30, N = 156). Cohen's effect size (d = 0.3) was moderate. With respect to caste, Dalit households (mean = 24.6, SE = 4.67, N = 27) contributed significantly [t(197) = 3.334, p < 0.05] more man-days per unit of irrigable land for O&M activities than their non-Dalit counterparts (mean = 12.85, SE = 1.19, N = 172). Cohen's effect size (d = 0.56) was large.

Table 3 also presents the combined monetary costs of participating in O&M activities and WUA meetings incurred by sample households. Farmers with small landholdings bear substantially higher costs per unit area of irrigation land as compared with their medium and larger landholding counterparts. Male-headed households play a significant role in decision-making processes through their higher level of participation in the WUA meetings, whilst female-headed households contribute significantly to labour-intensive canal O&M activities. However, female-headed Dalit households make a disproportionally larger contribution towards these tasks relative to the amount of irrigated land they cultivate. Additionally, whilst the contribution of female-headed households to irrigation-related decision-making is in general lower, Dalit female-headed households made the smallest contribution, further isolating Dalit female-headed households from this type of decision-making in rural Nepal.

Whilst Dalits, female-headed and tail-end farming households benefit least from irrigation, significant disparities exist amongst them in terms of the costs incurred in the O&M of canal infrastructure. A one-way analysis of variance (ANOVA) indicated that these cost differences were significant. Post-hoc comparisons using the Tukey HSD test indicate that the costs incurred by Dalit households were significantly higher than those incurred by tail-enders. However, the costs incurred by female-headed households did not significantly differ from Dalits and tail-enders, due perhaps to the fact that many Dalit households cultivate *khoriya* land, which is usually but not always located at the tail end of the canal. Taken together, these results suggest that given the amount of irrigable land available for Dalits, they contribute significantly more towards O&M of the canal infrastructure compared with higher castes and head-enders.

The field observations indicated that the head-enders were more reluctant to pay the water service fee, partly because they have an advantageous position in acquiring water from the canal. Also, the larger landholding farmers may attempt to hide the amount of agricultural land they hold in order to pay less. For example, some farmers still cultivate surveyed land allocated for residential purposes. Also, a significant proportion of head and tail-end farmers are reported not to have paid water service charges. About 42.5% of head-enders did not pay water service fees compared with 22.3% and 30.4% from middle and tail end respectively, which is a significant difference.

Table 3 also presents seasonal and overall water appropriation patterns among the sampled households. Although the difference in water appropriation is wealth sensitive, i.e., directly proportional to the amount of irrigable land, the location dimension indicates a head-tail inequality in water distribution. On average, the landholdings at the head end appropriate almost four times more water than landholdings at the tail end of the canal systems.

DETERMINANTS OF HOUSEHOLD LEVEL OF ACCESS TO IRRIGATION WATER

A multiple logistic regression model was estimated to predict the probability of strong access to irrigation water by farmers in households with different socio-economic characteristics (Table 4).

The model tested performs well with a Cox and Snell $R^2 = 0.382$ and Nagelkerke $R^2 = 0.516$ and an acceptable significance level of 95%. The results indicate that the physical condition of the canal had a statistically significant negative association with the odds of having strong access to irrigation water. The odds of farmers served by cement-lined canals having strong access to water are significantly less (1.7 times) than those served by non-cement-lined canals. Other physical characteristics of the canals also have a significant influence on household access to canal irrigation water. The odds of having strong access increased by 0.28 times for canals running in an east–west direction compared with those flowing in the north–south east–west direction. In Nepal, particularly in hilly areas, the canals flowing in a north–south direction have steep gradients and flow through difficult terrain compared with those flowing in the north–south east–west direction. These canals are generally long, elongated, prone to landslides and in need of frequent O&M for a smooth flow of water. However, the canals that flow in an east–west direction have mild gradients and flow through command areas which are flat river basins, making maintenance efforts lower and relatively easy.

A high level of trust and simplicity of rules is positively associated with access to water, and vice versa. The odds of having weak access to water increased 0.278 times for farmers reporting a low level of trust compared with the other farmers. Farmers reporting that the rules are simple and easy to understand were 1.55 times more likely to have strong access to water than those who reported that they were complex and difficult to understand. A perception of simplicity is of practical significance as some WUAs make significant investments in educating farmers about their rules making it easier for farmers to interpret and follow them. Key informants reported limited or no such educational programmes for farmers in the two of the irrigation systems considered in this study, with the result that farmers the rule governing their irrigation systems complex and difficult to understand.

The model predicts that other socio-economic characteristics of households significantly influence access to irrigation canal water. Strong access to irrigation decreased by 0.387-fold for farmers at the tail end of the canal implying that tail-end farmers face locational disadvantages, while farmers at the head had a spatial advantage for appropriating more water. Qualitative interviews confirmed this result. Farmers at the head end of canal systems considered they should have priority rights to irrigation water. Strong access to irrigation water was reduced 0.379-fold for farmers with small landholdings compared with farmers with large landholdings. Key informant interviewees repeatedly mentioned the dominance of the large farmers in the

Table 4. Descriptive statistics of selected variables and logistic regression results.

Predictor	*B*	SE *β*	Wald's χ^2	d.f.	*p*-value	e^{β} (odds ratio)	Collinearity statistics: Tolerance	Collinearity statistics: Variance inflation factor (VIF)
Constant	1.130	0.899	1.580	1	0.209	0.323		
Physical conditions of the canal	–1.774	0.595	8.888	1	0.003***	0.170	0.627	1.146
Rules governing the irrigation system	0.466	0.179	2.604	1	0.010**	1.55	0.862	1.160
High level of trust amongst farmers	0.554	0.509	1.187	1	0.276	1.740	0.662	1.063
Lower level of trust amongst farmers	1.278	0.603	4.495	1	0.034***	0.278	0.728	1.102
Caste (Dalits)	–0.203	0.567	0.129	1	0.720	0.816	0.886	1.129
Gender	0.217	0.483	0.203	1	0.652	1.243	0.915	1.093
Landholding location at the head end	0.828	0.645	1.648	1	0.199	2.289	0.633	1.580
Landholding location at the tail end	–0.949	0.481	3.891	1	0.049***	0.387	0.765	1.308
Farmers' agronomical knowledge	0.504	0.499	1.017	1	0.0313	1.655	0.662	1.212
Small farmers	–0.970	0.489	3.934	1	0.047***	0.379	0.610	1.640
Large farmers	0.942	0.540	3.043	1	0.081**	2.564	0.604	1.656
Source feeding irrigation system	1.336	0.521	6.589	1	0.010**	3.804	0.734	1.034
Gradient of the canal (east–west direction)	2.331	0.658	12.534	1	0.028***	0.280	0.543	1.231
Shape of the canal	–4.409	1.271	12.043	1	0.001***	0.012	0.782	1.826
Number of school year	–0.15	.017	.871	1	0.871	1.616	0.874	1.144

Notes: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, Chi-square = 2.860, d.f. = 8, Cox and Snell R^2 = 0.382; Nagelkerke R^2 = 0.516

management of the irrigation system in the Begnas irrigation system and emphasized that the irrigation systems lie at the heart of village-level politics, with irrigation issues used by the large and powerful farmers for political gain rather than creating benefits for marginal farmers. The odds of reporting strong access to water are significantly increased for large landholders. Farmers with larger landholdings were 2.564 times more likely to report strong access to irrigation water compared with farmers with small or medium landholdings. The nature of the water source also influences access to irrigation water. Famers whose landholdings are served by irrigation canals with a perennial river source are 3.804 times more likely to report strong access to irrigation water compared with those farmers whose landholdings are served by canals with a temporary source of water. The construction and governance of irrigation canals should therefore consider the water availability at source, particularly during the autumn and spring.

Nepalese society is still patriarchal: men are traditionally seen as the family bread-winners, while women are home-makers and nurturers (Narayan, Chambers, Shah, & Petesch, 2000) with little time for participating in village meetings (Thapa, 2001). This gender disparity has serious implications for power distribution, knowledge dissemination, environmental governance and access to resources for women. About 40% of female-headed households reported involvement in the WUA compared with just 9.2% of women from male-headed households (Chi-square = 23.960, d.f. = 1, $p < 0.01$). Women's absence from WUA decision-making means they have little contribution to make to the development of distributional rules (Agarwal, 1997).

Individuals with a higher level of education have exit options (services and business), better earning opportunities outside farming, and may find farming activities less attractive, as only 11.5% of respondents with a lower level of education reported to have an exit option compared with 43.9% of more highly educated respondents (Chi-square = 25.374, d.f. = 1, $p < 0.05$). This finding is similar to that of Gunatilake (1998), who observes that the education of the family members is negatively related to income from local commons in biosphere reserves in Sri Lanka. Higher educational levels may also be associated with greater opportunity costs for labour (Yanggen & Reardon, 2001).

CONCLUSIONS

Irrigation infrastructure contributes to the local economy and household food security, but allocation of water is often unequal. The main findings of this research are that access to irrigation water is related to both a households' socio-economic characteristics (such as resource endowment, caste, gender, level of trust and location) and the characteristics of the irrigation resources themselves. The existence of heterogeneities has created complex forms of inequality that are structurally reinforced by distribution of water from the canal systems. Tail-enders are consistently marginalized when accessing irrigation water, yet they bear disproportionate O&M costs. In contrast, head-enders have a natural advantage for water extraction and they continue to over-appropriate water and use it unproductively at the expense of the tail-enders.

The natural locational advantages enjoyed by the farmers at the head end of the canal have differential economic outcomes. The price of landholdings with good irrigation facilities at the head end is higher than landholdings at the tail end with less access to irrigation water; while tail-end farmers incur greater O&M costs than middle- and head-end farmers. Lower-caste households have a lower level of access to irrigation water than higher-caste groups due to the pattern and location of land distribution among the different castes. Previous studies have also attributed inequality in Nepal to the culture of discrimination against those from lower castes, ethnicities and rural areas (Blaikie, Cameron, & Seddon, 2001). Generally, farmers belonging to Dalit castes have marginal lands that are often located in unproductive areas called *khoriya*. Equally important, Dalit households' more limited access to water could reflect their low degree of influence in decision-making processes and lack of productive resources (Adhikari, Di Falco, & Lovett, 2004). In addition to differences in land endowment, water-appropriation inequalities between Dalits and non-Dalits also reflects household needs, as Dalits usually engage in traditional non-agricultural occupations alongside subsistence agriculture. More importantly, higher transaction costs for Dalits and lower levels of access to, and control over, natural resources also reflect inherent village socio-political dynamics in which Dalit castes are marginalized. Similar conclusions were drawn by Adhikari et al. (2004) in their study of forest resources in Nepal. There are persistent caste, gender and socio-economic status obstacles to increasing participation of marginalized groups in decision-making processes. For example, women do not usually have land in their name and their concerns related to irrigation and landholding need to be passed through men; and caste-based discrimination such as untouchability against the Dalit households has contributed to their socio-political exclusion.

This research highlights the importance of social capital for enhancing collective action for managing irrigation resources. The regression results suggest that communities with a high level of trust tend to have good access to water, and vice versa. Trust and understanding are critical factors for collective action to reduce defrauding, which has major implications for the maintenance of an unconstrained flow of water in the canal. The absence of trust creates conflicts in the maintenance of field channels and control structures, which in turn makes water delivery unreliable, inadequate and inequitable. In these circumstances, water theft is common, perhaps leading farmers to report weak access (Uphoff & Wijayaratna, 2000). Unreliable and inequitable access to water can cause resentment amongst irrigators, and those who do not obtain their fair share lose confidence in collective action and, hence, report a low level of trust. The level of trust among the irrigators is positively associated with collective action which is necessary for canal O&M (Seabright, 1993). Whilst this finding is consistent with earlier studies (Ostrom, 1990), it is indicative rather than definitive in identifying causality in the relationship between social capital and access to irrigation (Baland & Platteau, 1999). There are many enduring and successful FMIS with strong social aspects, while infrastructure-focused AMIS have failed to achieve their targets (Hilton, 1992; Meinzen-Dick, 2014).

In order to understand the distributional implications of irrigation enterprises, it is necessary to understand the socio-economic characteristics of the users as well resource-specific characteristics. The inequitable distribution of benefits from, and contributions towards, the O&M of irrigation canals across households with heterogeneous characteristics provides further evidence of inequity in irrigation management in Nepal. These outcomes can be viewed a reflection of the better negotiating capabilities of large landholders, often at the expense of marginal farmers (Chambers, 1977). Asymmetrical information, insufficient knowledge, low participation along with unequal power distributions result in inequitable benefit appropriation of the local commons. As a result, they constitute a disincentive for collective action and may lead to the degradation of the natural resource base.

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