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Natural Disaster and Households' Access to Drinking Water: Evidence from Nepal's Earthquake

Naveen Adhikari[1]

Abstract

Natural disasters like landslides, droughts, floods, and earthquakes have consistently shown adverse effects on households' access to safe and affordable drinking water. This study examines the impact of natural disaster on household access to drinking water taking a case of Nepal's 2015 Earthquake. Drawing on data from four rounds of the Annual Household Survey (AHS) spanning from 2013/14 to 2016/17, the study employs a difference-in-difference research design to examine how households were impacted in accessing drinking water in the earthquake affected districts of Nepal. The results reveal that households in earthquake affected regions experience a decline in the use of piped drinking water by six-percentage-points compared to other sources of water notably wells, spring and rivers. Concurrently, there was a corresponding increase in the use of open water sources, particularly rivers and springs, for drinking among these households. These findings underscore that during disaster, sources like rivers and spring water can serve as essential alternatives for households, especially in the Hill and Mountain regions of Nepal, where other drinking water alternatives are less feasible. However, it is an important to note that these open water sources are often deemed unsafe for consumption and carry potential health risks. In light of these insights, this study emphasizes the necessity for disaster preparedness plans to prioritize establishing mechanisms that guarantee the safety of such open water sources for drinking during natural disaster and extreme events in the future.

Keywords: *Natural disasters, Earthquake, Difference in difference, Drinking water, Access*

JEL Classification: *D11, I30, F61, C90.*

Introduction

Natural disasters like earthquake, floods, landslides, and hurricanes are well-known for their significant and lasting effects on both individuals and

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[1] Mr. Adhikari is a Ph.D. scholar and Assistant Professor at Central Department of Economics, T.U. Email: naveen.adhikari@cdec.tu.edu.np. ORCID : https://orcid.org/0000-0003-0347-4108.

communities (Quah & Cockerham, 2017; Sanderson, 2000). These events bring about a wide range of consequences that deeply affect the lives and livelihoods of people. These disasters often lead to the loss and destruction of not only homes and personal belongings but also critical infrastructure that is vital for the functioning of a community (Kellenberg & Mobarak, 2011). Infrastructure such as roads, bridges, and public utilities including essential systems drinking water distribution system can be severely damaged or rendered unusable. The aftermath of such infrastructure damage goes beyond the immediate costs of rebuilding. It also creates a situation where households are forced to seek alternative, often more expensive, and solutions to cope with the loss of these vital services (Smiley & Hambati, 2019; Johar et al., 2022). For instance, when the piped-drinking water system collapses, households may have to rely on water sources that are far away from the home increasing the economic costs to the households (Smiley & Hambati, 2019). In such contexts, this paper aims to understand the impact of natural disasters on drinking water choices by the household taking a case of earthquake that Nepal witnessed on 25th April, 2015.

Indeed, understanding the effects of natural disasters on drinking water is more important than others for several reasons. The seismic activity associated with disasters, particularly earthquakes and landslides, can have profound impacts on water systems by causing shifts in the landscape, inflicting damage upon critical infrastructure, and influencing subterranean aquifers (Kron et al., 2021). Drinking water systems encompass a network of infrastructure components, including dams, reservoirs, pipelines, treatment plants, and distribution networks, all of which can be vulnerable to seismic activity (Pagano et al., 2017). Such a complex relationship affects the restoration of drinking water supply systems for extended periods making the population dependent on such systems vulnerable. Beyond these physical damages to infrastructure, such disasters can also introduce intricate challenges to the quality of drinking water. These phenomena not only compromise the immediate availability of safe drinking water but can also have enduring health implications for affected communities.

Consequently, households within such regions may find themselves compelled to adopt more expensive options for accessing safe drinking water, a situation that would likely not have arisen in the absence of such disturbances. The disaster might force households to turn to compromised sources of lower quality and unsafe drinking water. For instance, disruptions in piped water systems could lead households to seek water from wells, springs, and rivers sources that often remain untreated and carry the potential to adversely affect the health of individuals who consume them (Howard et al., 1996; Kouadio et al., 2012). This shift to sub-optimal water sources underscores the broader significance of understanding the repercussions of disasters on drinking water choices, as the implications extend beyond immediate challenges and encompass health, and long-term sustainability considerations.

While natural disasters are the phenomena felt across the world, developing countries face additional risks given their existing dependence on unsafe drinking water and their ability to cope with such situations. For example, about 2.2 billion of the population do not have access to safely managed drinking water, of which 785 million live even without access to basic drinking water (UNICEF & WHO, 2019). These countries' populations already face a significant economic cost in terms of accessing safe water and adverse health impacts associated with unsafe drinking water. It is estimated that up to 80 percent of the illnesses are linked with inadequate or use of unsafe drinking water in developing countries. At the same time, these countries are more vulnerable to events such as natural disasters and climate change with limited resources to cope with such events, exacerbating the problem of accessing safe water.

Nepal witnessed devastating earthquake first on the day of 25th April, 2015, on the 7.9 Richter scale in magnitude, and subsequently an earthquake of 6.8 Richter scale on 12th May 2015, that claimed 9,000 lives, left 22,000 humans injured, and direct cost of damages and losses accounted as high as 5 percent of Nation's Gross Domestic Product (NPC, 2015). The effect of the earthquake was felt across every sector of the nation, yet the loss of human lives, injuries, damage, and loss of household assets, public buildings, and drinking water supply systems accounted for the major losses and damages. Specific to drinking water the Post Disaster Need Assessment (PDNA) report documented that earthquake exacerbated the access to drinking water by causing damage to storage tanks, pipes, pumps, and related structures. Geological changes in some cases even led to streams and springs drying up. Apart from the physical damage, the disruption of drinking water infrastructure disproportionately affected women and young girls, who traditionally bear the responsibility of collecting water for their households (NPC, 2015).

In this context, this study aims to contribute to existing literature to the understanding of the far-reaching implications of natural disasters, particularly earthquakes on household access to drinking water. By focusing on Nepal's experience with the 'Nepal's Earthquakes - 2015', the study offers insights from the demand side perspective that goes beyond physical damage assessment of drinking water systems. Knowing demand side response is important to understand adaptive responses by the household in the face of crises. Furthermore, this paper contributes to the literature from developing countries context where the frequency of natural disasters is high, are expected to experience more extreme events in the future in face of climate change. Therefore, understanding the magnitude of impact on household's access to drinking water sources could be helpful in designing the disaster preparedness plan.

The remaining section of the paper is organized as follows. The next section briefly touches upon the existing literature specifically focusing on the impact of natural disasters on altering drinking water choices faced by households. This section also provides an overview of literature relating to 'Nepal's 2015 Earthquake. The subsequent section explains the data and methodology used in the study. This is followed by a discussion on estimation strategy highlighting the rationale and identification strategy to estimate the impact. The next section presents the main results of the study followed a discussion where the robustness and validity of the results are discussed in addition to the findings derived from the main results of the study. The paper finally concludes by drawing upon some policy implications.

Review of Literature

It is well documented that piped-water systems are vulnerable to natural disasters including earthquakes thereby forcing households to rely on other sources such as ground water, spring, and rivers water as well as bottled one (Quah & Cockerham, 2017; Quintana et al., 2020; Balaei et al., 2021). Accordingly, households incur additional economic costs aftermaths of such disasters, and the cost may manifest in terms of increased water fetching time, cost to treat the water to make it safe, opportunity costs in terms of allocating additional labor to collect water, health costs arising out of drinking unsafe water, and higher price for other sources of water such as bottled one (Rose & Lim, 2002; Heflin et al., 2014; Smiley & Hambati, 2019).

The area where extensive literature is available is on drinking water and it's hygiene, with a strong focus on the resulting health implications for the affected population (Kouadio et al., 2012). The pressing issue of ensuring access to safe drinking water, to mitigate the continued loss of lives caused by the consumption of contaminated water, has led to a comprehensive exploration within the literature of both the health repercussions and the coping mechanisms in the aftermath of such calamities. This set of literature predominantly centers around topics such as the emergence of infectious diseases (Howard et al.,1996), strategies for preventing communicable diseases (Suk et al., 2020), and the behavioral patterns relating to water treatment and consumption (Pascapurnama et al., 2018; Ryan et al., 2019).

Specific to the impacts of earthquakes, numerous studies underscore the role of alternative drinking water sources as piped water systems remain vulnerable to seismic movements. Endo et al., (2022) investigate the role of groundwater sources, particularly 'Disaster Emergency Wells (DEWs)', in securing drinking water after the earthquake taking the case of the 'Kumamoto Earthquake' in Japan. Similarly, it was observed an increase in the use of bottled water from 2 percent in 2000 to as high as 49 percent in 2012 in Haiti following an earthquake in 2010 (Patrick et al., 2017). Mahmood et al. (2011), taking the case of an earthquake in Pakistan in 2005, observe increased dependence on surface and groundwater, and suggest that low-cost household sand filters can be an effective strategy to provide safe drinking water during an emergency. In Indonesia, it was found that the number of well users after the earthquake increased from 22.73 percent to 57.27 percent when an earthquake hit the city of Lombok in 2018 (Hidayat et al., 2020).

Some studies have been carried out in examining earthquake-drinking water in the context of Nepal's 2015 earthquake. For example, Laporte et al. (2022) proposed the (theoretical) water system model that helps optimize access to drinking water in Gorkha and Dolakha districts. Likewise, Mishra and Acharya (2019) assessed the performance of drinking water in providing safe water in the Aginchock and Salyankot VDC of the Dhading district. Some of the literature focuses on the health and behavioral aspects associated with Water Sanitation and Hygiene (WASH). Sekine and Roskosky (2018) documented the gaps and lessons learned for cholera prevention and control in post-earthquake in Nepal. A study by Uprety et al. (2017) assessed how households cope with water, sanitation, and hygiene issues after the earthquake and shows that the provision of a water tank by the municipality and the use of chlorine tablets for treating water helped households to cope with WASH issues. A study by Khanal (2022) showed that earthquakes were associated with an increased prevalence of diarrhea, fever, and cough among children less than five years old in earthquake affected districts.

Despite these contributions, measuring the impact of earthquakes on drinking water choices remained scant in the Nepali context and elsewhere. Further, the available studies rely on case studies or post-event surveys highlighting the recovery status and coping mechanism. Therefore, a study using a large-scale comprehensive data set such as Annual Household Survey (AHS) and a robust study design such as difference in-difference (diff-in-diff) is obviously of merit. Further, information on the magnitude of impact on drinking water sources is equally appealing as it helps to gauge the extent of the problem and in designing cost-effective post-earthquake coping strategies. Further, as Nepal remains vulnerable to climate change, these numbers could be helpful in designing disaster preparedness plan relating to drinking water in face of the extreme events in the future. This study aims to contribute to this shred of literature by specifically investigating households' reliance on drinking water sources in the aftermath of an earthquake in Nepal.

Data and Methodology

This study utilizes the four rounds of Annual Household Survey (AHS) conducted in the years 2013/14, 2014/15, 2015/16, and 2016/17 by Central Bureau of Statistics (CBS), Government of Nepal. Individual roaster information (in section 1) and information on the household's access to drinking water (in Section 20 are provided in the AHS household questionnaire along with other control covariates for the study. Importantly, the AHS questionnaire collects the information through interview date (day, month, and year) and household location (rural vs urban municipality- then referred to as VDCs / municipalites, districts, and Toles). This information has been useful in identifying earthquake affected and unaffected households along with the pre- and post-earthquake status in access to various drinking water sources in the data set.

This study considers households from the 14 severely earthquake-hit districts (A category) as defined in Post Disaster Need Assessment (PDNA) report as the affected households, while households remaining districts have been considered as the unaffected ones (NPC, 2015). According to NRA, seven districts namely Gorkha, Dhading, Rasuwa, Nuwakot, Sindhupalchok, Dolkha, and Ramechhap were among the top districts with severe damages and losses. Likewise, Kathmandu, Bhaktapur, Lalitpur, Kavrepalanchok, Okhaldhunga, Sindhuli, and Makawanpur were categorized as crisis-hit districts. This paper, thus, considers the households from these 14 districts categorized as severe and crisis-hit as the earthquake affected household. This is the strategy adopted to classify the households into affected and unaffected categories. However, this does not mean that household districts other than the above 14 districts were unaffected in the literal sense.

Likewise, the interviews recorded on or before 25thApril, 2015 are classified as the pre-earthquake outcomes, and information recorded after the cut-off date specified above is regarded as the post-earthquake outcomes. It is important to note that some of the information was based on the recall from the preceding week (notably the consumption expenditure and labor supply decisions) suggesting refining the cut-off date accordingly. However, this does not remain a concern in the case of drinking water as the questionnaire captures the ‘current source of the drinking water.

Table 1 shows the distribution of the sample size across the different rounds of AHS surveys further categorized as the earthquake-affected and non-affected households, as well as the sample before and after the earthquake was felt. The total household numbers interviewed for the years 2013/14, 2014/15, 2015/16, and 2016/17 were 3000, 4320, 4500 and 4500, respectively. All the interviews on Round 1st (2013/14) were conducted before the earthquake, and those interviews of the year 2015/16 and 2016/17 were all post-earthquake samples. For the year 2014/15, a sizable proportion of the samples were conducted before the earthquake: to be precise, 80 percent (3464 HHs) of the total households interviewed in Round 2nd were conducted before the earthquake, and 20 percent (856 HHs) were interviewed after the earthquake. The distribution further reveals that 30 percent (4890 HHs) of the total households interviewed during four rounds were from the earthquake-affected area (as per the definition discussed above), and 70 percent (11,430 HHs) belonged to the earthquake non-affected area. The final data set for the empirical estimation combines all four rounds of AHS. Therefore, this study relies on pooled cross-sectional data framework.

Table 1: Sample Size Distribution by Affected-non-affected and Pre-post-earthquake

Data Collection Rounds	Earthquake Affected		Earthquake Non-affected		Total
	Pre	Post	Pre	post	
Round - 1 (2013-14)	1,035	0	1,965	0	3,000
Round - 2 (2014-15)	1,066	149	2,398	707	4,320
Round - 3 (2015-16)	0	1,320	0	3,180	4,500
Round - 4 (2016-17)	0	1,320	0	3,180	4,500
Total (Affected-non affected)	4,890		11,430		16,320

Source: Author's compilation based on AHS (2013/14 - 2016/17).

Estimation Strategy

This paper utilizes the 'diff-in-diff' design to examine the impact of earthquakes on accessing diverse types of drinking water sources by households. The use of the 'diff-in-diff' estimation strategy remains a natural choice for the study. The outcome indicator of this study is observed before and after the event occurred (i.e. earthquake) but not all individuals were equally affected by the earthquake (i.e. the treatment status). A similar methodology is adopted on earlier studies in relation to earthquake's impact: Raut (2021) examines the effectiveness of the coping strategy, Shakya et al.(2022) evaluate impact on labor migration, and Khanal (2022) assesses the impact on child health. The basic 'diff-in-diff' estimator can be designed as following (Lechner, 2010).

$$Y_{idt} = \alpha + \beta_1\, post_t + \beta_2\, affec_d + \beta_3\, post_t * affect_d + \sum \theta_k X_{idt} + \mu_j + + e_{idt} \quad \ldots.\ (1)$$

In the above specification, Y_{idt} is the outcome variable of the interest in the study measured as a water source that ith household from dth districts during a period 't' is observed to rely on. Recategorization of the drinking water sources was done to construct measures of drinking water sources in line with the objective of this paper (See: Table 2 for the definition and measure of the outcome variables).

The variable 'post' is a dummy where it assumes '1' if a particular observation is from the post-earthquake period ('0' for pre-earthquake observation). Similarly, the variable affect is a dummy where it takes the value '1' if the observations are from the 14 districts highly affected by the earthquake as described in the data section (i.e. '0' for the households other than those from 14 districts). The coefficient of the interaction term post-affected measures the 'diff-in-diff' estimation of the outcome variable. The study further controls some of the observed household characteristics that could affect the household choice for drinking water. Such control covariates include age, sex, and education of the household head, place of residence, household size, and structure of the house. The detailed definitions of these variables are provided in Table 2 and summary statistics are reported in Table 3.

Finally, a primary sampling unit fixed effects (μ_j) are included in the model to capture other 'Primary Sampling Unit (PSU)' level unobserved factors that may affect the household reliance on the drinking water sources. Please note that the district and time fixed effects are already included in the model specification in equation (1). The $\boldsymbol{e_{idt}}$ is the residual term with usual ordinary least square (OLS) assumptions.

Equation (1) is estimated using an (OLS) technique. It is important to note that outcome variable (Y) is a binary defined as whether a household relies on a particular source of drinking water. Therefore, use of the 'Linear Probability Model (LPM)' may raise concern about the existence of the non-normality and heteroscedastic error terms (Maddala & Lahiri, 2009; Chatla & Shmueli, 2013). However, the literature suggests that the application of OLS under a binary outcome variable has merit under 'diff-in-diff' estimation strategy, for that matter in drawing the casual inferences, especially in view of fulfillment of parallel trend assumption in 'diff-in-diff' research design and straight forward interpretation of the estimated coefficient (Hellevik, 2009; Puhani, 2012). In the same note, the interaction coefficient of the non-linear models such as logit or probit may not give the right marginal effects and signs unless adjusted for the cross partial derivates in computing these effects (Ai & Norton, 2003). Therefore, this study relies on the LPM model to estimate the equation (1). Further, by including several fixed effects, it can be expected to help mitigate the concerns relating to use of LPM.

The definition and measurement of the variables used in the study are presented in Table 2. Regarding the outcome variables' construct, three different sources of drinking water, namely piped water, well, and open sources are considered in this study. Indeed, the AHS records various sources of drinking water like piped water, covered wells, tube wells, hand pump, open wells, spring water, and rivers etc. This study considers piped water as recorded in AHS, whereas covered well, hand pump / tube well, and open well are recategorized and labeled as well in the study. Similarly, the drinking water sources recorded as spring water and river are clubbed as open sources of drinking water. But, further information of other resources of disaster was not available in the data set. Plausibly, these other sources may include drinking water sources such as bottled and Jar Water, which would be interesting to see the reliance on these sources of water. However, the AHS dataset does not provide specific information on these other sources. A small share of the households (about 2.15 %) of pooled data was observed to rely on these other sources. In this construct, the use of piped water remains the preferred one and is considered safe source, among others. On the other hand, the open sources of water, namely the spring and river water are considered unsafe. The economic costs associated with fetching the spring and river water remain high. Table 2 presents the definition of the outcome variables and covariates used in this study.

Table 2: Description of the Variables Used in the Study

Variables	Description
Piped Water	Binary: '1' if the Household uses piped water (including all types of piped water: private, public, and community), '0' otherwise.
Wells	Binary: '1' if a household is dependent on various types of wells (covered, uncovered, hand pump, tube well), '0' otherwise.
Open Sources	Binary: '1' if a household uses the open sources for drinking water (Spring water, River, Rivulets), '0' otherwise.
Age	Age of the household head measured in completed years.
Education	Years of formal schooling of the household head ('0' for no formal schooling including illiterate, informally literate, and 14 for masters).
Sex	Binary: '1' if the household head is male, '0' otherwise.
HH Size	Number of family members in the house who usually reside at the place of residence.
Urban	Binary: '1' if household belongs to an urban area, '0' otherwise
Wall	Binary: '1' if the construction material of the exterior wall of the house is cemented, '0' otherwise.
Rooms	Number of rooms in the house.

Source: Author's illustration based on AHS dataset (2014-2017).

It should be noted that the validity of 'diff-in-diff' estimates relies on two key assumptions: the intervention is unrelated to the outcome at baseline, and the parallel (common) trend assumption (Lechner, 2010). Considering the earthquake as nature's experiment, the validity of first assumption is self-evident: the earthquake was not triggered in the selected districts based on the households' drinking water sources. However, substantiating the validity of the parallel (common) trend assumption necessitates discussion and additional supporting evidence. This assumption asserts that both affected and unaffected households would have exhibited the same behavioral patterns if the earthquake had not occurred. In present context, it implies that households' access regarding the sources if drinking water would have changed in a similar manner for earthquake-affected and non-affected households in the absence of earthquake. Accordingly, the validity of parallel trend assumption is also checked comparing pre-earthquake information on access to drinking water between earthquake affected and not-affected districts. In addition, the sensitivity of the results is also checked considering a restricted sample and simple specification of 'diff-in-diff'.

Results and Discussion

The summary statistics of the variables used in the estimation is reported in Table 3. Overall, 50 percent of the households were found to use piped water as a source of drinking water followed by 41 percent of households depending on covered well / hand-pump. About close to one-tenth (9 %) of households depend on sources such as open wells, rivers, and spring water. Variations are observed in using different water sources between earthquake-affected and unaffected households. A larger proportion of the earthquake-affected households are observed to rely on piped water (71 %) compared to unaffected households (43 %), the use of wells and handpump is more among the unaffected households. The use of river and spring water for drinking is higher among the earthquake-affected households which seems intuitive as these districts belongs to the hill and mountain regions of Nepal where ground water sources are scarce or are economically infeasible.

The average age of the household head is 44.85 years which is similar across the affected and unaffected households. The formal year of head of schooling of the households is about 5.15 years which is marginally higher among the earthquake-affected households (5.97) compared to the unaffected households (4.80). An outsize proportion of the male (72 %) occupy the position of the household head- such proportion is similar between affected and unaffected households.

Table 3: Summary Statistics of Variables

Outcome Variables	Mean	S.D.	Min.	Max.
Piped Water	0.50	0.49	0	1
Covered and uncovered Well / Hand-pump	0.41	0.49	0	1
River/Spring water	0.09	0.27	0	1
Age of the household head	44.85	0.11	12	105
Years of Formal Schooling	7.76	4.79	0	14
Sex of the household head (1 if male)	0.72	0.44	0	1
Family Size	4.43	2.16	1	22
Place of Residence (1 if in urban)	0.50	0.50	0	1
Exterior wall of the house (1 if cemented)	0.42	0.49	0	1
Number of rooms	4.48	2.20	1	33

Source: Author's computation based on AHS (2013/14-2016/17)

Table 4 reports the estimation results derived from the 'diff-in-diff' estimator. Column (1) - (3) shows the results from 'diff-in-diff' estimator considering Piped Water, Well, and Open Sources of drinking water as the outcome variables respectively. All the estimations in Table 4 include the month-by-year, districts, and primary sampling unit fixed effects. As discussed earlier, the main results are based on Linear Probability Model (LPM). The coefficient of primary interest labeled as 'diff-in-diff' in Table 4 shows a statistically significant impact of the earthquake on piped water and open sources of drinking water. The negative sign of the 'diff-in-diff' coefficient in piped water shows that households in the affected districts were observed with decreased access to the piped water. In particular, this coefficient corresponds to [exp. (0.0597)-1] = 6.15 percent decrease in the use of piped water for drinking in the earthquake-affected households compared to earthquake-affected counterparts.

Interestingly, the study reveals a compensatory trend in response to the decreased access to piped water. Specifically, households in earthquake-affected districts show an increased reliance on open sources of water. The positive sign of the 'diff-in-diff' coefficient for well water indicates a [exp. (0.0644) - 1] = 6.65 % rise in households' dependence on rivers and spring water sources in these regions. On the other hand, the 'diff-in-diff' estimates for wells are negative and insignificant.

Some control variables seem significant in the results reported in Table 4, though the paper's aim is not to investigate the specific role of these variables. The age of the household head is positively associated with piped water, and negatively with open sources. Male-headed households rely less on piped-drinking water whereas heads with an additional year of education are found to depend on piped water. Household size is negatively associated with piped water; such association is positive for wells. This may be suggestive that households with large family members need more drinking water so that reliance on wells increases. As expected, the urban households continued to rely on piped drinking water systems as their reliance on wells and open sources is limited in urban settings. The economic status of households, measured by construction materials and number of rooms in general, suggests their reliance on piped water compared to wells and open sources.

Table 4: Results from 'Difference-in-Difference' Estimator

Variables	Piped Water	Deep / Tube Well	Open Sources
Post ('1' if observation is from the post - earthquake period)	- 0.1849*** (0.0473)	0.0097 (0.0403)	0.1752*** (0.0322)
Affect ('1' if a household is from earthquake - affected districts)	0.4172* (0.2391)	- 0.4306** (0.2041)	0.0133 (0.1631)
'Diff-in-diff' (post-affected)	- 0.0597*** (0.0195)	- 0.0047 (0.0167)	0.0644*** (0.0133)
Age of the Household Head	0.0006*** (0.0002)	- 0.0002 (0.0002)	- 0.0004** (0.0002)
Years of Formal Schooling of Household Head	0.0050*** (0.0007)	-0.0035*** (0.0006)	-0.0015*** (0.0005)
Sex of Household Head ('1' if Male)	- 0.0229*** (0.0068)	0.0131** (0.0058)	0.0099** (0.0047)
Household Size	- 0.0100*** (0.0015)	0.0084*** (0.0013)	0.0015 (0.0010)
Place of Residence ('1' if Urban)	0.1017*** (0.0101)	- 0.0866*** (0.0086)	- 0.0150** (0.0069)
Construction Materials of Exterior Wall ('1' if cemented)	0.0600*** (0.0075)	- 0.0445*** (0.0064)	- 0.0154*** (0.0051)
Number of Rooms	- 0.1849*** (0.0015)	0.0097 (0.0013)	0.1752*** (0.0009)
Month-by-Year Fixed Effects	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes
Primary Sampling Unit (PSU) Fixed Effects	Yes	Yes	Yes
Constant	0.6838*** (0.0983)	0.0414 (0.0839)	0.2749*** (0.0670)
Observations	16,319	16,319	16,319
R-squared	0.5633	0.6715	0.3630

Source: Author's Computation based on Pooled AHS data set 2014-2017
Note: Standard errors in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.

The Month-by-Year fixed effect consider the month of particular year in the data set (2013/14 to 2016/17) when the interview was recorded.

The results reported in Table 4 carry some interesting findings. To begin, the result shows a decrease in household dependence on accessing piped water within earthquake-affected districts. This indicates that households relying on piped water for drinking are more vulnerable during earthquakes and other natural disasters. As piped water remains a safe and preferred choice for drinking in Nepal, additional care has to be in place to avail the safe drinking water during such crisis. On the one hand, this underscores the necessity to design more robust and resilient drinking water systems, ensuring continuous access to piped water in the face of future natural disasters. Similar practices have been implemented in other disaster-prone areas worldwide (Balaei et al., 2021; Pagano et al., 2017).

However, the disaster preparedness plan should focus on ensuring access to safe drinking water without piped water. Furthermore, the findings reveal that households' dependence on groundwater sources (i.e., wells) remains limited in earthquake-affected districts. As these districts are situated in Mountain and Hilly regions of Nepal with limited groundwater availability, it is understandable that wells do not serve as a viable alternative to piped water in these areas. This also indicates the scarcity of low-cost alternatives such as wells in this region. Nonetheless, groundwater has proven to be an effective low-cost substitute when piped water access is restricted due to disasters globally (Endo et al., 2022; Vrba & Renaud, 2016).

Importantly, the increased reliance on open water sources by households carries two major implications. Firstly, households are forced to depend on open sources that are typically far from their settlement area, that significantly increases the time spent in fetching water (Cassivi et al., 2018). Moreover, in developing countries including Nepal, women are primarily engaged in water-fetching tasks (Sorenson et al., 2011). Secondly, open water sources are considered unsafe for consumption and are more susceptible to contamination following disasters (Chan et al., 2019). Consequently, these findings underscore the need for a gender-focused disaster preparedness plan along with mechanisms to ensure treatment of open water sources prior to consumption. In the latter case, interventions like providing information on boiling water or distributing water treatment tablets could serve as effective strategies to mitigate the health crisis stemming from the use of unsafe drinking water.

Validity of Parallel Trend Assumption

As discussed in methodology section, the validity of parallel trend assumption is examined comparing trends in pre-treatment (pre-earthquake) outcomes between both affected and unaffected households. To account this, outcome variables are derived from the Nepal Living Standard Survey (NLSS) data collected in 2010/11 and compared with the Annual Household Survey (AHS) data from 2013/14 Since the Annual Household Survey (AHS) follows a similar methodological approach and sampling design as the NLSS, making a comparison on the outcome variable between these datasets is considered reliable. The outcomes of this comparison are presented in Table 5. A typical approach to validating the parallel trend assumption involves visual inspection. The outcomes for piped water, wells, and open water sources are shown in Figures A, B, and C respectively (See: Appendix III). These visual representations indicate the validation of the parallel trend assumption in this study. Table 5 along with the graphs reported in the Appendix III confirm that validity of parallel trend assumption is supported. Also, with the inclusion of the time varying covariates that are likely to affect the household's access to drinking water such as place of residence and proxy of wealth indicators as captured by number of rooms and construction materials of exterior wall, it further cushions the sensitivity of the results in connection to parallel trend assumptions.

Table 5: Outcomes in Pre-earthquake Period (2010/11 and 2013/14)

Drinking Water Sources	**Affected**		**Unaffected**	
	NLSS - 2010/11	**AHS - 2013/14**	**NLSS - 2010/11**	**AHS - 2013/14**
Piped water	72.2	74.1	39.8	42.1
Well	13.6	10.3	51.1	47.1
Open sources	7.5	4.8	8.9	5.8

Source: Authors compilation based on NLSS III (2010/11) and AHS (2013/14)

In addition to the parallel trend assumptions, the sensitivity of the results is checked. First, a simple 'diff-in-diff' was computed without including covariates. These results are reported in Appendix I. Likewise, another specification excludes the observations from year 2016/17 with an anticipation that post-earthquake relief programs could have started to take place affecting the outcome via other channels other than the earthquake. These results are reported in Appendix II. In all results, the coefficient of primary interest ('diff-in-diff') remains consistent.

Conclusion

Leveraging the data from four waves of the AHS and employing a difference in difference research design, this study estimates the impact of earthquake in 2015 of Nepal on the sources of household drinking water. The findings suggest that access of households to piped water decreases by 6 percent in earthquake-affected districts compared to their unaffected counterparts. On the other hand, households' dependence on open sources increases in these affected districts almost with same magnitude. This study also conducted several alternative specifications to confirm the results are valid and robust.

The findings of the study highlight the vulnerability of piped water infrastructure to seismic events and underscore the challenges faced by households in maintaining their usual access to safe drinking water. At the same time, findings are suggestive of the fact that open source of water becomes a more prominent alternative when piped water access diminishes due to the impact of earthquake. Given the growing reliance of households on open sources in earthquake affected regions, this paper contends that ensuring the safety of open water sources for consumption can serve as a crucial strategy in alleviating the crisis arising from disruptions to the piped drinking water systems. Therefore, disaster preparedness plans should emphasize establishing mechanisms to make such open water sources safe to drink in such regions to prevent the negative health effects of consuming untreated water. This holds particular significance within the Mountainous and Hill districts of Nepal which exhibit higher vulnerability to natural disasters and extreme events within the context of climate change.

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Appendix I: Results from Simple 'diff-in-diff' (without control covariates)

Variables	Piped-water	Wells	Open Sources
Post ('1' if observation is from post-earthquake period)	- 0.2126*** (0.0479)	0.0307 (0.0408)	0.1819*** (0.0323)
Affect ('1' if a household is from earthquake affected districts)	0.5616** (0.2421)	- 0.5522*** (0.2061)	- 0.0094 (0.1631)
Difference-in-difference	- 0.0530*** 0.0198)	- 0.0118 (0.0168)	0.0648*** (0.0133)
Month by Year Fixed Effects	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes
Primary Sampling Unit (PSU) Fixed Effects	Yes	Yes	Yes
Constant	0.6877*** (0.0989)	0.0606 (0.0842)	0.2516*** (0.0667)
Observations	16,319	16,319	16,319
R-squared	0.5498	0.6635	0.3235

Source: Author's Computation based on pooled AHS data set.
Note: Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

Appendix II: Results on Restricted Sample (2013/14 to 2015/16)

Variables	Piped Water (1)	Deep/Tube Well (2)	Open Sources (3)
Post ('1' if observation is from post-earthquake period)	- 0.1836*** (0.0495)	0.0090 (0.0428)	0.1746*** (0.0333)
Affect ('1' if household is from earthquake affected districts)	0.4231* (0.2507)	- 0.4327** (0.2164)	0.0096 (0.1683)
Difference-in-difference	- 0.0589*** (0.0205)	- 0.0054 (0.0177)	0.0643*** (0.0138)
Age of the Household Head	0.0006** (0.0003)	- 0.0002 (0.0002)	- 0.0004* (0.0002)
Years of Formal Schooling of Household Head	0.0056*** (0.0009)	- 0.0036*** (0.0008)	- 0.0019*** (0.0006)
Sex of Household Head ('1' if Male)	- 0.0231*** (0.0083)	0.0121* (0.0072)	0.0110** (0.0056)
Household Size	- 0.0117*** (0.0018)	0.0104*** (0.0016)	0.0013 (0.0012)
Place of Residence ('1' if Urban)	0.0991*** (0.0107)	- 0.0839*** (0.0092)	- 0.0152** (0.0072)
Construction Materials of Exterior Wall ('1' if cemented)	0.0626*** (0.0091)	- 0.0512*** (0.0078)	- 0.0114* (0.0061)
Number of Rooms	0.0121*** (0.0019)	- 0.0079*** (0.0016)	- 0.0042*** (0.0012)
Month by Year Fixed Effects	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes
Primary Sampling Unit (PSU) Fixed Effects	Yes	Yes	Yes
Constant	0.6805*** (0.1033)	0.0418 (0.0891)	0.2777*** (0.0693)
Observations	11,819	11,819	11,819
R-squared	0.5146	0.6270	0.2906

Source: Author's Computation based on pooled AHS data set.
Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

Appendix III: Validation of Parallel Trend Assumptions

Figure A: Use of Piped Water in 2010/11 and 2013/14

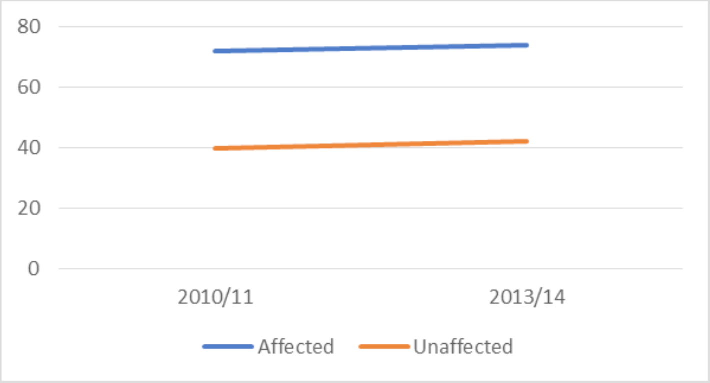


Figure B: Use of Wells in 2010/11 and 2013/14

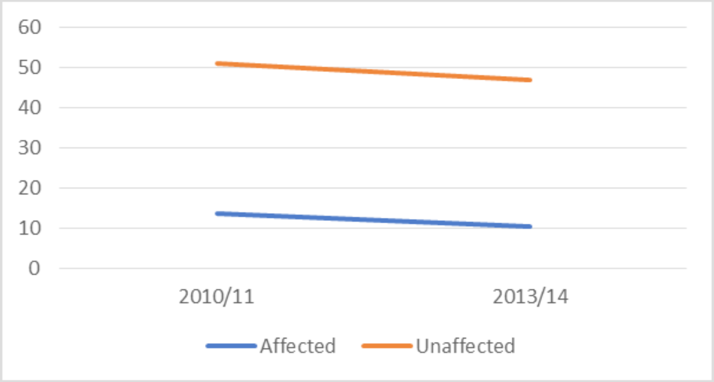
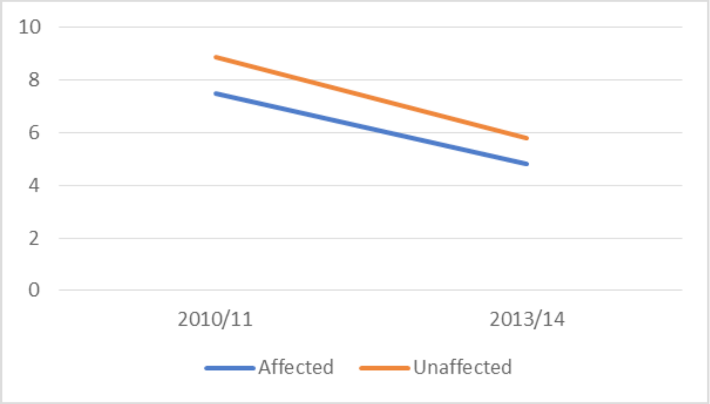


Figure C: Use of Open Sources in 2010/11 and 2013/14



Source: Table 5