SSM - Population Health 6 (2018) 276–285

Contents lists available at ScienceDirect

SSM - Population Health

journal homepage: www.elsevier.com/locate/ssmph

Development of an objective water security index and assessment of its association with quality of life in urban areas of developing countries

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ARTICLE INFO

Keywords:
Community level
Composite index
Experiential dimension
Physical dimension
Water scarcity

ABSTRACT

A composite metric assessing water security's physical dimension at the micro/ community level is lacking but is essential for setting priorities for program and policy implementations. We prepared an objective index (OI) of water security to measure the physical dimension using a model centered on household water-use behavior in developing countries' urban areas. A cross-sectional household survey (n = 1500) with multi-stage cluster design was conducted from December 2015 to February 2016 in the Kathmandu Valley, which has faced long-term, severe water shortage. A structured questionnaire probed socio-demographic characteristics, water sources, frequency and quantity of water use, cost related to water, etc. A 15-item water insecurity scale was used to measure subjective and experiential dimension of water insecurity. The World Health Organization Quality of Life – BREF was used to measure quality of life (QoL). The QoL has been considered as proxy of well-being in this study. The OI measured differential water security within small cities, the utility's service areas for instance, and identified area-specific key dimensions that need improvement. Overall, the OI and its key dimensions can be useful measures to design water-scarcity averting programs and policies, specific to a particular community's needs. The increased OI values were significantly and positively associated with better physical and psychological health and better social relationship domains of QoL suggesting health implications of water security.

1. Introduction

The concept of "water security" emerged in the 1990s, and has since evolved significantly (Cook & Bakker, 2012). One popular definition by Global Water Partnership states, "Water security, at any level from the household to the global, means that every person has access to enough safe water at affordable cost to lead a clean, healthy, and productive life, while ensuring that the natural environment is protected and enhanced" (GWP, 2000). The definition varies widely across disciplines, so do analytical approaches and variables of analysis (Cook & Bakker, 2012).

The Asian Development Bank (ADB) developed a national framework of water security measure, the national water security index (NWSI), which has been applied to compare nations' water security performance in Asia and the Pacific region (ADB, 2016). The NWSI has five key dimensions: household, economic, urban, and environmental security and resilience to water-related disaster. Another research group Aggarwal, Punhani and Kher (2014) proposed a "water insecurity index" (WII) applied on a regional scale in India (Aggarwal et al., 2014; Kher et al., 2015). The framework consisted of six key dimensions: resource, access, consumption, capacity, environment, and climatic stress. Both the NWSI and the WII are broad scale measures, and while helpful, these indices limit the ability to assess multiple dimensions of water security at the micro level (Jepson, Wutich, Colllins, Boateng & Young, 2017).

Recently, social scientists and public health researchers have designed and implemented a few water security metrics at the community/micro/household scale. Wutich and Ragsdale (2008) introduced the concept of household water insecurity in three dimensions: inadequate water supply; insufficient access to water distribution systems; and dependence on seasonal water sources. Later, Hadley and Wutich (2009) developed an experience-based water insecurity scale (WIS), an ethnographically grounded composite metric providing a unique score. Extending its notion, Stevenson et al. (2012) and Aihara,

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https://doi.org/10.1016/j.ssmph.2018.10.007
Received 11 July 2018; Received in revised form 9 October 2018; Accepted 10 October 2018

Shrestha, Kazama, and Nishida (2015) developed a similar household WIS in different cultural settings and investigated the association of WIS with emotional/psychological distress.

Nonetheless, these WISs are an individual's (interviewee's) personal experience that may differ by individual within the household, and the accuracy of reports on other household members is unverifiable (Jepson et al., 2017). The WIS ranks experiences of water unavailability, insufficiency, and the stress of managing water. Such aspects of water insecurity are subjective, whereas rather objective aspects include quantifiable proxies, for instance, piped-water supply, quantity of water used, household socioeconomic status etc. In this study, we posit the concept that water security has two dimensions: experiential (subjective) and physical (objective); individually, they are unlikely to depict micro-level water security completely. In addition, a composite metric of water security that can integrate different indicators into a single value is recommended to allow information to be summarized, assessed, and compared in standardized fashion (Jepson et al., 2017).

The merit of a community level metric lies in its ability to be integrated with various aspects of society. Significant association with authenticated measures of human health or well-being not only provides evidence of water scarcity's effect on society, but also provides evidence of the metric's validity (Stevenson et al., 2012). A previously developed WIS was significantly associated with emotional (Wutich & Ragsdale, 2008; Hadley & Wutich, 2009) and psychological distress (Stevenson et al., 2012; Aihara et al., 2015). In this study, we assumed that the daunting task of water management had impacted every aspect of human life, more precisely, quality of life (QoL).

The aim of this study was to develop a composite index that measures the physical dimension of water security focusing on micro/community level. It has been named as objective index of water security (OI). Here, we first introduced a conceptual model for creating the OI based on data collected from the Kathmandu Valley, the most urbanized area of developing Nepal and severely water scarce. Since WIS and OI assess two dimensions of community level water security, we assessed the relationship of the newly developed OI with previously developed WIS. And, we further investigated their independent association with quality of life (QoL).

2. Materials and methods

2.1. Study setting

Nepal's Kathmandu Valley includes 85% of the Kathmandu district, the entire Bhaktapur district, and 50% of the Lalitpur district. It is Nepal's capital city and the largest urban core, with a population of 2.51 million (CBS, 2011) and water demand of 370 million liters per day (MLD; KUKL, 2015). But the utility, Kathmandu Upatyaka Khanepani Limited (KUKL), supplies only 69 MLD in the dry and 115 MLD in the wet season, with leakage of 40% (KUKL, 2015). With unacceptably low performance by the utility, residents must use multiple sources, for example, private wells, stone spouts, springs, and rain to self-supply. KUKL has 10 service areas where it supplies water through 10 branch offices in the valley (KUKL branches), and these branches differ in volumes of water production and supply (Fig. 1). Our study focused on municipal areas of all KUKL service areas, except the Bhaktapur municipality (Fig. 1, white area of B-10). In this study, administrative divisions refer to those before January 2017.

2.2. Conceptual framework for Objective Index of water security

This study proposed a conceptual model of a multidimensional metric of water security, OI. The OI is an objective assessment based on quantifiable indicators, and its model centers on household water-use behavior in water-scarce urban areas (Fig. 2). Various water-related and socioeconomic factors that shape the behavior are considered key dimensions of the OI: *central water supply, alternative water sources,*

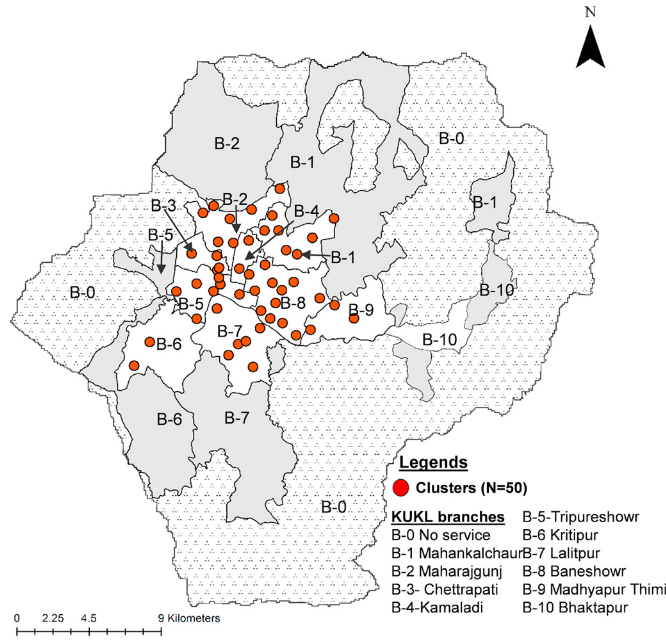

Fig. 1. Distribution of sampling clusters in the study area. Kathmandu Upatyaka Khanepani Limited (KUKL) branches are designated water service areas. White areas refer to municipal boundaries, and gray areas to village development committee boundaries of respective KUKL branches. Our study focused within municipal boundaries, except for B-10. Red circles are clusters (N = 50). Thirty households were selected in each cluster (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

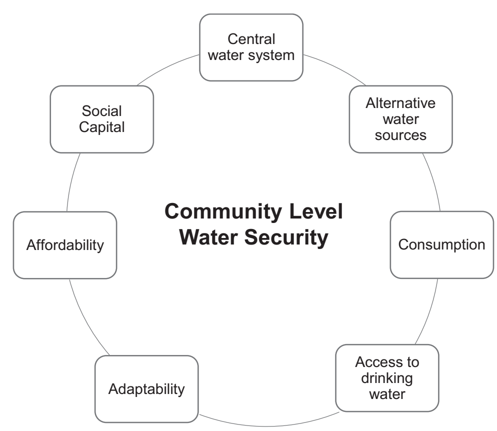

Fig. 2. Conceptual model of an objective index (OI) for water security and its seven dimensions.

consumption, access to drinking water, adaptation, affordability, and *social capital.*

Central water supply, piped-water supply (PWS) is a fundamental factor shaping household water-use behavior. Despite poor performance of *central water supply*, residents rely on it heavily (Shrestha et al., 2017) and the intermittent supply affects coping strategies (Guragai, Takizawa, Hashimoto & Oguma, 2017). Another dimension of OI is *alternative water sources*. Cities in developing countries, including those in Africa, are neither able to provide full PWS coverage or a continuous supply (ADB 2010; Hopewell & Graham, 2014; Shrestha et al., 2017; Guragai et al., 2017). Thus, residents must rely partially—or completely for households without piped-water access—on multiple alternative water sources (Pattanayak, Yang, Whittington & Bal Kumar, 2005; ADB, 2010; Pasakhala, Harada, Fujii, Tanaka, Shivakoti & Shrestha, 2013; Shrestha et al., 2017). Furthermore, the

Table 1
Seven key dimensions of the objective index (OI) of water security and the components (variables) used to calculate them. Signs beside the components and key dimensions explain the direction of their impact on the OI.

Key dimension	Components
Central water system (+)	Piped-water connection (No/Yes) (+) Duration of piped water supply (hours/week) (+)
Alternative water sources (+)	Groundwater use (No/Yes) (+) Rainwater (No/Yes) (+) Jar water use (No/Yes) (+) Tanker water use (No/Yes) (+) Stone spout (No/Yes) (+) Spring (No/Yes) (+) Public well (No/Yes) (+)
Access to drinking water sources (+)	Drinking piped water (No/Yes) (+) Drinking jar water (No/Yes) (+) Drinking both water sources (No/Yes) (+)
Consumption (+)	Per capita water consumption per day in liters (+)
Affordability (+)	Total monthly expenditure (NRs/ month) (+)
Adaptation (+)	Water storage in overhead/underground tank (No/Yes) (+) Water treatment practice (No/Yes) (+)
Social capital (+)	Associated with community group (No/Yes) (+)

diversity of available alternative sources is also a factor influencing water-use behavior. *Consumption* per capita per day is another dimension of OI, which is a common proxy of water availability that has been widely used by several disciplines, such as public health (Shrestha, Aihara, Yoden, Yamagata, Nishida & Kondo, 2013).

Adaptability or coping strategies adapted due to water shortage, for instance, water buying and water storage (Pasakhala et al., 2013), are also deemed responsible for shaping household water-use behavior. On the other hand, *affordability* or household economic status influences these coping strategies (Pasakhala et al. 2013; Shrestha et al., 2017). *Social capital* could facilitate collective action in areas related to management of water resources and facilities (Bisung & Elliot, 2014) and could decentralize the water supply system to mitigate water-scarce conditions (Shrestha, 2010). For constructing OI, these seven key dimensions are considered as independent factors and standardized and aggregated taking reference from Aggarwal et al. (2014) and Kher et al. (2015).

2.2.1. Objective index for water security (OI) key dimensions / components

Table 1 enlists the seventeen variables that have been used in this study to characterize seven key dimension of OI and these variables were chosen based on their relevance in the current study area and data availability. Table 1 also provided the direction of impact of the components on the OI (+ direction indicated that if the component value increases OI increases). The data collection was made in household basis but the component values are calculated on area/ cluster (Fig. 1) basis. For continuous components, such as duration of piped water supply, average value was calculated for an area/ cluster and for components with binary responses (Yes/No), such as having piped water connection at home, percentage of households in the area/ cluster was calculated.

Central water system reflects the piped water availability provided by the city. It has two components: having piped water connection at house and the duration of piped water supply. The key dimension for an area/ cluster was calculated based on the percentage of households having piped water connection and average duration of piped water supply per week. OI was assumed to increase when higher percentage of households have piped water connection and piped water is being supplied for longer duration.

Alternative water sources key dimension reflects the richness of the area on variety of water sources. The components included in this key dimension were use of groundwater, rainwater, tanker water, stone spout, spring water, jar water, and public well. The value for this key dimension is calculated in percentage, for instance if a household is using 7 out of 7 enlisted water sources, then the key dimension value for the household will be 100%. The value of this key dimension for an area/ cluster is calculated as average of the percentage value.

Access to drinking water measures households' approachability to safe drinking water. The components included in this key dimension were use of piped water and jar water for drinking purpose. In the study area, piped water (62% of users) and jar water (100% of users) are the two major drinking water sources (Shrestha et al., 2017). Hence, the access component is quantified in terms of usage of piped water or jar water or both for drinking purpose by the household. The value of this key dimension for an area was calculated as the percentage of households using either piped water or jar water or both for drinking purpose.

Consumption reflects amount of water used by an individual per day. The component is estimated per capita water use per day in liters (LPCD). The raw value is the absolute value estimated for a household and the component value is the average LPCD for an area/ cluster.

Affordability is defined as the household's capability of managing water, including buying it. This component considered for this key dimension is total household expenditure since expenditure is equivalent to income. The value of this key dimension for an area/ cluster is the average total household expenditure.

Adaptation incorporates residents' coping strategies for water scarcity. Residents store water in vessels whenever it is available for future use. Since quality of wide variety of water sources is poor (Warner et al. 2008), it is common to use several water treatment methods to treat poor quality water specially and make it potable. Hence, storing and treating water are two common strategies by residents in the Kathmandu Valley (Pattanayak et al., 2005). The components used for this key dimension were use of overhead or underground water storage tank and use of water treatment method. OI is assumed to increase when people store water in large tanks and treat poor quality water. The value for adaptation key dimension is calculated as the percentage of households using overhead or/and underground storage tank and the percentage of households using water treatment method.

In this study, *social capital* reflects the association with a community group. Since community groups are involved in managing resources for the decentralized water supply (Shrestha, 2010), connection with community group has positive impact on OI. For an area/ cluster, the key dimension is calculated as the percentage of households connected with some kind of community groups.

2.2.2. Standardization of components

Different components of a key dimension are measured on a different scale, for instance 'piped water connection' component of '*central water system*' key dimension was measured as the percentage of household having piped water connection at home whereas 'duration of piped water supply' component was estimated as the average of duration of piped water supply in hours/ week. Hence, these components are first standardized (Kher et al., 2015) as follows:

$$Ci = \frac{ci - cmin}{cmax - cmin}$$

where, c_i is ith component value, *cmax* and *cmin* are the maximum and minimum values of the component among all the areas/ clusters, and C_i is the standardized ith component. It is at this stage that all the components values (*ci*) measured in different scales are converted into a comparable value, *Ci,* which ranges from 0 to 1.

2.2.3. Calculation of key dimensions

Each key dimension was calculated by giving equal weights to all the components those belong to one key dimension and then aggregating the respective components. The equation for aggregating components to calculate key dimensions is as follows (Kher et al., 2015):

$$\mathrm{KDx} = \frac{\sum_{i}^{n} Ci}{n}$$

where, KDx is a key dimension of water insecurity index, Ci is ith component value belonging to key dimension KDx, and n is the number of components for the key dimension. KDx values ranged from 0 to 1.

2.2.4. Calculation of OI

OI was estimated by giving equal weight and aggregating the key dimensions. The following equation was used for the aggregation (Aggarwal et al., 2014):

$$\mathrm{OI} = \frac{\mathrm{KDcws} + \mathrm{KDaws} + \mathrm{KDadw} + \mathrm{KDcn} + \mathrm{KDafd} + \mathrm{KDad} + \mathrm{KDsc}}{7}$$

where, *cws* is central water system, *aws* is alternative water source, *adw* is access to drinking water, *cn* is consumption, *afd* is affordability, *ad* is adaptation, and *sc* is social capital. The OI values ranged from 0 to 1; the higher the value, the higher the water security.

2.3. Study design

The number of households surveyed was 1500 in a multi-stage cluster survey design including two steps for sample selection. First, 50 clusters were selected using the probability proportional to household size sampling technique (Fig. 1). Here household sizes in wards in Kathmandu metropolitan city, Lalitpur sub-metropolitan city, Kritipur municipality (KrM), and Thimi municipality were considered for selecting clusters. For the second selection stage, a random geographical location was chosen, and 30 households closest to the location were selected. Only one household per house (building) was surveyed, although more than one household could be residing there. Inclusion criteria for respondents were: being a household member; aged from 15 to 60; and able to understand and answer the questions. The survey was conducted from December 2015 to February 2016.

2.4. Questionnaires

Trained interviewers collected data through face-to-face interviews. The structured questionnaire included socio-demographic and economic characteristics, domestic water-use behavior, water expenditure, the WIS, and QoL.

2.4.1. Water Insecurity Scale (WIS)

The WIS consists of 15 items, rated on a 6-point Likert-type scale. Total scores range from 0 to 75, with higher scores indicating higher water-insecurity perception. Aihara et al. (2015) validated the scale in the study area. For analyzing each item, *never* and *rarely* responses are combined as a *negative response*; and *sometimes*, *often*, *mostly*, and *always* are combined as an *affirmative response*.

2.4.2. Quality of Life (QoL)

QoL has been considered as a proxy of well-being in this study. We used the World Health Organization Quality of Life – BREF (WHOQOL-BREF), a 26-item abbreviated version of WHOQOL-100 to measure QoL (WHOQOL Group 1998). This scale has four domains, physical health, psychological health, social relationships, and environmental. Each item rating varies from 1 to 5 on a Likert-type scale; the higher the score, the better the QoL. We used the Nepali version, which had shown good internal reliability (Cronbach's alpha = 0.85) in a previous study measuring QoL of people living with HIV/AIDS (Yadav, 2010).

2.4.3. Water-related characteristics

Questions on water-related characteristics included: water source (e.g., piped water, groundwater, jar water, tanker water), purpose of use, amount of water used, and monthly household expenditure on water. Piped water is defined as a municipal water supply provided by a utility; groundwater is water tapped from underground through tube-wells and dug-wells; jar water is water marketed in 20 L jars; tanker water is defined as sources marketed by private vendors carrying water in a truck or tanker. Per capita water consumption was calculated by dividing the daily household consumption by the family's size. Monthly household expenditure on water was defined as the cumulative cost for using different water sources per month. Expenditures for installation and maintenance of groundwater wells, electricity bills for pumping water, and cost of water treatment were not included.

2.4.4. Respondents' socio-demographic and economic characteristics

Respondents' socio-demographic characteristics included age, gender, literacy, ethnicity, family size, and socioeconomic status. Ethnicity (Brahmin, Chettri, Janajati, Dalit) was based on participants' caste because it also indicates a social hierarchy in which a lower class, such as Dalit, is often a disadvantaged group (Baniya, 2007). Socioeconomic status was determined by constructing a wealth index based on household asset possession, for instance, mobile phone, refrigerator, motorbike, vehicle, invertor, and so on (Cordova, 2009). The questionnaire for household assets possession was adapted from Rutstein and Kiersten (2004). The wealth index represented the household's long-term economic status. Principal component analysis (PCA) was used to identify weighting of each asset prior to constructing the wealth index, on which households were categorized into five quintiles: very poor, poor, medium, rich, and very rich. In addition, total monthly household expenditures were also included in the questionnaire.

The questionnaire was developed in English, translated into Nepali, and back-translated into English. Separate groups of Nepalese in the water research field were involved in translation and back-translation. After revising the Nepali questionnaire, it was pretested in 30 study area households, and additional modifications were made based on the results.

2.5. Statistical analysis

Factor analysis (FA) was conducted to extract factors underlying the WIS. We performed oblique rotation using Kaiser Normalization. Pearson correlation analysis was also used to examine correlation of factors of WIS with OI and with the seven key dimensions. Independent t-tests and one-way analysis of variance (ANOVA) were conducted to examine the difference in OI and factors of WIS, separately, across socio-demographic and water-related characteristics. Nonparametric substitute of one-way ANOVA, the Kruskal-Wallis test, was performed when sample size was small. Multilevel mixed-effect models were used to reveal the independent association of WIS factors and the OI with the four QoL domains. Cluster was a random effect variable. Models were adjusted for age, gender, education, and physical health (only for the QoL physical health domain). The statistical program IBM SPSS Statistics Version 20.0 (IBM Corporation, Armonk, NY, USA) was used for all statistical analyses. The significance level was set at < 0.05 for all analytical procedures.

2.6. Ethical considerations

Participants were informed about study objectives and procedures and were assured of their anonymity and confidentiality. They were then requested to participate voluntarily. Those who agreed to the terms and conditions signed the informed consent form. Skipping questions and withdrawing from the study were allowed at any time during the interview.

3. Results

3.1. Socio-demographic and water-related characteristics of households

The mean (± standard deviation) age of participants was 39 (± 12). Among 1500 households surveyed, female respondents numbered 747; and 55%, 28%, and 16% of households were from Janajati, Brahmin, and Chettri ethnicities, respectively.

The coverage of PWS was 68%, and 66% of households used groundwater, and 5% rainwater. From vendors, 77% of households bought jar water, and 24% bought tanker water. The mean (± standard deviation) duration of PWS per week was 2.45 (2.27) h, mean (± standard deviation) water consumption per person, per day in liters (liter per capita, per day, LPCD) was 87 (± 158) L, and monthly water expenditure was NRs 1881 (± 2969). The exchange rate of USD 1 is NRs 101.64 as of January, 28, 2018.

3.2. Objective index of household water security (OI)

OI values for 50 clusters were first estimated. Then all 30 households for each cluster were assigned with the cluster's OI value. The OIs for KUKL branches were calculated by averaging values of individual clusters. Here, results of the OI for clusters are presented first, followed by those for KUKL branches. The OI for households were utilized to investigate its relationship with QoL, presented later in the results section.

The OI ranges from 0 to 1, with higher value indicating higher water security. However, variation in the OI was wide across clusters, ranging from 0.254 to 0.697 (Fig. 3). Identification of clusters with the poorest water security and the poorest key dimension in each cluster or in the whole area is possible through the OI. However, implementing programs and strategies for improving water security for each cluster could be unrealistic. Similarly, identical programs and strategies for whole areas could be less beneficial because area-specific needs could be diverse. To overcome this issue, we introduced the concept of KUKL branches. The OI and its key dimensions' values for each KUKL branch were estimated from values of clusters belonging to the particular branch.

OI values varied from 0.461 and 0.580 across KUKL branches (Fig. 4). In comparison, Chettrapati has the best water security (OI = 0.580) followed by Tripureshowr 0.566, Kamaladi 0.534, Baneshowr 0.525, Lalitpur 0.515, Kritipur 0.499, Mahankalchaur 0.494, and Madhyapur Thimi 0.478. Maharajgunj had the poorest water security (OI = 0.46) among KUKL branches. Fig. 5 shows the performance of key dimensions across KUKL branches, with standard deviations representing variation between clusters belonging to the branch. Within Maharajgunj, Madhyapur Thimi, and Mahankalchaur, KUKL branches that had lower OI values, the three poorly performing key dimensions were *consumption*, *alternative water sources*, and *social capital*. Among these three branches, Maharajgunj had wider variation in *consumption* across its clusters. Regarding *social capital*, wide variation was observed in both Maharjgunj and Madhyapur Thimi; regarding *alternative sources*, wide variation was observed in the Mahankalchaur branch. The poorest key dimension in Kritipur was *central water supply*. Consequently, *alternative water sources* was stronger compared with other KUKL branches and had narrow cluster variation. Other poorer key dimensions of the Kritipur branch were *social capital* and *access to drinking water*. Lalitpur branch was poorest in *affordability* followed by *social capital*. *Central water system*, *alternative water sources*, *consumption,* and *adaptability* performed nearly equally. *Social capital*, *alternative water sources*, and *affordability* were poor in the Baneshowr branch. *Consumption* performed better, but variation was wide. This pattern was similar for *adaptability* as well. Although Kamaladi branch had third highest OI

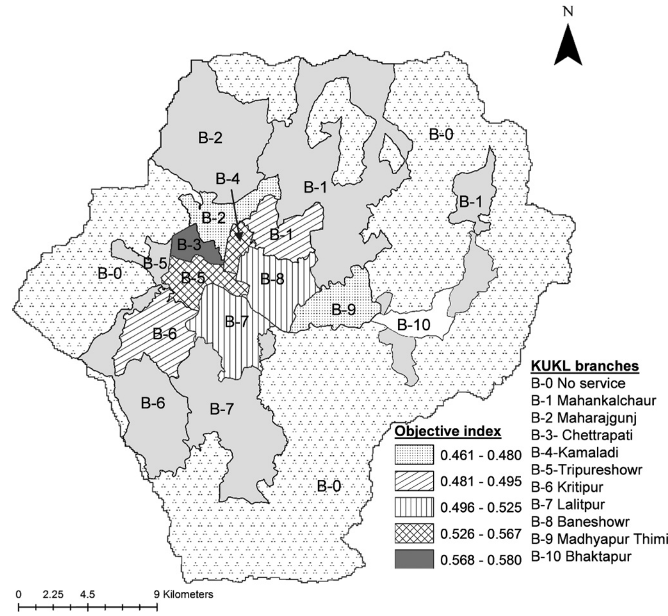

Fig. 4. Objective index of water security (OI) variation across KUKL branches.

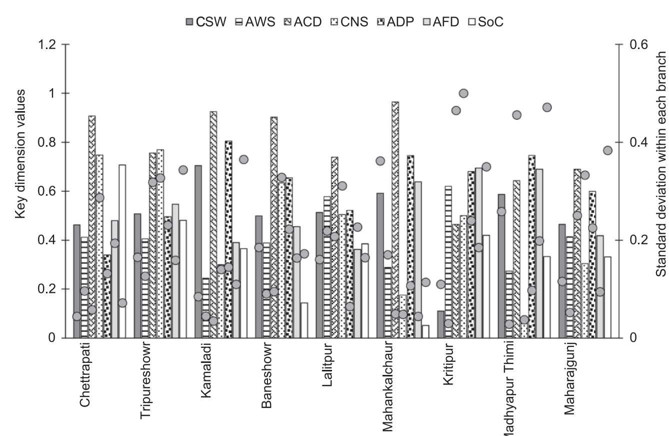

Fig. 5. Values of key dimensions across KUKL branches and standard deviation for each key dimension within each branch. CWS stands for *central water supply*; AWS for *alternative water supply*; ACD for *access to drinking water*; CNS for *consumption*; ADP for *adaptability*; AFD for *affordability*; SoC for *social capital* key dimensions. Grey dots are the standard deviation value of respective key dimension within each branch.

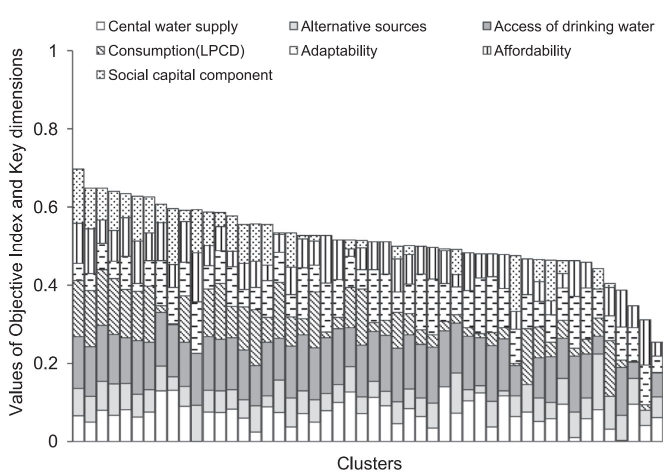

Fig. 3. Objective index of water security and seven key dimension values across 50 clusters.

Table 2
Affirmative responses on items of the Water Insecurity Scale (WIS).

Water insecurity scale items	Affirmative	
	N	%
Cook undesirable food because there was not enough water	260	17.4
Dispute with family members due to water	292	19.5
Slept very few hours due to water collection duty	322	21.5
Dispute with neighbors/ tenants/ owner due to water	332	22.2
Could not participate in any social activities due to water collection	283	18.9
Reduced time for daily work/ income generative activities due to water collection	321	21.5
Reduced time for studies or missed school due to water collection	272	18.2
Have health problems/ weakness/ tiredness because of water collection	320	21.4
Collected water from an undesirable/ dirty source	546	36.5
Collect less amount of water than needed	971	64.8
Could not use safe drinking water	818	54.6
Use poor quality of water	701	46.8
Paid much money to buy safe water	982	65.6
Could not clean enough due to less amount of water	537	35.8
Long times spent for water collection	546	36.5

values, values of *alternative water sources* and *consumption* were considerably lower compared with *central water system, access to drinking water,* and *adaptability*. *Social capital* varied widely within the branch. Both in Chettrapati and Kamaladi branches, *alternative water sources* and *adaptability* performed poorly compared with other dimensions (Fig. 5).

3.3. Water insecurity scale (WIS)

In this study, the WIS had internal consistency of 0.90 (Cronbach's alpha). Table 2 shows the percentage of affirmative answers on its 15 items. More than 50% of respondents reported worrying about "collecting less water than needed," and about "using unsafe drinking water." Interestingly, 66% of respondents worried "they were paying much money for water." Around 20% of respondents worried about "the dispute they have with their neighbors/tenants/owners and their family members due to water," and about "their reduced time for daily income-generating work due to water collection." A similar proportion of respondents also reported "disturbances in study," "in sleep," and "health problems" due to water collection.

Factor analysis of the 15 WIS items showed two factors with eigenvalues exceeding 1, and a scree plot with a clear break after the second component. Eight items related to perception of impact of water insecurity had high factor loadings on one factor, which explained 48.7% of total variance; the factor was then termed *perception of inconvenience* (PIN). These eight items are listed on the first eight rows of Table 2. Seven other items related to perception of poor quality and quantity of water had high factor loadings on another factor, which explained 16.5% of total variance; the factor was then termed *perception of unsafe water* (PUW). These are the rest of the seven items in Table 2.

3.4. Relationship between objective index (OI) and factors of water insecurity scale (WIS)

This study considered OI measured the physical dimension and WIS measured the experiential dimension of water security. Since lower WIS and higher OI indicate higher water security, the correlation between two measures should be negative. The OI was weakly and negatively correlated with PIN and very weakly and positively correlated with PUW. PIN was negatively and very weakly, weakly, and moderately correlated with *central water supply*, *social capital*, and *consumption*, respectively. PIN was also positively strongly and very weakly correlated with *adaptability* and *affordability*, respectively. On the other hand, PUW was negatively and weakly correlated with *central water supply*, but positively and very weakly correlated with all remaining key dimensions.

3.5. Objective index of water security (OI), perception of inconvenience (PIN), perception of unsafe water (PUW), comparisons across socio-demographic and water-related characteristics

Table 3 shows comparison of OI, PIN, and PUW scores on various socio-demographic and water-related characteristics. Male gender reported significantly higher OI than female, but no gender difference was observed for PIN and PUW. Janajati ethnicity reported significantly higher water security (OI) than that of Brahmin and Chettri ethnicity groups. PIN was significantly lower in Janajati ethnicity compared with that of Brahmin and Chettri ethnicity, but PUW was significantly higher in Janajati ethnicity compared to that of the other two ethnic groups. The OI did not differ across wealth status categories. However, both PIN and PUW were higher in the very rich group compared with other groups. Households associated with community groups had higher OI, lower PIN, and higher PUW. Households without access to piped water had lower OI and higher PIN and PUW. Groundwater non-users had significantly lower OI, but such a difference was not observed for PIN and PUW. Households that buy any kind of water had significantly higher OI, but also had significantly higher PIN and PUW, except for PIN among tanker-water buyers.

Monthly water expenditure reflects coping cost while ignoring cost of water collection time. In this study, we visualized the pattern of the mean OI, PIN, and PUW scores across four groups of monthly expenditures for water (Fig. 6). The OI increased (Fig. 6a) and PIN decreased (Fig. 6b) with increased monthly expenditure, while no

Table 3
Comparison of objective index (OI), perception of inconvenience (PIN), and perception of unsafe water (PUW) across socio-demographic and water-related characteristics.

Characteristics	OI		PIN		PUW	
	Mean	p-value	Mean	p-value	Mean	p-value
Gender						
Female	0.512	0.03	5.32	0.93	11.32	0.30
Male	0.522		5.29		11.67	
Caste						
Brahmin	0.494	0.00	6.35	0.00	10.90	0.00
Chettri	0.491		5.60		10.27	
Janajati	0.536		4.76		12.19	
Dalit	0.538		7.00		11.00	
Wealth status						
Very poor	0.513	0.22	4.79	0.00	10.74	0.00
Poor	0.520		4.49		11.77	
Medium	0.525		4.32		11.16	
Rich	0.512		5.00		10.87	
Very rich	0.522		7.65		13.05	
Community group						
No	0.493	0.00	6.39	0.00	11.13	0.00
Yes	0.571		2.82		12.28	
Piped-water						
No	0.489	0.00	7.11	0.00	12.83	0.00
Yes	0.531		5.44		10.85	
Groundwater						
No	0.523	0.03	4.91	0.07	11.61	0.65
Yes	0.514		5.51		11.43	
Buying water						
No	0.488	0.00	4.51	0.01	8.74	0.00
Yes	0.524		5.50		12.17	
Jar water						
No	0.492	0.00	4.11	0.00	9.39	0.00
Yes	0.526		5.72		12.22	
Tanker water						
No	0.509	0.00	5.89	0.00	10.92	0.00
Yes	0.545		3.31		13.43	

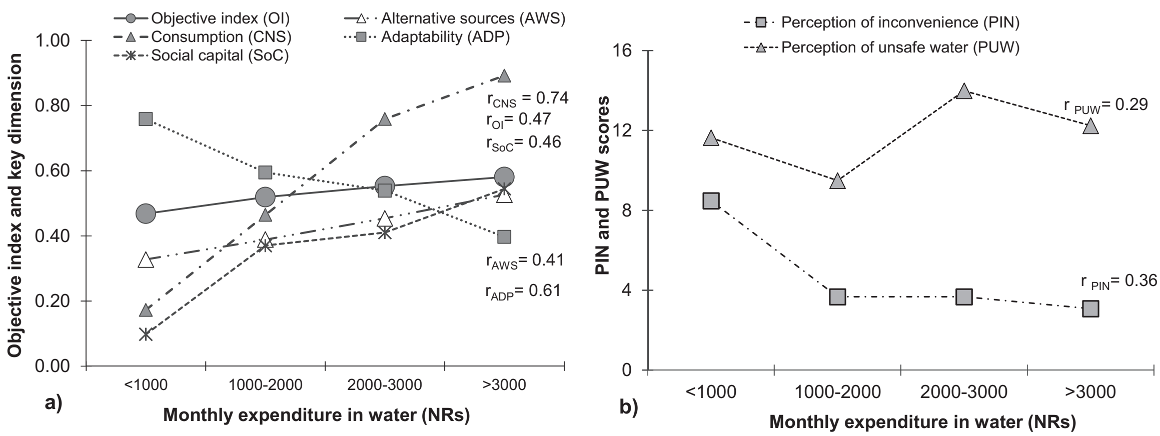

Fig. 6. Pattern of (a) objective index of water security (OI) and its key dimensions and (b) factors of water insecurity scale (PIN and PUW) across monthly expenditures for water (in NRs).

consistent pattern was observed for PUW (Fig. 6b). Correlations of OI, PIN, and PUW with monthly water expenditure were 0.41, 0.36, and 0.29, respectively. While analyzing key dimensions of OI across monthly expenditure, *adaptability* rapidly decreased (r = 0.61) and *consumption* sharply increased (0.74) with increased monthly expenditure. Besides that, *alternative water sources* (r = 0.41) and *social capital* (0.46) increased with increased monthly expenditures.

3.6. Impact of water security on well-being

Mixed-effect models were used to test association of the OI and two factors of WIS (PIN and PUW) with four QoL domains—physical health, psychological health, social relationships, and environmental health—separately, while controlling for other factors (Table 4). The higher the OI community values, the more likely the people had better physical health (β = 4.79, p-value < 0.05), psychological health (β = 3.69, p-value < 0.05), and social relationships (β = 8.04, p-value < 0.01). Although the direction of relationships was positive, OI values were not significantly associated with QoL in the environment domain. The PIN had significant negative association with all domains. These results indicated that when PIN increases, all four QoL domains are likely to decrease: physical health (β = -0.06, p-value < 0.001); psychological health (β = −0.07, p-value < 0.001); social relationships (β = −0.09, p-value < 0.001); and environmental health (β = −0.02, p-value < 0.05). With increased PUW, QoL decreased in physical health (β = −0.02, p-value < 0.05) and social relationships (β = −0.05, p-value < 0.001).

Among socio-demographic factors, caste and education predicted QoL. Compared with Dalit groups, Brahmin, Chettri, and Janajati ethnic groups had poorer QoL in physical and psychological. Interestingly,

Table 4
Factors of physical health, psychological health, social relationship, and environmental quality of life (QoL) domains.

Factors	QoL domains							
	Physical health		Psychological health		Social relationship		Environment	
	β	p-value	β	p-value	β	p-value	β	p-value
Intercept	14.07	0.000	14.78	0.00	13.93	0.000	13.95	0.000
Age	−0.01	0.004	0.00	0.54	−0.01	0.03	0.00	0.69
Gender								
Male	Ref.		Ref.		Ref.		Ref.	
Female	−0.05	0.56	0.00	0.96	0.13	0.21	0.06	0.46
Caste								
Dalit	Ref.		Ref.		Ref.		Ref.	
Brahmin	−1.94	0.02	−2.19	0.01	−1.24	0.25	−1.27	0.11
Chettri	−1.79	0.03	−2.03	0.01	−1.02	0.35	−1.24	0.12
Janajati	−2.03	0.01	−2.19	0.01	−1.22	0.26	−1.26	0.11
Education								
Tertiary	Ref.		Ref.		Ref.		Ref.	
Secondary	−0.40	0.000	−0.43	0.00	−0.27	0.03	−0.52	0.000
Primary	−0.43	0.001	−0.82	0.00	−0.32	0.05	−0.82	0.000
Illiterate	−1.06	0.000	−1.11	0.00	−0.99	0.00	−0.97	0.000
Marital status								
Married	Ref.		Ref.		Ref.		Ref.	
Divorced/Windowed	−0.14	0.64	−0.15	0.61	0.43	0.31	0.13	0.67
Unmarried	0.14	0.30	0.28	0.03	−0.24	0.18	0.12	0.34
Physical health symptoms								
Yes	Ref.							
No	0.37	0.14						
Perception of inconvenience (PIN)	−0.06	0.000	−0.07	0.000	−0.09	0.000	−0.02	0.04
Perception of unsafe water (PUW)	−0.02	0.03	0.00	0.59	−0.05	0.000	0.00	0.81
Objective index of water Security (OI)	4.79	0.03	3.69	0.01	8.04	0.003	1.81	0.19

people with tertiary-level education had better QoL on all domains than those with secondary and primary education and illiterates. Similarly, with increased age, QoL in physical health and social relationship domains decreases.

4. Discussion

This research's main aim was to introduce a community level water security metric (OI) that captures physical dimension and is based on household water-use behavior. In this discussion section, we describe indirect validation of the OI by its ability to predict well-being and by its similarities and relationship with well-established measures of experiential dimensions of water insecurity. In addition, applicability of the OI and its key dimensions are discussed. Furthermore, the study area specific findings, the current limitation of the metric, and future plans are discussed.

4.1. OI metric: Indirect validation and usefulness

Previously, Hadley and Wutich (2009), Stevenson et al. (2012; Stevenson, Ambelu, Caruso, Tesfaye & Freeman, 2016), and Aihara et al. (2015) presented a prominent relationship between the WIS they developed and multiple facets of human life (emotional/psychological distress). Their evidence further validated the scales' usefulness. In this study, the OI was significantly and positively associated with three of four QoL domains: physical health, psychological health, and social relationships. These findings well-provided and supported empirical evidence that well-being is likely better when water security is better. In addition, the direction of the relationship between the OI and well-being was the same as that between WIS factors and well-being. Such evidence could be an indirect validation of the OI's appropriateness as a proxy of the physical dimension of water security. Unlike other studies that used multiple indicators of physical dimension of water security such as *water quantity* (Wutich & Ragsdale 2008; Stevenson et al. 2012), this study presented one composite proxy.

The OI and PIN/PUW, exhibited similarities regarding variation across households' socio-demographic and water-related characteristics. Significantly higher water security (greater OI and smaller PIN) was observed among Janajati ethnicity and among households associated with community groups, compared with Brahmin and Chettri ethnicities and households not associated with community groups, respectively (Table 3). Majority of population within Janajati ethnic group is 'newars' who are regarded as the indigenous population inhabiting the Kathmandu Valley since the pre-historic times (Dongol, 2010). In this study, out of 825 households that belong to 'Janajati' ethnicity, 539 households (65%) were 'newars' (data not shown). Since mostly 'newars' are local people of the valley, they could have easy access to water sources compared to that to Brahmin and Chettri ethnic group. In addition, 'newars' usually have traditional community group or 'social capital' called 'Guthi' (Dongol, 2010) which has served as an important key dimension in OI. Our results also supported that those areas that have poor performance on 'social capital' key dimension have lower OI. Similarly, better water security was observed (greater OI and smaller PIN/PUW) among households with access to piped water and groundwater non-users compared to households without access to piped water and groundwater users, respectively. Across *monthly expenditure in water* categories, the OI constantly increased, and PIN constantly decreased with increasing cost; correlations of monthly expenditure with the OI and PIN were 0.47 and 0.36, respectively (Fig. 6). Both the OI and PIN exhibited similarities by indicating increased water security with increased expenditure. Nevertheless, both measures captured their respective dimensions of water security. Buying is a common coping strategy in water shortage areas (Pattanayak et al., 2005; Pasakhala et al., 2013) that increases water quantity, while also increasing financial burden. Both the OI and PIN/PUW were significantly higher among water buyers compared with households that did not buy. Here, when buying water, the OI captured physical water availability (physical dimension), while PIN/PUW relayed the cost burden (experiential dimension).

The OI negatively correlated with PIN, as anticipated; however, it was positively correlated with PUW. We did not adjust water quality dimension while preparing the OI. When households accepted poor water quality to increase quantity, the physical dimension (OI) improved, but users may still worry about water quality, so PUW can worsen. Positive correlation of PIN with *adaptability* and *affordability* could indicate that adaptation to the water-scarce situation and paying more for water increased daily inconvenience. In this study, very rich households had significantly higher PIN and PUW compared with all other less wealthy categories (Table 3), and households buying water had significantly higher PIN/PUW. Negative correlation of PIN/PUW with *central water supply* indicated that access to piped water has increased convenience. Households considered it the safest source because, regardless of the water utility's performance, residents depend highly on the PWS (Shrestha et al., 2017).

As a composite proxy of physical dimension, the OI can be used to compare small communities on water security. In this study, wide variation in water security between clusters was identified as the OI varied from 0.254 to 0.697 (Fig. 3). Of clusters, 50 percent were below the OI value 0.52. To redirect limited resources, application of the OI can determine areas rich or poor in water security. In the study area, for instance, OI values were lowest in Maharajgunj, Madhyapur Thimi, and Mahankalchaur (in ascending order) KUKL branches, indicating they should be prioritized. Other OI assets are its key dimensions. Comparison between key dimensions in each area can further identify poorly performing dimensions that need improvement. For instance *consumption*, *access to alternate water sources*, and *social capital* were poorly performing in KUKL branches with low OI values. On a lighter note, standard deviation of each key dimension can further rank it on the basis of inequality within the community. Hence, the OI and its key dimensions are useful measures to design water- scarcity averting programs, specific to particular communities' needs.

4.2. Study area specific findings

KUKL branches with the lowest OI values were Maharajgunj, Madhyapur Thimi, and Mahankalchaur, which had three common, poor performing key dimensions: *consumption*, *alternative water sources*, and *social capital*. Our results showed wide variation in water consumption (LPCD) in the study area. Water supply pattern is a determinant of water consumption (Fan, Liu, Wang, Geissen & Ritsema, 2013). In the valley, piped water supply greatly varied depending upon utility service areas, altitude of the household location etc. (Shrestha et al., 2017) that might have contributed to the wide variation in water consumption. In addition, use of groundwater or tanker water was associated with higher volume of water consumption in the valley (Shrestha et al., 2017). There is a large proportion of population which does not use tanker water ($3/4^{th}$) and small portion that does not use groundwater ($1/3^{rd}$) (Shrestha et al., 2017) which could have attributed to wide variation in water consumption in the study area. The utility KUKL performs poorly in the study area, providing short supply hours per week (Guragai et al., 2017), so alternative water sources are crucial for maintaining sufficient amounts. When a community is not rich in diverse alternative sources for a swelling population, consumption could be compromised. Furthermore, absence of *social capital* could prevent potential good management of available water resources. Lack of social capital hinders collective action for community-based water and sanitation initiatives (Bisung and Elliot, 2014). Indeed, investment in building social capital may have some benefit in addressing common environmental challenges (Bisung, Elliot, Schuster-Wallace, Karanja & Bernard, 2014). These findings suggest that in these three KUKL branches, initiatives can awaken communities to collaboration and collective management of existing water sources for sustainable use. They can also explore new resources like systematic rainwater harvesting, for instance, for better water security. Additionally, KUKL can reallocate the PWS while increasing the amount supplied in these areas and reducing it in more water-secure areas.

As for QoL in this study, PIN was associated with all four domains, OI with three, and PUW with two. These findings provided empirical evidence that water scarcity not only distresses people emotionally and psychologically, but affects overall well-being. Additionally, these findings are evidence that water-scarcity impacts males and females alike in the Kathmandu Valley, where previously, only females were participants in such investigations (Aihara et al., 2015). Despite the female gender bearing the incomparably huge responsibility for water management (Wutich & Ragsdale, 2008), a gender gap did not exist either for PIN or PUW in this study, and males reported higher OI than females. Women's increasing employment and decreasing family work (ILO, 2016) could have resulted in men's involvement and experience in managing water. Or, due in part to chronic water scarcity, responsibilities of water acquisition and use may be dispersed across household members (Jepson et al., 2017).

Besides water security metrics, gender, caste, and education were significantly associated with QoL domains. On the basis of social hierarchy, the Dalit caste is the most underprivileged group with the lowest socioeconomic status. Although better socioeconomic status positively correlated with better life satisfaction (Daraei & Mohajery, 2013), interestingly, Dalits have better QoL compared with that of upper castes (Brahmin, Chettri, Janajati). This could be because as a deprived group, Dalits might have lower life expectations. However, investigating these findings more deeply will be exciting. Obviously too, people with higher education had better QoL compared with the less educated and the illiterate; better education helps attain healthy lifestyles, more paid work, and better socioeconomic status (Ross & Wu, 1995).

4.3. Limitation

Our findings should be interpreted in the light of a limitation. A community level water security metric that defines physical dimension is a rather new area. Hence, its proper validation is a difficult issue. However, this study investigated its appropriateness by: i) examining its predictive ability of QoL and ii) comparing it against a well-designed WIS. Besides the OI's significant relationship with QoL, the direction of the association was the same as that of WIS factors. In addition, there are multiple similarities between variations of OI and WIS factors across socio-demographic and water-related characteristics. However, these simple and indirect validation approaches do not compensate the statistical soundness of index creation that will be pursued in future papers. Except for this limitation, this study provides a unique metric to measure water security at the community level and to define useful physical dimensions that identify some water-insecure areas against others and allocate limited resources judiciously.

5. Conclusions

This study introduced for the first time an objective assessment that measures the physical dimension of water security on a micro/ community scale. The OI is a composite index that grasps the multidimensionality of water security. Significant association of the OI with QoL and similarities of the OI with factors of the well-established WIS provided indirect validation of the metric's appropriateness. The OI revealed notable differences across clusters and the utility's service areas in the study setting. Comparison of key dimensions' performances within a community could suggest areas that need improvement in water security. Over all, the OI and its key dimensions could be useful measures to design water-scarcity averting programs and policies specific to a particular community's needs. This study's empirical focus was water-scarce urban areas of developing countries. Similar models based on household water use behaviour could be helpful in assessing the physical dimension of water security in similar settings. This study also provided empirical evidence that water scarcity not only distresses people emotionally and psychologically, but also affects their overall well-being. The findings of association of water security with well-being suggests that the health-related costs of water security could be even higher than previously anticipated (Wutich, 2009). Besides conventional quantifiable components of physical assessment, *social capital* was added as a key dimension of OI with the expectation of capturing water-management initiatives by society or social groups that can be included as a policy measure to improve water security.

Ethical approval

The ethical review board of the University of Yamanashi, Japan and the Nepal Health Research Council, Nepal reviewed and approved the study protocol, with application number 1 (November 28, 2014) and 262/2014 (January 18, 2015), respectively.

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