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RESEARCH PAPER



# Water poverty in the context of climate change: a case study from Karnali river basin in Nepal Himalaya

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**ABSTRACT**
It has long been recognized that there is a link between sustainable development, poverty and consistent access to useable water. Increased population is requiring more water and changing climate is altering the hydrological cycle making the water less accessible at the time when it is required. Combining the measurement of water availability and the socioeconomic capacity towards its access gives new insights in the fields of water resources management and poverty alleviation, which ultimately address the agenda of sustainable development. This paper customizes the water poverty index (WPI) indicators to encompass the climatic extremes and social settings to analyse the water stresses to the community people and their capacity to manage the water extremes focusing on the water availability in climatic variability condition in Karnali river basin in western Nepal. The indicators of the WPI were based on the multiple aspects of water focusing to water quantity and availability. The WPI is not only a useful tool to monitor progress; but it can even be used to identify areas of greatest need, thereby enabling prioritization of action in the water sector.

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Water poverty; climate; Karnali; Nepal; socioeconomic

## Introduction

Major challenges to addressing poverty throughout the world are both to locate where it is most concentrated, and to identify its causes (Nihila *et al.*, 2012). Though it is complex, the relationship between water and poverty is fairly established (Giné Garriga and Pérez Foguet 2013). Lack of safe water and poverty are mutually supporting to each other as access to source of water consistently is crucial to reduce poverty. For instance, availability of quality water significantly contributes to reduce family expenditures on health and hygiene, and the time which can be used to other productive sectors (Hussain and Giordano 2004). Water poverty may prevail not only due to insufficient water for basic needs but also due to the fact that people cannot afford water (Komnenic *et al.* 2009). There is two ways vicious relationship between income and water accessibility: people might lack water because of their poverty and they might be poor because they lack adequate water (Kher *et al.* 2012). It is widely recognized that water is both an essential part of livelihood systems, and sometime its presence is detrimental when it is untimely and in places where not needed (Cook *et al.* 2007, Ahmad 2003). Water is seen as one of the most critically stressed resources, due to climate change (Shrestha and Aryal 2011) and over population, particularly in cities, lack of institutional capacity to manage the available water (Shahjahan and Harvey 2012) and much attention is now being paid at global water stress and the water needs of the poorest people. It is predicted that one third of the developing world will face severe water shortages in the twenty-first century even though large amounts of water will continue to annually flood out to sea from water scarce regions (Keller *et al.* 2000). Improper water management undermine both human capital (through morbidity) and natural capital (through pollution), providing a major shortcoming to welfare growth. As a result, suitable management of water resources has an important role to play in poverty alleviation in developing countries (Garriga and Pérez-Foguet 2008). Perhaps, one of the most notable international events to address those issues was the UN World Summit on Sustainable Development (2002) which adopted Millennium Development Goals (MDGs), and the goals were updated and replaced by another summit in 2015 called Sustainable Development Goals (UN 2015). The goal#6 (ensure availability and sustainable management of water and sanitation), goal#10 (reduce inequality among and within countries) are directly linked to the water availability in usable form and goal#1 (end poverty in all its forms everywhere) is also significant because water is a fundamental basis of all life, nobody can be lifted out of poverty without adequate access to water.

Physical science and hydrological modeling, which require many dataset, can provide us with detailed assessments of water resource availability, however due to unavailability of the geo-physical datasets and inability of those models' skill to capture the hydrology of the mountain basins like Karnali those assessments are limited in use. A number of numerical indices have been developed to assess the water demand and scarcity using physical, social and economic information (Garriga Ricard and Foguet Agustí 2010). Also, many indicators have been used and developed in different parts of world to quantify and document the state of water availability against water demand and identify water stressed areas (Feitelson and Chenoweth 2002). Indicators like Falkenmark Water Stress Indicator (Falkenmark *et al.* 1989), water scarcity (Heaps and Raskin 1998), Water availability index (Meigh *et al.* 1999), Water Resources Vulnerability Index (Paul 1997) are being used and most of them are based on only one dimension of the water resource. The Water Poverty Index (WPI) introduced by (Sullivan 2002) is a holistic water

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management tool for managing water stress at the community level (Sullivan *et al.* 2003). WPI incorporates the household and community level information and helps to aid national decision makers, donor agencies, in effective monitoring of available resources and management of the socio-economic factors which impact on those resources (Lawrence *et al.* 2002). It also helps in the comparison and ranking of communities and nations with an account of both physical and socio-economic factors associated with water scarcity. On top of that, the framework can be easily localized and one of the most attractive features of the indicator is that it is based upon causal connections between the water situation and adaptive capacities, both financial and institutional (Feitelson and Chenoweth 2002). It can be used to determine a priority for action and to monitor progress towards targets. It consists of five major components (Table 1): Resources, Access, Capacity, Use and Environment each with several sub-components. Resources means physical availability of surface and ground water, Access means extent of access to safe water for drinking and cooking and also for irrigating crops, Capacity means effectiveness of people's ability to manage water that is interpreted in the sense of income to allow purchase of improved water, and education and health which interact with income and indicate a capacity to lobby for and manage a water supply, Use means the ways in which water is used for different purposes. It includes domestic, agricultural and industrial use, and Environment means evaluation of environmental integrity related to water and of ecosystem goods and services from aquatic habitats in the area (Nihila *et al.* 2012). On those five major components, in this research we have added climate change component under the 'environment' as this is pressing problem for water poverty in recent context. Few authors have already modified the original WPI indicators based on the site specific needs and data availability (Van Ty *et al.* 2010, Jemmali and Sullivan 2014).

Water poverty level of Nepal is increasingly high because of poor water quality, inadequate supply of water, high irrigation demand, low economic growth, increasing population, and less human and institutional capacity to manage the existing water in an efficient and effective way. Moreover, natural factors such as high variability of rainfall (Panthi *et al.* 2015, Dahal *et al.* 2016, Karki *et al.* 2017, Shrestha *et al.* 2000) and their impacts on river flow, harsh topography that limits transferring water from one place to another are pushing the water poverty level up (WWF 2012). In the mid-hill and high mountain regions of Nepal, most households have little or no access to basic social services such as primary health care, higher education, clean drinking water and sanitation services. The poverty survey conducted by the Central Bureau of Statistics during 2010/2011 reflects that 25% of the total population is below the poverty line and the percentage boosts extremely in the rural regions (Thakur *et al.* 2017, CBS 2014). The water poverty within a basin is analysed to (a) enable a better target of those people who are adversely affected by inadequate access to water, (b) identify how water scarcity induces poverty, and (c) help understand to what extent it could be alleviated through sound water resources management (Pérez-Foguet and Giné Garriga 2011). Western Nepal where Karnali basin is a major part has been experiencing increasing incidences of drought in the recent past (Sigdel and Ikeda 2010, Karki *et al.* 2017) and large scale meteorological phenomenon are one of the reasons for the drought. As an example winter drought in western Nepal in 2009 was caused by the inter-annual variation of arctic oscillation, warming of sea surface

**Table 1.** Major components and sub-components, information sources and their functional relationship with water poverty.

| Major components | Sub components | Source of information | Functional relationship with WPI |
|---|---|---|---|
| 1. Resource | 1.1 Runoff potential (nearby river) | DHM | Higher is the potential, higher is the availability and then lower is the poverty |
| | 1.2 Rain potential | DHM | Higher the potential, higher is the chance of accessibility |
| | 1.3 Reliability of water supply | Grey literature | Reliability reduces the water poverty |
| | 1.4 Number of perennial ponds or lakes | NLCDC | Negatively attributed, it makes higher accessibility of water in dry time |
| 2. Access | 2.1 Time to reach to the water source (drinking water) | Survey | Higher is the time, higher is the water poverty level |
| | 2.2 Number of months the irrigation water is enough for farming | Survey | Higher the number of months, lower the water poverty |
| | 2.3 Percentage coverage of pipe water supply (drinking water) | DWSS | Higher the coverage. Lower is the poverty |
| 3. Capacity | 3.1. Economically active population | CBS | Higher the active population, higher is the income that people can alternatively manage water |
| | 3.2 Literacy rate | CBS | Literate do have better idea to manage water |
| | 3.3 Improvement in water-use efficiency in the basin, in the period studied | Survey | If presence lowers the poverty |
| 4. Use | 4.1 Percentage of irrigated land | CBS | Higher percentage lowers the poverty (Namara *et al.* 2010) |
| | 4.2 Water consumption (per person per day) | Survey | Positively attributed |
| | 4.3 Water conflict reported in last six months | Survey | Positively attributed, high conflicts means no coordination |
| 5. Climate change and environment | 5.1 Area with natural vegetation | ICIMOD/NASA | Higher percentage lowers the poverty |
| | 5.2 Variability in annual rainfall amount | DHM | Higher pushes the poverty level high |
| | 5.3 Increase in temperature (per year) | DHM | Higher increase makes water more variable and pushes up the poverty |
| | 5.4 Number of flood events in past 10 years | UNISDR | Positively attributed because those disaster limits the water availability |
| | 5.5 Number of drought events in past 10 years | UNISDR | Positively attributed because water demand increases in drought condition |

temperature in Indian Ocean and increased concentration of aerosols in atmosphere (Wang *et al.* 2013).

The main purpose of this paper is to apply WPI framework as a tool to analyse and visualize the water poverty situation using the available physical data and current social knowledge taking the Karnali basin as a case study. As a secondary approach, because the Himalayan mountain region including Nepal is highly affected by the change in climatic system, we aim to customize the WPI indicators adding climatic components. While modifying the indicators, 'climate change and variability' component has been added to the conventional WPI indices so that the climate stresses coupling with geographic, resource and socio-economic limitations are well captured in a single mapping, and the analytical framework is coherent with the global change phenomenon such as climate change and its variability. Yet, another purpose of the research is to identify the water poor areas in the Karnali basin taking representative areas as study sites. This type of water poverty assessment is the first to the Karnali river basin. A study was carried using WPI in Nepal taking few small-sized watersheds (Pandey *et al.* 2012) to see the water poverty variation and similar study was carried out in upper Bagmati basin in Central Nepal to identify the water stresses in different villages (Thakur *et al.* 2017). This paper adds value to ongoing researches by adding climatic components in the analytical framework and piloting the index in an understudied region.

## Materials and methods

### *Study area*

Karnali river basin is laid in the mid and far western development region of Nepal. The Karnali is a trans-boundary river that enters from China and passes to India through Nepal and more than 90% of the basin area lies in Nepal. The Karnali River is an antecedent river meaning that the river was formed before the formation of the Himalayas (Hagen 1960). Rain, snow, groundwater are the major components of the hydrological cycle in the Karnali basin (Dhami *et al.* 2018) and 80% of the total rainfall occurs only in the summer monsoon season (Khatiwada *et al.* 2016). Western Nepal has experienced consecutive and worsening winter drought conditions since 2000, culminating in a severe drought episode during 2008/2009 (Wang *et al.* 2013). The decreasing trend of rainfall and increasing trend of temperature (1981–2012) in the Karnali basin may aggravate the situation that leads to poor quality of livelihood, thereby increasing vulnerability (Khatiwada *et al.* 2016). Karnali River Basin and its watersheds are among the most vulnerable ones in Nepal due to climate change (ADB 2012) mainly because of severe drought condition, human, physical and ecological risk coupled with extreme climate. We selected three districts for surveying: Humla – a highland district, Kalikot – a mid-hill district and Kailali – a lowland district in the Karnali basin. As per the national census 2011, the poverty rate in Kalikot is 59%; the rate in Humla is 56% while in Kailali it is only 34%. Only 58% of the people in Kalikot district have access to safe drinking water. The major source of drinking water in the district is piped supply (58%) followed by natural spring. The drinking water access rate in Humla is 70% and the water is mostly supplied by pipe (70%) followed by spouts. The situation in Kailali is far improved. The safe water accessibility coverage is 94% and private tube-wells are the major sources (81%) followed by pipe supply. Being in hilly region, rain-fed agriculture is the major occupation of the people in Kalikot and Humla district while canal irrigation system is well covered in Kailali district (CBS 2014).

### *Data source and survey procedure*

One Village Development Committee (VDC) within the sub-watershed as shown in Figure 1 was selected from each of the

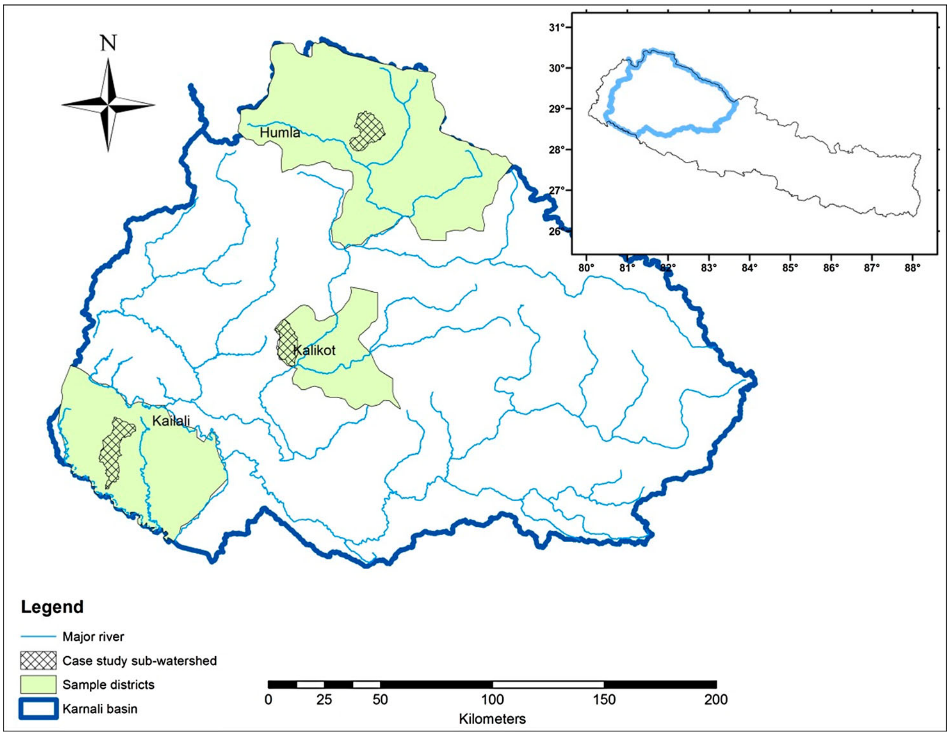


**Figure 1.** Karnali river basin in Nepal and case study sites for WPI study.

**Table 2.** Index value for major components and their sub-components.

| Major component | Sub-components | Index value for Kailali | Kalikot | Humla | Value for major components Kailali | Kalikot | Humla |
|---|---|---|---|---|---|---|---|
| 1. Resource | 1.1 Runoff potential (nearby river) | 1.0 | 1.0 | 1.0 | 0.8 | 0.6 | 0.8 |
| | 1.2 Rain potential | 1.0 | 0.7 | 0.4 | | | |
| | 1.3 Reliability of water supply | 1.0 | 0.5 | 0.8 | | | |
| | 1.4 Number of perennial ponds or lakes | 0.3 | 0.0 | 1.0 | | | |
| 2. Access | 2.1 Reciprocal of one way time to reach to the water source (drinking water) | 1.0 | 0.0 | 0.7 | 0.8 | 0.3 | 0.3 |
| | 2.3 Number of months the irrigation water is enough for farming | 0.5 | 0.2 | 0.1 | | | |
| | 2.3 Percentage coverage of pipe water supply (drinking water) | 1.0 | 0.7 | 0.0 | | | |
| 3. Capacity | 3.1 Economically active population | 0.4 | 0.4 | 0.5 | 0.5 | 0.4 | 0.5 |
| | 3.2 Literacy rate | 0.5 | 0.4 | 0.3 | | | |
| | 3.3 Improvement in water-use efficiency in the basin, in the period studied | 0.5 | 0.5 | 0.8 | | | |
| 4. Use | 4.1 Percentage of irrigated land | 0.8 | 0.2 | 0.3 | 0.6 | 0.1 | 0.2 |
| | 4.2 Reciprocal of water consumption (per person per day) | 0.0 | 0.1 | 0.3 | | | |
| | 4.3 Reciprocal of number of water conflict reported in last six months | 1.0 | 0.0 | 0.0 | | | |
| 5. Climate change and Environment | 5.1 Percentage of area with natural vegetation | 0.6 | 0.7 | 0.3 | 0.4 | 0.3 | 0.5 |
| | 5.2 Reciprocal of percentage change in annual rainfall amount | 0.1 | 0.1 | 0.0 | | | |
| | 5.3 Reciprocal of average change in temperature (per year) | 1.0 | 0.2 | 0.0 | | | |
| | 5.4 Reciprocal of average number of flood events in past 10 years | 0.0 | 0.2 | 1.0 | | | |
| | 5.5 Reciprocal of average number of drought events in past 10 years | 0.5 | 0.5 | 1.0 | | | |
| | Integrated Water Poverty Index (WPI) | 0.63 | 0.35 | 0.45 | | | |

three districts for the household survey. The districts were selected using multi-criteria: elevation, river network, atmospheric temperature, precipitation, socio-ethnic settlement and accessibility. The village within sub-watershed in each of the districts was selected based on the stakeholder's consultation, and avoiding extreme cases in most of the indicators. Key informants such as district water supply and sewerage officer, disaster management coordination committee, irrigation officers were also consulted for primary data. The survey was conducted in April 2015, just before the major earthquake that stroke Nepal (April 25, 2015) and in May–June 2017 with a set of standardized questionnaire. We selected 25 participants from the Hepka VDC in Humla, 20 participants from Gadariya VDC in Kailali district and 10 participants from Kotbada VDC in Kalikot district. Household head was identified and interviewed, in the absence of the head of the household during our visit, another member were participated in this survey, but no respondents were less than 25 years to reduce bias in historical recall. Secondary data were collected from multiple sources that include government, UN official records and grey literature. Records of landslides and flooding events at a district level were collected from the United Nations International Strategy for Disaster Reduction – UNISDR (UNISDR 2014). The UNISDR collects that disaster information from different sources such as newspaper. One of the limitations of the information from the UNISDR is that it does not record the magnitude of the disaster, however one can assume that those disaster reported in media are of high concerns. The climate change component was encompassed into environment component of the existing WPI indicators because the climatic indicators are also part of the environment as a whole. Temperature and rainfall data for the weather station in each district but near to the case study watershed were collected from the Department of Hydrology and Meteorology (DHM), Kathmandu, Nepal. These data were collected from 1981 to 2012 from the respective stations, for Kailali (station index: 215, Godavari), for Kalikot (station index: 202, Chainpur Bajhang) and for Humla (station index: 311, Simkot). For Kalikot district the station at Bajhang is considered due to the unavailability of the climatic station in Kalikot, and both the districts are located in the same altitudinal and physiographic regions. The missing precipitation data were not included in the precipitation analysis, while the year with more than two months of missing data were not considered for the temperature analysis. We calculated the average rise in temperature and average annual rainfall variability with the station observed data for the three districts. Because the physical and social data were collected from various sources, inconsistencies are inevitable (Pandey *et al*. 2012). However, careful attention was given while using the data in the analysis for evaluating the water poverty situation in the study areas.

### *Water poverty index (WPI) calculation*

Each of the five major components of the WPI comprises several indicators or sub-components (Table 1). Sub-components considered under each major component, the source of information, and their functional relationship with water poverty are also presented (Table 1). The subcomponents within the major components of the water poverty were customized to the local context in consultation with field-level stakeholders including local government bodies such as district development committee.

Each of the components was standardized within the range of 0 to 1 using the min-max approach applied for indexing the Human Development Index (HDI) using the formula shown in equation 1 below. Then simple arithmetic mean was computed to get the index value for major components as well as for the entire poverty index for a particular location with equal weightage to each of the sub-components and major components.

$$\text{Index of sd} = \frac{\text{Sd} - \text{Smin}}{\text{Smax} - \text{Smin}} \quad (1)$$

Here, Sd is the original sub-component for the district d, Smin and Smax are the minimum and maximum values (reflecting high and low water poverty), respectively, for each sub-component determined using the data from all three districts and the entire Karnali basin. The calculated

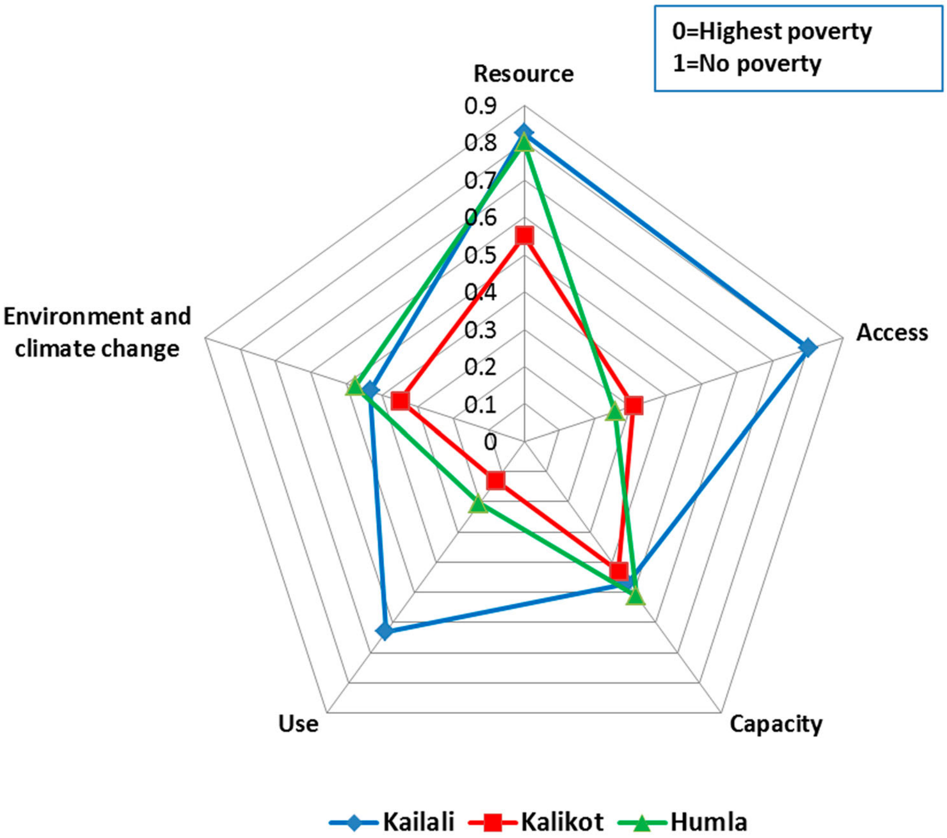


**Figure 2.** Spider diagram showing the index value to major components of WPI.

WPI ranges from 0 to 1 and higher the WPI value lower is the water poverty and vice versa.

## Results

The water poverty level for Kalikot district, a mid-hill district in the Karnali basin is highest (0.3533) followed by Humla (0.4498), mountain district. Consequently the water poverty level at Kailali district, which is a lowland area, is lowest (0.6319). The mid-hill and mountain districts have higher water poverty than the national average which is 0.541 for Nepal (Lawrence *et al*. 2002). The WPI value for Indrawati sub-basin, a part of Koshi basin in eastern Nepal, is 0.52 ranges from 0.4 to 0.65 (WWF 2012). It reflects that the value for Kalikot in Karnali district is far-less than the minimum value of the villages in Indrawati. Moreover, the water poverty situation in the Kalikot and Humla districts of Karnali is worse than Babai, Bagmati, Kamala and Kankai watersheds of Nepal (Manandhar *et al.* 2012). In a study carried out in the Kali Gandaki river basin in Western Nepal, the average WPI value for the basin was found to be 0.49 ranging from 0.37 to 0.56. It implies that the water poverty situation of the Kalikot district in Karnali could not fit into the WPI range of Kaligandaki basin districts. The major factors pushing the water poverty of Kalikot high are climatic and environmental change, water availability and reliability and the people's capacity to manage the available water resources. Kalikot is among the very high vulnerable in drought and high vulnerable to climate change (NAPA 2010). Due to availability of private well in each of the households' areas and having irrigated lands in Kailali, its water poverty level is the least; both the factors are the characteristics of lowland areas of Nepal. In Kalikot district, all the major components of water poverty have the lowest value that ultimately defines the district as the one with highest water poverty. The major components of WPI for the district can be listed in descending order as: Use > Access > Environment and Climate Change > Capacity > Resource. In our survey, people reported that there are water conflicts while fetching the water from community tap and irrigating their agriculture fields. That is obvious because the water is not accessibly available to the district. The second lowest value is for 'Access' and 'Environment and climate change'. Since the later component is quite far from the local people's control, providing adequate water through pipeline supply to people's household may significantly increases the access. Interestingly, in Kailali district, the lowest water poor district, all the components have the highest value except 'Environment and climate change' component which is in second position after Humla. The major components to the district can be listed in descending order as: Environment and climate change > Capacity > Use > Access and Resource. The highest numbers of flood frequency and drought incidences are the major indicators for declining the 'Environment and climate change' component to the district. In Humla, the highland district, most of the major component values are in between Kalikot and Kailali district. The components can be organized in descending order as: Use > Access > Capacity and Environment and climate change > Resource. Water conflicts in community taps and less percentage of irrigation facilities to cultivable areas are contributing to declining the 'Use' component. Overall, resource availability is not a problem in the basin. However it is not used properly due to lack of human and institutional capacity to manage the available water and topographic challenges that makes water inaccessible (Figure 2).

The average increase in temperature in the Karnali basin is 0.03°C per year (Khatiwada *et al.* 2016) which is slightly less than the national average (Baidya *et al.* 2008), while the maximum temperature trend 0.05°C (Khatiwada *et al.* 2016) which is similar to the national average (DHM 2017, Shrestha *et al.* 1999). There is decreasing rate of annual precipitation and the precipitation itself shows significant spatial variation. Average temperature change is always positive and the rate is higher in high altitude regions (Khatiwada *et al.* 2016). With the variability in rainfall amount and timing, agriculture system which is the major livelihood of people could be affected severely. Also, the climate variability could affect the Karnali river flow regime spatially and seasonally which needs a detailed study.

## Discussion

### *Alleviating the water poverty*

The economic poverty and the water poverty show strong linkage in the study districts. Kalikot was the water poorest among these three districts which has the least per capita income ($578 per year). Similarly Humla has the higher per capita income ($794) and Kailali the highest ($942) in these three districts (NPC 2014) that exactly follows the water poverty level. The community level water approaches discussed above will definitely help the government of Nepal to achieve its ambitious SDG targets. Nepal government under SDG targets to achieve access to safe and affordable drinking water for all by 2030, adequate and equitable sanitation to all (NPC 2015). Reducing the water collecting time by providing pipe water supply, for instance, will reduce the water poverty and help to achieve the goal#6 of SDG target of Nepal. There are several indicators used for composing a single water poverty index, however not all these indicators are in our control to overcome water poverty. For instance, we cannot change the climate and topography but there are several indicators which policy makers can address, so providing better alternatives to those which cannot be changed. Some of the potential solutions are discussed here. Since water availability, accessibility and use are the major problems prevailing in the region, effective use of available water could be one of the best and plausible options. One of the techniques is multiple and multi-purpose use of water. The same water can be used in different sectors in household activities, such as waste-water from kitchen and cleaning activities can be collected and applied for irrigation. Drying up of the natural springs in recent years is a serious issue especially in the mid-hills of Nepal. Massive construction of community ponds to harvest the rainwater may help recharge the groundwater and provide the sustainable supply in dry season. Promotion of efficient technologies such as drip irrigation system may reduce the water poverty. Development of low-cost locally produced and effective technologies are a dire need to significantly reduce the water poverty in the region.

### *Applicability of the WPI in local planning*

One of the key operating principles to proper water resource management is decentralization, meaning devolution of rights and responsibilities for water sources to the lowest appropriate level, with the central government providing policy and regulatory support. Such a decentralized approach should focus on the river basin because it is the natural unit for territorial planning, and management of water resources (Chaves and Alipaz 2007). The new federal structure of Nepal has given more water rights to the local government bodies to manage the available water in a scientific and equitable way. The WPI index could be one of the tools to prioritize water resource development program according to the poverty level and evaluate development progress. One can customize the indicator as per the user need. For instance, those living in the highland can add snow-fall and melting timing and duration in the assessment framework. However, due to the variation in indicators and scale factors, the WPI can't be compared from one site to another if its assessment is carried out using different sets of analytical framework.

### *Limitation of the WPI*

As the only indicator to assess the multiple dimensions of water poverty, the WPI, by definition, is the best tool available. However, the issue of scale continues to be challenging whilst predictions of water poverty are complex and marred by subjectivity (Fenwick 2010). A lack of consensus surrounding appropriate variables is problematic and inhibits comparisons across localities. Community perceptions of water poverty at the community level differ from the results obtained using the WPI, further questioning its reliability (Fenwick 2010). In using WPI, two conceptual weaknesses have been identified: One weakness involves how the basic input data are combined, and the other involves the statistical properties of the index (Garriga Ricard and Foguet Agustí 2010). Notwithstanding, the WPI index highlights the need for a multi-dimensional approach to the determination of water poverty, by demonstrating the lack of relationship between water resources availability and overall water poverty across scales (Fenwick 2010).

## Conclusions

The values for the Water Poverty Index vary in three elevation zones and indicate that the mid-hill (Kalikot) has the highest water poverty. Overall in the basin, resource availability is not a problem, however the available water is not used effectively. The indexed values for each component and sub-component varied noticeably across sites, which provided insight into the design and implementation of site-specific water management strategies for reducing the poverty. Among these three districts Kalikot can be improved by higher coverage of water supply and increasing its reliability. In highlands, harvesting of snow and use the melt water for livestock and irrigation has been practiced and could be replicated widely to other similar parts of the nation. In this study, we took only three districts, therefore the water poverty index value can't represent the whole basin about the complexity of the water issues as the basin is very large in area and diverse in topography and climate, however it can be a basis for further investigation and some macro level information for broader decision support system. Also, with the few study sites, we cannot generalize the results in the altitudinal zones though mid-hill district (Kalikot) has the lowest water poverty index in the Karnali basin. Moreover, this WPI is more focused to the quantity of water since the water quality information was not available; therefore a research integrating both quality and quantity is a crucial need for a holistic approach for mapping the water poverty.

Another potential research approach could be rural-urban comparison of water poverty in the basin. If the WPI is updated at reasonable intervals, it can be used to monitor the progress of any development project at local and national levels. WPI helps to prioritize the water stress areas requiring immediate attention for developing countries like Nepal.

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## Annex I: WPI calculation Procedure (An example).

| Major component | Sub-components | Unit | Value (Sd) | | | Maximum value (Smax) | Minimum value (Smin) | Sub-component Index value for | | | Major component index value | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Kailali | Kalikot | Humla | | | Kailali | Kalikot | Humla | Kailali | Kalikot | Humla |
| Access | 2.1 Reciprocal of one way time to reach to the water source (drinking water) | Minute | 1.0 | 0.1 | 0.7 | 1.0 | 0.1 | 1.0 | 0.0 | 0.7 | 0.8 | 0.3 | 0.3 |
| | 2.3 Number of months the irrigation water is enough for farming | Number | 6.0 | 3.0 | 2.0 | 12.0 | 1.0 | 0.5 | 0.2 | 0.1 | | | |
| | 2.3 Percentage coverage of pipe water supply (drinking water) | Percentage | 88.6 | 79.1 | 48.4 | 90.6 | 48.4 | 1.0 | 0.7 | 0.0 | | | |

2.1 For the time to fetch water it has a negative relationship with the WPI (Table 1), therefore its reciprocal was taken. Sd is the average reciprocal of time taken to reach to drinking water source for each of the districts, and Smax is the maximum value obtained from the survey and Smin is the minimum. The index value for Sd was computed using the standard formula given in Equation 1 [Index of sd = Sd − Smin/Smax − Smin]. This formula always gives the value between 0 and 1.
2.2 For the irrigation sub-components, it has positive relationship with the WPI (Table 1), therefore this is not taken as reciprocal. The average number of months the irrigation water is sufficient to households is the Sd value and Smax is the maximum of all the districts' household and Smin is the minimum. The same equation was applied to compute the Index value of Sc.
2.3 For the water supply coverage, it has positive relationship with WPI (Table 1), therefore no reciprocal value was taken. The water supply coverage is the single value for each of the districts and since this is in percentage unit, Smax is always 100 and Smin is 0. The Index value computation formula is the same (Equation 1).

Now, the Major component index value is the arithmetic mean of the sub-components.