Analyzing Water Poverty Components Using Geospatial Tools: Resource and Environmental Constraint in Kathmandu District

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KEYWORDS

Water poverty, Groundwater, Topographic Wetness Index, RUSLE, Resource and Environmental constraint

ABSTRACT

This current paper examines water poverty situation in Kathmandu district in terms of water resource and environment constraints. Integrated methodology was adopted for the study. Water source sample survey was carried out using GPS tool. Study area comprised total of 13 water sample sites. Household questionnaire survey was carried out for water poverty mapping and analysis. Resource component of water poverty comprised indicators, namely seasonal variation in water availability, water supply frequency and groundwater recharge potential. The environment constraint component comprised water quality rate of soil erosion and topographic wetness index. The result show that the average calculated value of water resource limitation component is 6.31 and out of 13 studied communities, 7 communities fall below average. It is found that environmental constraint is less associated with urban housing density. It is found that environmental constraint is less associated with urban housing density. The average calculated value of environmental component is 3.43 and out of 13 studied communities, 8 communities fall below average. Spatial variability in water poverty is prominent and highest water poverty is found in urban cores. Communities with lower water poverty are found in peri-urban location near the foothills. The average calculated value of water poverty is 9.74 and out of 13 studied communities, 9 communities fall below the average. The study concluded that water poverty index and resultant map is a very effective tool to visualize the distribution of water poverty at local spatial scale and to present the complex nature of water poverty.

1. INTRODUCTION

Bio-physical and socio-cultural assessment of resource and environmental constraints in water access and use in urban context is important research agenda in the wake of increasing domestic water demand. Studies show that water extraction for domestic and other use has increased with rapid urbanization in Kathmandu valley (Udmale et. al., 2016; Shrestha & Shrestha, 2013). The annual rate of change in basic water supply between 2000-2015 is -0.23, i.e. decreasing water supply, in urban area of Nepal (WHO/UNICEF, 2017).

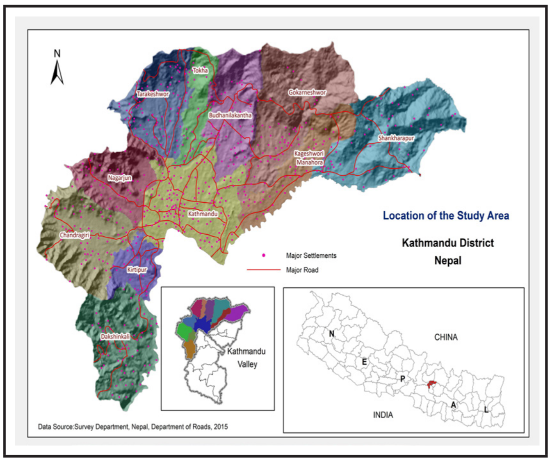
Kathmandu valley, the capital region of Nepal is most populated and rapidly urbanizing region. The rapid urbanization and subsequent expansion of the built-up area has increased the spatial extent and demand of household water use. The implication of rapid population increase and degree of urbanization is water shortage and degraded water quality. Projected water demand for Kathmandu Municipality was 147mld for 2011 and 195mld for 2016 (Udmale et. al., 2016). The household water demand of Kathmandu valley in 2020 is 420 mld whereas average production is only 129 mld and supply through the water supply authority is only 103 mld excluding 20% real loss during supply (KUKL, 2020). The differential spatial distribution of water sources, differential capacity to access in one hand and improper utilization and management on the other, results conflict/rivalry and overuse of natural resource leading to water poverty. In this context, understanding and confronting the water resource availability and environmental constraints at urban household level becomes imperative.

A variety of methods, tools and techniques has been applied to examine and address the problem of water availability and access, equitable allocation and resource management. Spatial analysis and mapping of water poverty has become appealing research area in geographical research with the advancement of geospatial tools and spatial data availability. GIS-based spatial overlay and multi-criteria analysis devising analytic hierarchy process, AHP is becoming widespread in evaluating water poverty analysis involving multiple and diverse criteria (Estoque, 2012). Water poverty concept integrates water scarcity (bio-physical resource condition) with social and economic dimension of water resource management (Pan et. al., 2017). It is referred to as a condition where a nation or region cannot afford the cost of sustainable clean water to its people (Feitelson & Chenoweth, 2002). The most common tool used to analyze water poverty is Water Poverty Index, WPI (Tahmineh et. al., 2021). The concept of the WPI was originally developed by Sullivan (Sullivan, 2002; Sullivan et. al., 2002) as a tool, with total of 17 indicators, integrating both physical and social aspect of water allocation and management. WPI comprises five components, namely resource, access, capacity, use and environment.

Growing demand and extraction of groundwater in has intensified the resource condition which has lessened physical access to resource in some parts and has escalated vulnerability in other areas. Examining variations in water resource availability, access and constraints in terms of place vulnerability is very limited and most them are confined to climate change and environment rather than on resources access and use (Aksha et. al., 2019; Falkenmark, Lundqvist, & Widstrand, 1989). Besides, the earlier studies on water poverty of the country indicates that Bagmati basin is among one of the water poor area (Pandey et. al., 2012). In this context, this paper examines water poverty situation in Kathmandu district in terms of water resource and environment constraints.

2. STUDY AREA

Kathmandu district is the capital region of Nepal comprising 11 local administrative units with 1 metropolitan and 10 municipalities. The total area of the district is 413.6 km^2. It is located in the central hill region of the country and elevation ranges from 1023 to 2571 meters. The location map of Kathmandu district, the study area is presented in Figure 1. The average rainfall is 1400 mm, most of which occurs during months of June to August (DWIDP, 2009). The district comprises two primary landforms namely, river floodplains and elevated river terraces and are regarded as one of the most productive agricultural regions of the country. Major geomorphological divisions of the district include hill slopes, rocky outcrops, terraces, flood plains mostly with the lacustrine surface and riverbed (JICA, 2018). Bagmati River is the main river of the district flowing from north to south with tributaries like Bishnumati, Dhobi khola, Balkhu Khola and Manohara.



Data Source:Survey Department, Nepal, Department of Roads, 2015

Figure 1: Study Area

According to preliminary result of national census 2021, Kathmandu is the most populated district among 77 districts of the country comprising 6.91% with total population of 20,17,532. It has highest population density of 4885 person/km^2 and holds the largest number of urban population of the country.

3. DATA AND METHODS

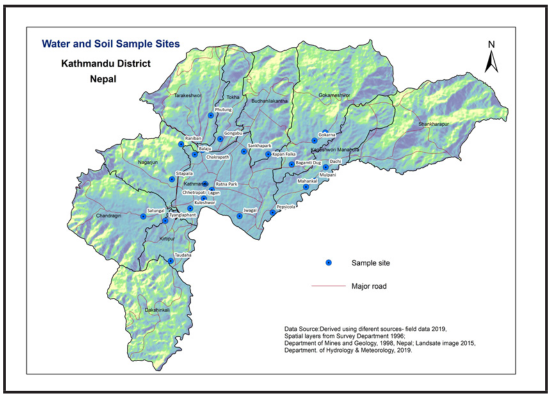
The study is based on primary and secondary data sources. Field data collection tools were developed for sample water sources, community and household survey, KII and FGD. Reconnaissance survey and field observation was carried out prior to water sample and household (HH) questionnaire survey and sample checklist was tested randomly. HH survey, KII and FGD were carried out to collect data and information on water availability and use, water demand, consumption and household water issues and problems.

Sample water source location was recorded using GPS and related information is recorded in GPS inventory sheet. Field survey checklist was prepared for Key informant interviews and Focus Group Discussion. Field survey questionnaire was used for household information collection. Informal discussion and community survey was carried out using Water Poverty Indicator checklist. Most of the spatial data required for resource and environmental components of water poverty analysis were collected from secondary sources and others were derived from Spatial data and their sources are presented in Table 1.

Table 1: Spatial Data source.

SN	Spatial data layer	Source
1	Groundwater sources: Shallow/ Deep wells	KUKL, KVWSMB and DoMG, 2019
2	Geology, Lithology, Lineaments	Department of Mines and Geology, 1998
3	Geomorphology	JICA, 2018
4	Soil	SOTER, Nepal. 2009
5	Rainfall	DHM, 2019
6	Administrative Boundary, settlements,	Topographical Sheets, Survey Department, 1998, 2021
7	Land cover / use	Derived from Google Earth, 2019
8	Drainage Density, Slope, Topographic Wetness Index (TWI)	Derived from SRTM DEM 30m USGS/ NASA, Topographical Sheets, Survey Department, 1998

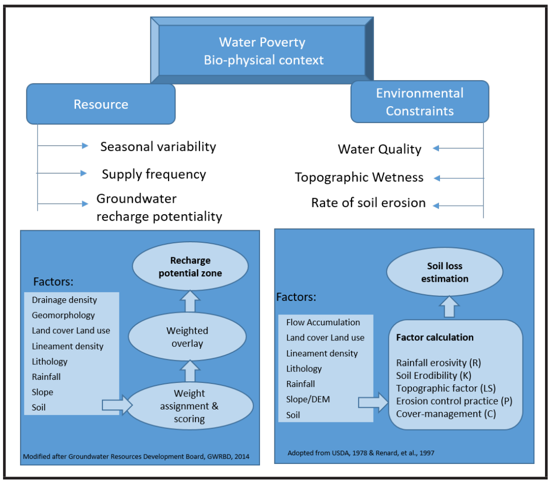
The stratified spatial sampling method was adopted for selecting sample water source locations, the community water users (for public well) and household users (for private well). The stratified sampling method is used because study sample was of mutually exclusive and exhaustive subgroups. Sample selection reference was based on monitoring well of KUKL located in 13 different locations (Figure 2).



Data Source:Derived using diferent sources- field data 2019,
Spatial layers from Survey Department 1996;
Department of Mines and Geology, 1998, Nepal; Landsate image 2015,
Department. of Hydrology & Meteorology, 2019.

Figure 2: Water and soil sample sites in Study area

Water poverty mapping and analysis comprises five components, namely resource, access, capacity, use and environment. Resource and environment component focus on bio-physical aspects whereas access, capacity and use incorporates socio-cultural economic and institutional aspects. These five components incorporate number of indicators depending upon geographic scale and data availability (Koirala et. al., 2020; Shadeed et. al., 2019; Merz, 2004; Sullivan et. al. 2002). relevance of water poverty analysis using Water poverty index, WPI over traditional water assessment technique is that it overcomes the weakness of spatio-temporal dimension and incorporates temporal and spatial variability and their weightage in local context priority (Sullivan et. al. 2002). The overall methodological framework of this study is based upon bio-physical aspects of water poverty. The two components of water poverty namely, Resource availability/ constraints and environmental constraint situation was examined through the methodological framework presented in Figure 3. Multi-criteria weighted summative function, modified after weighted average of Sullivan et.al. (2003) was adopted for both resource and environmental component of water poverty analysis. The calculated index value is interpreted as higher the calculated index value better is the water resource condition (Sullivan et. al., 2003). The calculated value for each component was classified into five classes: very high, High, Moderate, Low and very Low. The classification into five class value was based on the Jenks natural break method.



Modified after Groundwater Resources Development Board, GWRBD, 2014

Adopted from USDA, 1978 & Renard, et al., 1997

Figure 3: Methodological Framework

Analysis method for resource component of water poverty: Three indicators for resource component namely, seasonal variability, water supply frequency and groundwater recharge potentiality were selected for water poverty analysis. Seasonal variability and water supply frequency data were collected through HH survey and FGD. Groundwater recharge potential mapping was carried out using weighted overlay analysis with 8 spatial controlling/influencing factors listed in methodological framework. Resource component was calculated as:

$$R = \Sigma(R_g + R_v + R_f) * \Sigma(X_i + X_j \ldots\ldots + X_n) / N \quad (1)$$

Where,

Rg - is groundwater recharge potential (GWRP) which is mapped and calculated as presented in Figure 2 using equation 2.

Rv - is Seasonal variability of water availability (wet and dry season) which is based on difference in number of water supply in piped water sources and water level in shallow/deep dug wells.

Rf - is supply frequency of water ranging from 24 hours to less than 1 hour and supply duration ranging from daily to weekly.

Xi…Xn is value of component indicators and N is total number of locations (Study site/Community).

Technique identified by GWRDB (2014) was modified and adopted as following for calculating groundwater recharge potential zones.

$$GWRP = \sum(LTw * LTf + GMw * GMf + LDw * LDf + DDw *DDf + SGw * SGf +SLw * SLf + RFw * RFf + LUw* LUf \quad (2)$$

Where;

GWRP = Groundwater recharge Potential, w = weight and f = factor rate assigned to each class category of individual factor; and (LT: Lithology, GM: Geomorphology, LD: Lineament Density, DD: Drainage density, SG: Slope gradient, SL: Soil Type, RF: Rainfall, and LU: Land cover)

Analysis method for environmental component of water poverty: Three indicators for environmental component namely, water quality (turbidity, acidity (pH) and iron content (Fe)), topographic wetness and rate of soil erosion were selected for water poverty analysis. Water samples were collected from 13 sites and physio-chemical properties of water was laboratory tested using digital technology.

The Environment (E) component is calculated as:

$$E = S(E_q + E_s + E_v) * \Sigma(X_i + X_j \ldots\ldots + X_n) / N \quad (3)$$

Where,

E_q - is water quality which includes water sample testing of turbidity, iron(Fe) and acidity (pH) methodology for water quality test is provided in section 2.2.7.

E_{ss}- is rate of soil erosion, Methodology for rate of soil erosion is presented under section 2.2.8.

E_v – is vegetation (forest) cover in the community, forest cover in or within 2.5km of the community

Topographic wetness is calculated using Topographic wetness, TWI as described by Beven and Kirkby (1979), i.e., TWI = ln(α/ tan θ), Where, a = upslope contributing area (m2), b = slope in radians.

Smaller values of the TWI indicate less potential for water accumulation and soil moisture.

Similarly, rate of soil erosion is calculate using modified USLE, i.e., RUSLE model as recognized by Wischmeier & Smith, (1978) using equation 4 as following. Erosion factors were calculated as adopted by different scholars namely: R and LS factor as per Morgan & Davidson, 1991), K factor as per Sharpley & Williams (1990), C factor as per Renard, et al. (1997), and P factor as per Wischmeier & Smith (1978).

$$E = R * K * L\,S * C * P \qquad (4)$$

Where,

E = Annual average soil erosion rate

R = Rainfall erosivity

K = Soil erodibility

LS = Topographic factors

C = Land cover management factor

P = Protection factor

The potential soil loss estimation map is produced based on individual factor calculation of R, K, LS, P and C factor and integrated in RUSLE equation.

4. RESULT AND DISCUSSION

Study show that groundwater level in Kathmandu has decreased by 1 meter per year (GWRDB, 2014) and many parts of the valley are becoming critical in groundwater resource availability (KVWSMB, 2015). Three different zones for water extraction has been identified based on groundwater availability, water level, recharge potential and population/housing density in Kathmandu valley so that alarming rate of water extraction could be regulated. Safe area is the first zone for groundwater extraction and use comprises 23% of the total valley area and is confined to northern part, semi-critical area, the second zone, comprises 18.5% area and mostly include densely settled urban core of Kathmandu, Lalitpur and Bhaktapur municipalities. Southern part of the valley is identified as critical area (he third zone) in terms of groundwater extraction and use which comprises 33% of the valley area.

Resource component of water poverty included three indicators namely seasonal variation in water availability, water supply frequency and groundwater recharge potential. The seasonal and spatial variation of the static groundwater level (SGL) is found very high in the study area. The static groundwater level (Shallow wells) during wet season varied from 1.5 meters in Taudaha to 13 meters in Chhetrapati, both located in semi-critical groundwater extraction zone whereas seasonal variability of 12 meters was found in Kapan located in safe zone. Water supply frequency at household level from sources, varied in both duration and frequency. Field survey data show that, supply duration varied from 1 hour to 3 hours and frequency ranged from 1-3 daily, hours, 1-2 hours twice a week to 3 hours-once a week.

Resource potential mapping of groundwater was explored through 4 controlling factors: rainfall, geology, lineaments and slope and 4 influencing factors: drainage density, land cover land use, geomorphology and soil. The upper hill slope is mostly area of limited infiltration/recharge and covered by vegetation. Water usually accumulates in lower slopes, so only lower slope and valley floor is considered in the current study. Groundwater recharge potential in Kathmandu varies considerably. Most of the district area is moderate to low recharge potential. Fifty-one percent area is low to very low recharge potential (Figure 4). Of the total potential recharge area, only 2% area has very high recharge potential an 15% area has high recharge potential.

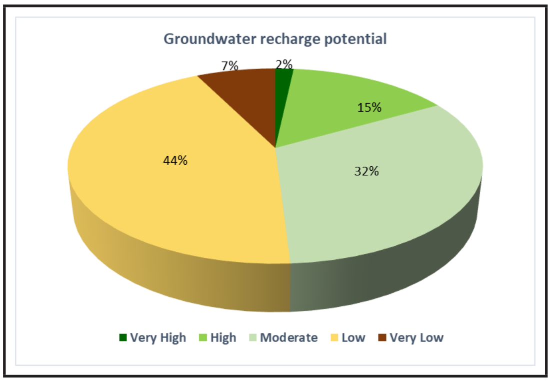
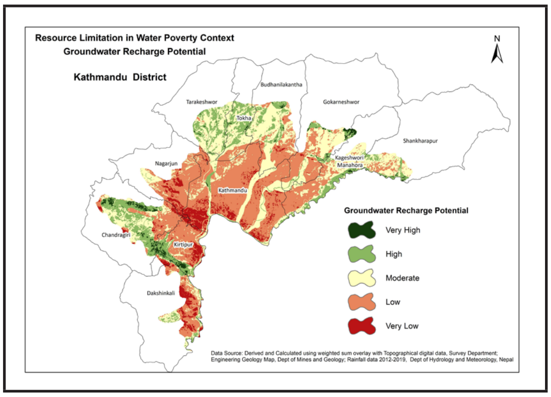


Figure 4: percent share of groundwater recharge potential area

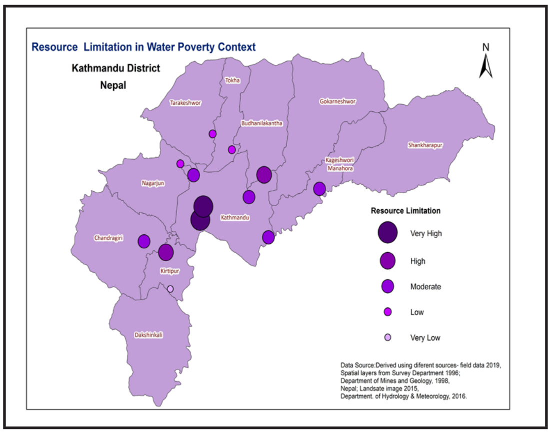
Geology and soil are dominant controlling factors on spatial distribution of recharge potential. Patches of high recharge potential area are found in Sundarijal and Chunikhel in the north, Machhegaun, Chundevi and Chandragiri in the south (Figure 5).



Data Source: Derived and Calculated using weighted sum overlay with Topographical digital data, Survey Department; Engineering Geology Map, Dept of Mines and Geology; Rainfall data 2012-2019, Dept of Hydrology and Meteorology, Nepal

Figure 5: Spatial distribution of groundwater recharge potential

Resource limitation component in the study area is calculated based on three resource component as presented in Figure 6. It is found that the dense core urban area has very limited resource. At community level resource limitation is very high in Chhetrapati, and high in Jaisidewal, Kapan and Nayabazar- Kirtipur area. The average calculated value of water resource limitation component is 6.31 and out of 13 studied communities, 7 communities fall below average. Communities located in the north-western part are relatively high in resource availability as evident from Figure 6.


Resource Limitation in Water Poverty Context

Kathmandu District

Nepal

Data Source:Derived using diferent sources- field data 2019,
Spatial layers from Survey Department 1996;
Department of Mines and Geology, 1998,
Nepal; Landsate image 2015,
Department. of Hydrology & Meteorology, 2016.

Figure 6: Water resource limitation in water poverty context in Kathmandu

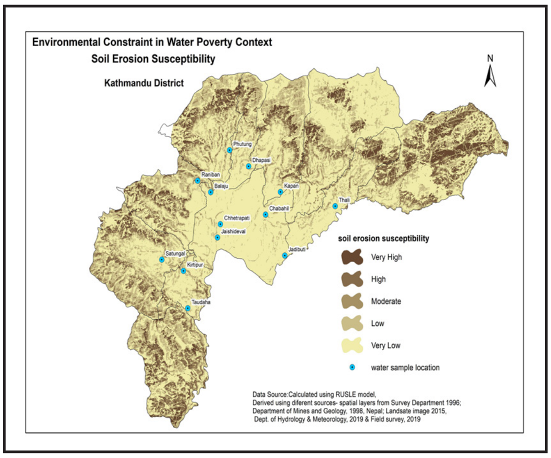
The environment constraint component comprises water quality (turbidity, iron content and pH content) rate of soil erosion as proxy to environmental degradation and topographic wetness index as proxy to natural state of ecosystem productivity.

Water quality parameters tested as per WHO standard (WHO, 1996) for environment component included 3 parameters: turbidity, iron content and pH content. The summary statistics of measured parameters for 13 water sample location is provided in Table 2. The acceptable turbidity level for drinking water is up to 1mg/liter. A highest turbidity value of 14.7 mg/liter is found in Dhapasi, which doesn't meet the acceptable WHO standard for drinking purpose whereas Taudaha and Kapan has 0.1 mg/liter turbidity. Likewise, only 4 locations among 13 samples meet the standard pH value (6.6-8.0) for drinking purpose and 9 locations has less than 6.5 pH content which may cause metal corrosion and toxic release. Iron content is also low ranging from 0.36 (in Thali) to-0.55 (Dhapasi) than drinking water standard (1-3mg/liter). The summary statistics of water sample parameters is presented in Table 2.

Table.2: Measured parameters of water samples

Statistics	Turbidity (mg/liter)	Iron content (mg/liter)	pH
Minimum	0.07	0.36	5.05
Maximum	14.67	0.55	6.7
Mean	1.86	0.44	5.98
Standard Deviation	3.74	0.06	0.47

Spatial pattern of soil erosion susceptibility plotted against 13 sample study sites show that very high soil erosion susceptible area is largely confined to northern and south-western hill slopes. Foot hills and valley floor has low to very low erosion susceptibility (Figure 7). However, in 13 study sites, moderate to low erosion susceptibility was found. Raniban, Phutung and Kirtipur are moderately susceptible whereas soil erosion susceptibility is low in all other study sites. Major controlling factor of lower susceptibility is lower slope.


Environmental Constraint in Water Poverty Context

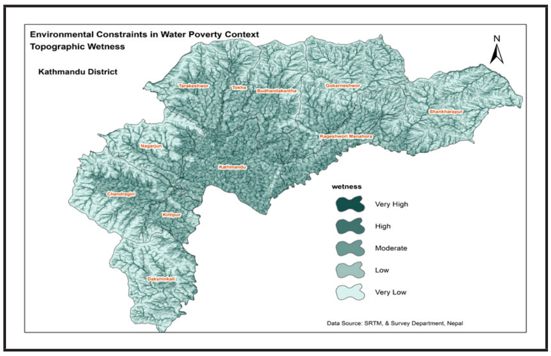
Soil Erosion Susceptibility

Kathmandu District

Data Source:Calculated using RUSLE model,
Derived using diferent sources- spatial layers from Survey Department 1996;
Department of Mines and Geology, 1998, Nepal; Landsate image 2015,
Dept. of Hydrology & Meteorology, 2019 & Field survey, 2019

Figure 7: Soil Erosion susceptibility in Kathmandu

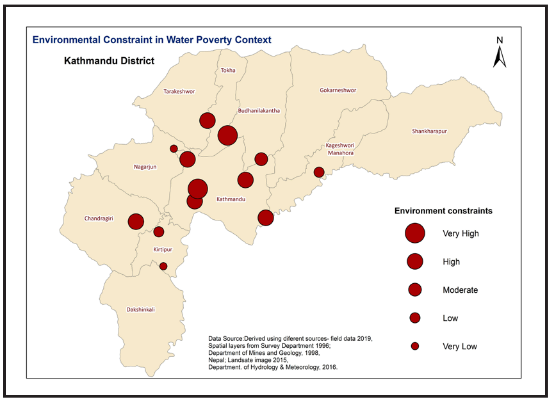
TWI is the indicator of topographic control on water distribution, runoff, direction of flow and accumulation. The calculated TWI values differs considerably depending on the topography of the landscape. Topographic wetness in Kathmandu is depicted in Figure 8. Area under very high and high wetness in combination covers nearly 13% of the total area while 63% area is under low topographic wetness and 24% area has moderate wetness.


Environmental Constraints in Water Poverty Context
Topographic Wetness

Data Source: SRTM, & Survey Department, Nepal

Figure 8: Topographic Wetness in Kathmandu

In contrast to resource component, environmental constraint was found more serious in water poverty context. It is found that environmental constraint is less associated with urban housing density. At community level, environmental constraint is very high in Dhapasi followed by Chhetrapati, and high in Jaisidewal, and Jadibuti area. The average calculated value of environmental component is 3.43 and out of 13 studied communities, 8 communities fall below average. Thimi, Phutung, and Satungal though, are peri- urban in characteristics, still has high environment constraint because of increasing urban sprawl. Kirtipur conversely, has low environment constraint largely due to open space and vegetation cover of Tribhuvan university complex as depicted in Figure 9. Taudaha and Raniban has lowest environmental constraint due to lower housing density and higher vegetation cover.


Environmental Constraint in Water Poverty Context

Data Source:Derived using diferent sources- field data 2019,
Spatial layers from Survey Department 1996;
Department of Mines and Geology, 1998,
Nepal; Landsate image 2015,
Department. of Hydrology & Meteorology, 2016.

Figure 9: Environmental constraint in water poverty context in Kathmandu

Resource limitation, environmental constraint and overall integrated water poverty at community level is presented in Table 3 and summary statistics is presented in Table 4. Chhetrapati has the highest water poverty level followed by Jaisidewal, both located in traditional urban core. It is followed by Jadibuti, Kapan and Satungal with similar WPI value.

Table.3: Water poverty at community level

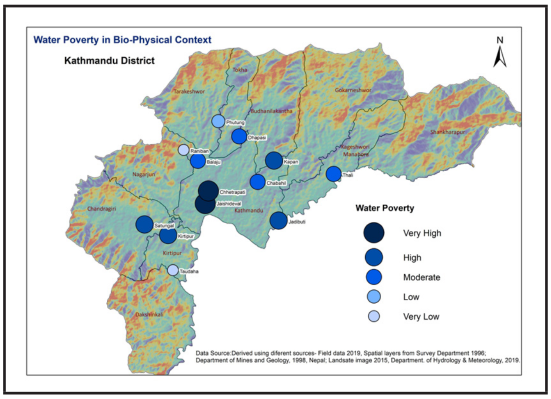
Community	Resource Limitation	Environment constraint	Integrated WPI	Water poverty rank
Chhetrapati	3.28	2.56	5.84	1
Jaisidewal	4.1	2.75	6.85	2
Jadibuti	5.74	2.75	8.49	3
Kapan	4.92	3.74	8.66	4
Satungal	5.74	2.95	8.69	5
Nayabazar	4.92	4.13	9.05	6
Chabahil	6.56	2.95	9.51	7
Dhapasi	7.38	2.16	9.54	8
Balaju	6.56	3.15	9.71	9
Thali	5.74	4.33	10.07	10
Phutung	8.2	2.95	11.15	11
Raniban	8.2	5.31	13.51	12
Taudaha	10.66	4.92	15.58	13

So far as overall water poverty is concerned, the variation is higher in maximum value regarding environment component whereas there is only slight variation in resource component (Table 4). The average calculated value of water poverty is 9.74 and out of 13 studied communities, WPI value of 9 communities fall below the average. Water poverty level of Taudaha, Phutung, Raniban, Thali and Balaju are relatively low. Standard deviation is also high as compared to individual resource and environment components.

Table.4: Summary Statistics of WPI Components

Component	**Min**	**Max**	**Mean**	**Standard Deviation**
Resource	3.28	10.66	6.31	1.96
Environment	2.16	5.31	3.43	0.97
WPI	**5.84**	**15.58**	**9.74**	**2.56**

Spatial variability in water poverty level is depicted in Figure 10. The communities with the highest water poverty tend to be the more urban cores located in central valley floor such as Chhetrapati and Jaisidewal. Recently urbanized locations like Jadibuti, Kapan, Satungal are also facing relatively high water poverty. Communities with lower water poverty tend to be the predominantly peri-urban located in or near the foothills such as Taudaha, Raniban, Phutung and Thali.



Data Source:Derived using diferent sources- Field data 2019, Spatial layers from Survey Department 1996; Department of Mines and Geology, 1998, Nepal; Landsate image 2015, Department. of Hydrology & Meteorology, 2019.

Figure 10: Water poverty in Bio-physical context

Studies show that water poverty in Kathmandu is more of an issue of mismanagement in water collection and distribution as compared to bio-physical constraint of resource availability (Shrestha, 2021; Gyawali et. al., 2019). Major distinction on water poverty is found among core urban and peri-urban area. Vulnerability of place and people has increased without effective management of resource This is exemplified by increased water poverty in communities like Kapan, Thali, and Satungal.

5. CONCLUSION

The current study exhibits that water poverty index helps to identify location specific and sector specific problems related to water resource allocation. Water poverty index and resultant map is a very effective tool to visualize the distribution of water poverty at local spatial scale and to present the complex nature of water poverty.

It is concluded that, in Kathmandu district, area with very high population concentration and high housing density has low to very low resource potential. It implies that the functioning and effective management of water authority, plays a significant role in combating water poverty issue and in depth examination of access, use and capacity components is required.

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