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Journal of Geographical Research

Volume 3 | Issue 3 | July 2020 ISSN 2630-5070 (Online)

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Volume 3 Issue 3 • July 2020 • ISSN 2630-5070 (Online)

Journal of Geographical Research

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Volume 3 | Issue 3 | July2020 | Page1-39
Journal of Geographical Research

Contents

ARTICLE

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Journal of Geographical Research
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ARTICLE

Groundwater Recharge Potential Mapping in Far Western Middle Mountain of Nepal: A GIS-based Approach

Shobha Shrestha*

Central Department of Geography, Tribhuvan University, Kirtipur Kathmandu, Nepal

ARTICLE INFO

Article history
Received: 16 July 2020
Accepted: 23 July 2020
Published Online: 30 July 2020

Keywords:
GIS/RS
Influencing factors
Middle-mountains
Springs
Spatial analysis
Watershed

ABSTRACT

The larger population in the middle mountain region of Nepal is dependent on spring for domestic water use. Availability and flow regularity of springs rely on groundwater recharge (GWR) potential which is attributed to various natural and human factors. The present study is an attempt to explore the GWR potential using GIS and Remote sensing (RS) method in two watersheds of the far western middle mountains of Nepal. Spatial analysis is carried out using a weighted overlay analysis of six factors namely, slope, lithology, lineament, drainage density, rainfall, and land cover/ land use. The result shows that only 16 percent of the total watershed area is under a very high recharge potential zone while 31 percent area falls under very low recharge potential. It is found that the distribution of existing spring sources is random concerning GWR potential. Water stress in Rel Gad watershed is evident which accentuates the proper management of recharge areas. The study concludes that the GIS RS tool is useful in identifying recharge potential zones. It aids to better planning for increasing recharge potential. Proper management of recharge potential area and spring water sources direct the future water availability to fulfill the increasing water need of the communities.

1. Introduction

The role of water in human life and livelihood is well known and it's availability and accessibility impose constraints on water use [7]. The global demand for water has been increasing at a rate of about 1% per year as a function of population growth, economic development, and changing consumption patterns with the majority of the growing demand occurring in countries with developing economies. In 2010, twenty-seven percent of the global population lived in potential severely water-scarce areas which increased to an estimated 45 % (water-scarcity at least one month per year) in 2018 and estimated to increase to 60 percent by 2050 [48]. Similarly, it is estimated that 30 percent of all freshwater on earth exists as groundwater [43]. The demand for groundwater resources is increasing with the depletion of available primary surface water supplies. According to a study, groundwater use in the Asia region could increase by 30%

**Corresponding Author:*
Shobha Shrestha,
Central Department of Geography, Tribhuvan University, Kirtipur Kathmandu, Nepal;
Email: shova216@gmail.com

 DOI: https://doi.org/10.30564/jgr.v3i3.2160

by 2050 with severe groundwater stress in the Northern Plain of China and Northwest India[1]. Of the total global population, 31% depend solely on groundwater resources to satisfy their basic daily water needs [42]. It provides drinking water to at least 50% of the global population and accounts for 43% of all of the water used for irrigation [8]. The role of groundwater discharge is also vital for maintaining water levels in rivers originating from the mountains [45]. With the projected water scarcity and reduced renewable surface and groundwater resources, water availability and quality would be one of the major issues for societies, and rural areas are expected to experience major impacts on water availability and supply [15]. World Economic Forum reported that the highest level of societal impact over the next 10 years will be from water crises [47].

Open access to spatial data and availability of mapping and spatial analysis tools like Geographic Information System (GIS) and Image Processing/Remote Sensing (RS) has made a breakthrough in the field of groundwater recharge potential mapping and analysis [9,37]. GIS and RS based groundwater recharge potential mapping aids to field sample selection and site-specific exploration using geological, hydro-geological, and geophysical methods [13,26]. Integration of in situ methods like long term observation and measurement, flow analysis and modeling, and hydro/geostatistical analysis with GIS and RS tools in characterizing groundwater aquifers and modeling groundwater recharge is enduring research interest [6,22,25,49].

Groundwater exploration was first initiated in Nepal in 1967. Survey and mapping of groundwater recharge potential have been a field of interest for resource development and exploration in Nepal since the 1990s [33,37]. The renewable groundwater potential of Nepal is estimated to be 12 km^3 and in the middle hills and mountain region annual groundwater reserve is estimated to be at least 1713 MCM whereas in total shallow and deep groundwater aquifers are estimated to be 8.8 BCM annually [10.44]. However, most of the groundwater exploration using traditional methods is concentrated in the Terai plain area of the country, and urgency systematic study and exploration and assessment of the groundwater resources in the hill and mountain region is realized [2.30].

The larger population in the middle mountain of Nepal is dependent on natural spring water sources. Of the total population residing in upstream mountain slope areas, 80% of the communities have no direct access to the river water source, and natural springs are the primary source of water for sustaining domestic and agricultural water needs [34]. Pertaining to the IPCC assessment, the number of recent studies had reported decreasing water level and drying up of springs in the middle mountains of Nepal. Major factors attributed to decreasing water level and drying up of springs are, increasing population, changing land cover-land uses, environmental degradation, and spatial and temporal variability in rainfall [21,39]. In this context, the present study is an attempt to explore the groundwater recharge potential based on natural and human factors using GIS and Remote sensing method in two watersheds of the far western middle mountain region of Nepal.

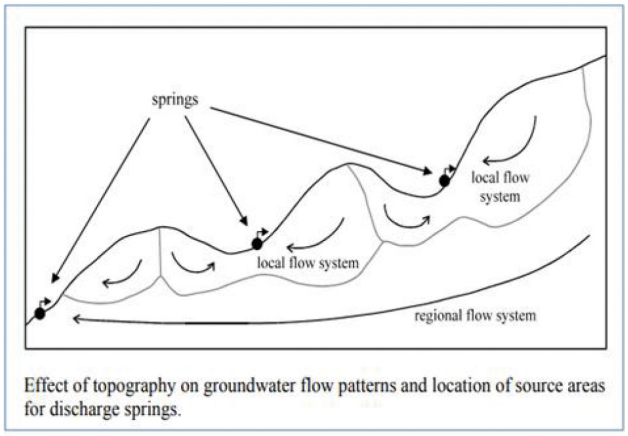
2. Concept

Groundwater is stored in the open spaces within rocks and unconsolidated sediments beneath the earth surface between the unsaturated and saturated zone. Groundwater doesn't always flow in the same way as the surface water. However, it always flows from the recharge area to the discharge area. Recharge involves the influx of groundwater to an aquifer, while discharge involves the outflow of groundwater from an aquifer [31]. It flows downward passing between porous soil, sand, gravel, or rock due to gravity and also flows sideways due to pressure generated by water-resistant non-porous rock and soil. The direction and speed of groundwater movement are determined by the various characteristics of aquifers and confining layers of subsurface rocks. Groundwater movement through steep land slopes results in hillside flow to land surface in the form of natural springs or flow horizontally towards streams, rivers, or ocean [46]. Spring is an outflow of groundwater in a discharge zone at or below the intersected location between water table (with filled aquifer) and the geological structure/topography [24].

Geological structure dictates the occurrence and flow of spring, and topography drives the direction of groundwater flow whereas rainfall would influence the timing and amount of recharge and the volume and variability of discharge [41]. However, human activities also can influence the volume of water that discharges besides, size

DOI: https://doi.org/10.30564/jgr.v3i3.2160

of the caverns within the rocks, the water pressure in the aquifer, the size of the spring basin, and the amount of rainfall [43]. Availability and flow regularity of spring water rely on groundwater storage and recharge potential of groundwater (Figure 1). Groundwater recharge potential, on the other hand, is attributed to many factors like rainfall, lithology, lineaments, slope, drainage density, and land cover/ land use, etc.



Effect of topography on groundwater flow patterns and location of source areas for discharge springs.

Source: Kreye et. al., 1996.

Figure1: Groundwater flow system

3. Materials and Method

The study has adopted an integrated approach and includes both desk work and fieldwork. Primary and secondary data sources are used for the proposed study.

3.1 Study Area

The two watersheds, one located in the southern slope and the other located in the northern slope of the middle mountain region of Far western Province of Nepal, is selected as the study area (Figure 2).

3.1.1 Dhung Gad Watershed

Dhung Gad watershed lies in the southern slope of the Baitadi district and covers 92 km^2 area. The altitude of the watershed ranges from 712 to 2807 m above the mean sea level. The settlement distribution is random and is located up to 2350m but most of the settlements are confined to the lower slopes and narrow river valleys (Figure 2). The Dhung Gad river originates from the north-western part and flows to the south-eastern part of the watershed. It is known as Dhung Gad in the southern part and confluences into the West Seti river. The average annual rainfall of the area is 1600 mm. The topography is rugged and 46 percent area is above 40-degree slope. More than 18 percent of the watershed area is barren and rocky which lies in the north-western part. Forest is the dominant land cover/use covering 56 percent of the total area. Agriculture covers around 29 percent of the total watershed area and settlements comprise 3 percent area coverage. The total population of the watershed area is 11, 116 and the total household is 1790 with an average household size of 6. The population density of the area is 120 persons per Km^2. The lower southern part of the study area is inhabited by different castes groups such as Brahman, Chhetri, and Dalit [4]. The primary occupation of the people living in this watershed is agriculture followed by foreign labor.

3.1.2 Rel Gad Watershed

Rel Gad watershed lies in the northern slope of the Doti district and covers 41 km2 area. The altitude of the watershed ranges from 723 to 2467 m above mean sea level. The settlement distribution is random and is located up to 1900m but most of the settlements are confined to the southern lower slopes and narrow river valleys. The Rel Gad river originates from the southern part and flows to the north-western part of the watershed. It is known as Golmagad in the southern part and confluences into the West Seti river. The average annual rainfall of the area is 1800 mm. As compared to Dhung Gad watershed, the topography is relatively moderately slope and around 9 percent of the total area is above 40-degree slope and 51 percent area is in-between 20 to 30-degree slope. However, more than 11 percent of the watershed area is barren and rocky which lies in the north-western part. Forest is the dominant land cover/use covering 66 percent of the total area. Agriculture covers around 21 percent of the total watershed area and settlements comprise only 1 percent area coverage. The total population of the watershed area is 5077 and the total household is 972 with an average household of 5.2. The population density of the area is 123 persons per Km^2. The lower north-eastern part of the study area is inhabited by different castes groups such as Brahman, Chhetri, and Dalit [4]. The primary occupation of the people living in this watershed is agriculture followed by foreign labor.

 DOI: https://doi.org/10.30564/jgr.v3i3.2160

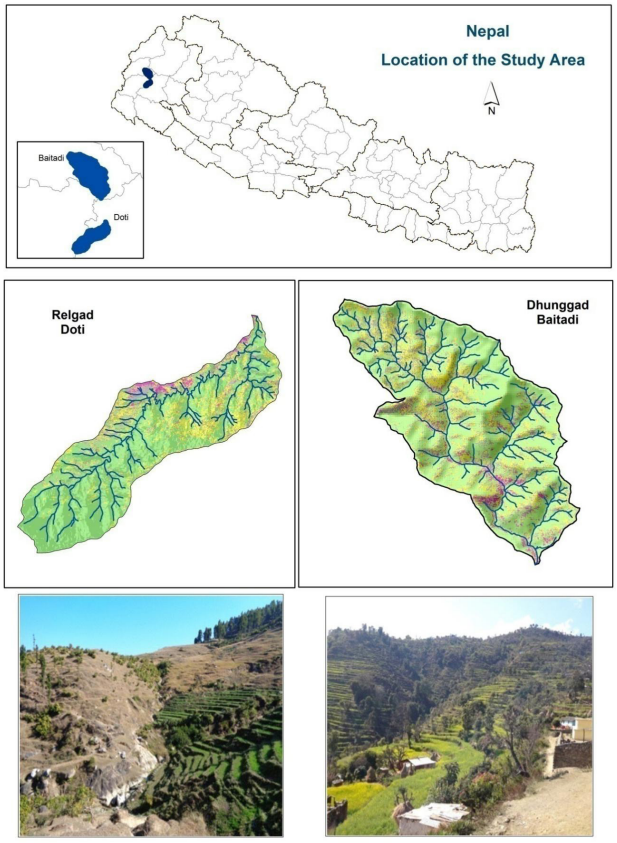


Figure 2: Study Area

3.2 Data and Method

Primary data was collected using questionnaires for household surveys, field observation, and key informant interviews. Primary spatial data i.e. spring locations were collected using GPS and inventory form. Secondary spatial data layers included lithology, soil, geomorphology, land cover/ land use, River network, elevation and rainfall which are collected from relevant authorities either in digital, or hardcopy sources while other spatial data layers (slope, drainage density, lineament density, watershed boundary) were derived using these data layers.

GIS and Remote sensing tools are applied to groundwater potential zone identification and exploratory analysis. Spatial analysis is carried out using weighted overlay analysis in GIS. Weight and factor rate assigned to each factor and factor classes are based on the review of several previous studies in the similar and different geographic settings [9,11,13,28,35,38,40]. The total assigned weight per factor class is calculated by multiplying weight and factor rate. This study is carried without incorporating the recharge and groundwater head data (pumping test of a well) and the location of spring sources is taken as a proxy to groundwater recharge aquifer. The six factors namely, drainage density, land cover/ land use, lineament density, lithology, slope gradient, and rainfall have been used in inferring the groundwater recharge potential area. The factors, weight per factor class, and factor rate are illustrated in Table 1.

Table 1. Groundwater Recharge Potential Factor Weight Assignment

SN	Factor	Class	Weight	Factor Rate	Assigned weight	Factor class
1	Drainage Density	Very High	6.5	1.5	9.75	0 .0 - 0.0012
		High	5		7.5	0.0012 - 0.0025
		Moderate	3.5		5.25	0.0025 - 0.0037
		Low	2		3	0.0037 - 0.0050
		Very Low	0.5		0.75	0.0050 - 0.0062
2	Land cover/ land use	Very High	6.5	2.5	16.25	Water/Snow
		High	5		12.5	Agriculture
		Moderate	3.5		8.75	Barren/ Abandoned
		Low	2		5	Forest
		Very Low	1		2.5	Built-up
3	Lineament Density	Very High	10	2	20	0.000152 - 0.000219
		High	8		16	0.000108 - 0.000152
		Moderate	6.5		13	0.000066 - 0.000108
		Low	5		10	0.000025 - 0.000066
		Very Low	3		6	0 - 0.000025
4	Lithology	Very High	10	3	30	NA
		High	8		24	Calcacareous Slate & Sandstones
		Moderate	5		15	Dolomitic Limestones
		Low	2		6	Phyllite and Phyllitic Quartzites
		Very Low	1		3	Augn Gneisses
5	Slope Gradient	Very High	10	1.5	15	0 - 10
		High	8		12	10 - 20
		Moderate	6.5		9.75	20 - 35
		Low	5		7.5	35 - 50
		Very Low	2		3	>50
6	Rainfall	Very High	10	3	30	2000 mm/ annum
		High				
		Moderate	6.5		19.5	1800 mm/ annum
		Low	3		9	1600mm/ annum
		Very Low				

DOI: https://doi.org/10.30564/jgr.v3i3.2160

Recharge potential areas are divided into five categories from very good to very poor based on a calculated value from weighted overlay. Existing spring water sources, spring source user households, and settlements were overlaid against all categories of recharge potential to explore the relationship between the distribution of spring sources and recharge potential zones and existing use of sources. The groundwater recharge potential area is calculated using equation 1. The total calculated value using equation 1 was grouped into five classes from rank 1 to 5. The overall ranking into five classes is based on Jenk's natural break of the output data value. Jenk's natural break method is suggested for comparative analysis [18].

$$GWR_p = \sum(DD_w * DD_r + LD_w * LD_r + SG_w * SG_r + LT_w * LT_r + LU_w * LU_r + RF_w * RF_r) \quad \text{.....equation (1)}$$

where; GWR_p = Groundwater recharge Potential

DD: Drainage density, LD: Lineament Density, SG: Slope gradient, LT: Lithology, LU: Land use and RF: Rainfall, w = weight and r = factor rate assigned to each class category of individual factor

4. Result and Discussion

4.1 Groundwater Recharge Potential Factors

The present study used six factors as primary influencing factors namely, lineament density, lithology, land cover/ land use, drainage density, slope gradient, and rainfall. Three major types of relationship between different factors and groundwater recharge potential are exemplified in various literature [9,13,14]. Some influencing factors have a direct relationship with recharge potentials such as lineament density whereas some have a variable relationship like geology/lithology and land cover/ land use. Drainage density and slope gradient have an inverse relationship with GWR potential. Higher the drainage density, greater the runoff and lower is the GWR potential while steeper the slope, faster the runoff and hence lower the GWR potential. Table 2 summarizes the percent share of all six factors to GWR potential in the study area. The GWR factor map and potential GWR per factor are presented in Figure 3a for Dhung Gad and Figure 3b for Rel Gad watershed.

Lithology (LT) is regarded as the primary factor for infiltration and groundwater aquifer development. In the Hills and Mountains Region of Nepal groundwater occurs in unconsolidated sedimentary deposits [30]. The study area consists of metamorphic (dominantly, phyllites, phyllitic quartzites, and gneisses), sedimentary-metamorphic (dominantly calcareous quartzites and dolomitic limestones) and sedimentary (dominantly calcareous slate, shale, and sandstones). Sandstone, limestone, and slate are considered as having higher GWR potential, whereas phyllite, granite/gneisses is considered as having low GWR Potential. In the study area, only 11% of the total area has high GWR potential and is found in Dhung Gad, and no high GWR potential area is found in Rel Gad watershed while more than 61% has low GWR potential.

The lineaments features like faults, joints, and fractures provide open spaces for water inflow and underground storage. Higher the lineament density (LD) more favorable is the condition for the GWR Potential [32]. Lineament density is regarded as a proxy factor as the detailed lineament analysis needs detailed field investigations. Lineaments for the current study are identified from the satellite in the study area and not many lineament features are present. Higher lineament density is found in the northern part of Dhung Gad whereas density is higher in the southern part of Rel Gad. Of the total area, 44% is high potential to GWR and 39% is moderately potential. A study carried out in the middle mountains of Nepal also shows the strong likelihood of spring occurrence in the area of dense lineaments [9]. The existence of permeable fracture zones in less permeable high-grade metamorphic rocks increases the groundwater storage and spring occurrence. GIS and RS based studies show that the role of landforms and lineaments for the occurrence of high yield groundwater availability in hard rock terrain is very important as compared to weathered rocks [35].

Land cover land use (LU) is another important factor influencing groundwater recharge. However, it has a variable relationship depending upon other physical and human factors such as surface slope and intensity of use. In general, the area near water and snow cover tends to have higher potential followed by agriculture use while the built-up and barren area has lower potential as infiltration is constrained and runoff is faster [28]. Forest has moderate recharge potentiality. Forest is the dominant land cover comprising 59 % of the total area followed by agriculture area with 22 %. Upstream is of both watersheds are covered by dense forest and agriculture is found in lower hill-slopes. Barren and abandoned land cover 16% of the total area. Water and the built-up cover are very low with 2% and 0.04% respectively. Of the total area, 22% is a high potential for GWR while 61% area is under low to very low GWR potential. The effect of different land use on GWR potential is highlighted in several studies [2,14,40]. Correspondingly, the transformation of one land use class to another has also a variable effect on GWR potential [16]. A study has reported 11 to 100 percent of the natural groundwater recharge loss due to the transformation of

 DOI: https://doi.org/10.30564/jgr.v3i3.2160

the forest into built-up loss and up to 19 fold increase in runoff [12].

Drainage density (DD) reflects the infiltration and permeability capacity of underlying soil and geology. In general, a lower drainage density is found to be associated with regions having highly permeable subsoil material, whereas a high value of drainage density is noted for the regions of weak or impermeable subsurface materials [29]. However, relative relief and slope steepness largely control the drainage density, and the contribution of rivers and streams flowing through high degree slope is considered less significant to groundwater recharge. Low drainage density is thus associated with higher GWR potential. In the study area, 44% of the area is under high GWR potential and 17% area is under low to very low GWR potential. Interestingly, high GWR potential area in consideration of drainage density is found towards the southern part of north-facing watershed i.e. Rel Gad and towards the northern part of the south-facing watershed i.e. Dhung Gad.

The slope gradient (SG) controls the runoff and infiltration capacity of water. Steeper the slope gradient lower is the GWR potential due to rapid runoff and less possibility of water holding capacity and infiltration. This means the likelihood of GWR potential in the downslope area. The slope gradient is variable in the study area. of the total area, 52% is under a moderate slope of 20 to 35 degrees whereas 19% area is above 35-degree slope which is less potential for GWR. Likewise, less than 10% area is under 10-degree slope and is concentrated also narrow river valleys which have high GWR potential. The high frequency of the springs on straight slopes indicates the seepage of groundwater flow on a larger quantity from the downslope below the concave slopes, which acts as an intake of rainwater for groundwater recharge [9]. Water tends to store at lower topography rather than the higher topography. The higher the elevation, the lesser is the groundwater potential and vice versa.

Rainfall (RF) is the major controlling factor of GWR potential. A higher amount of rainfall increases the possibility of higher groundwater recharge. However, slope gradient and shape, vegetation cover, and underlying lithology largely determines the water holding and quantity of infiltration in an area of rainfall. The average annual rainfall in the study area ranges from 1600 to 2000mm. and more than 85% of the rainfall occurs during the monsoon period of June to mid-October. The study area lies in three different climate zone namely, tropical, subtropical, and temperate zone where temperature differs and so is the rate of Evapotranspiration which again affects the groundwater infiltration and storage. GRW potential regarding rainfall is high in 13% area of the total study area but is confined to the southern slope of Rel Gad. Low GWR potential is found in the Dhung Gad watershed. The nature and gradient of the surface onto which the rain falls have a significant influence on the infiltration rate. A gentle gradient with high vegetation cover will allow increased infiltration in comparison to the barren land. Barren land has a low capacity to absorb water and causes rapid runoff [13].

Table 2. Percent share of factors to GWR potential

GWR Potential	LD	LU	LT	DD	SG	RF
Very High	0.05	0.04	11.2	11.3	6.5	
High	43.6	22	27.4	40.9	22.4	13.7
Moderate	38.8	16	30.9	19.9	52.4	29.5
Low	15.3	59	20.5	14.5	18.0	56.8
Very Low	2	2.8	10	13.2	0.06	

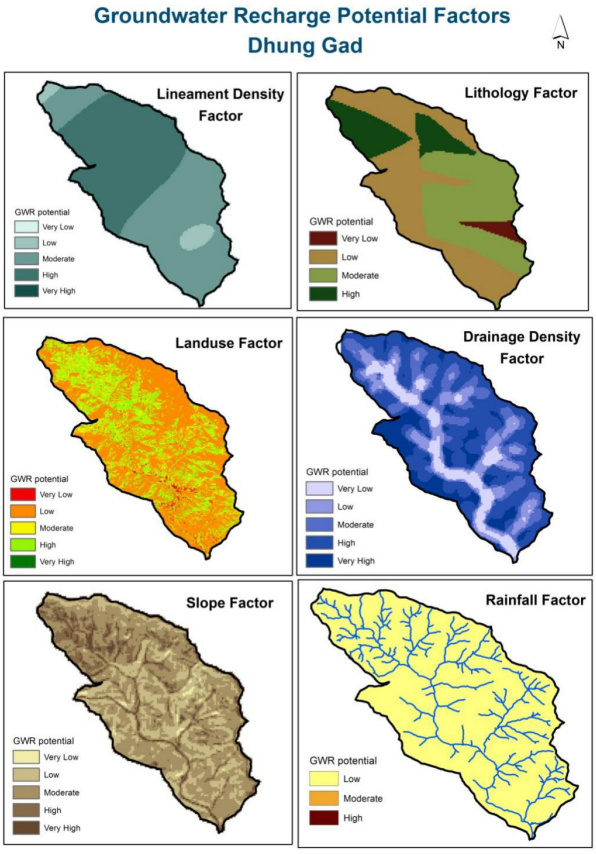


Figure 3a. Groundwater recharge potential factors in Dhung Gad, Baitadi

DOI: https://doi.org/10.30564/jgr.v3i3.2160

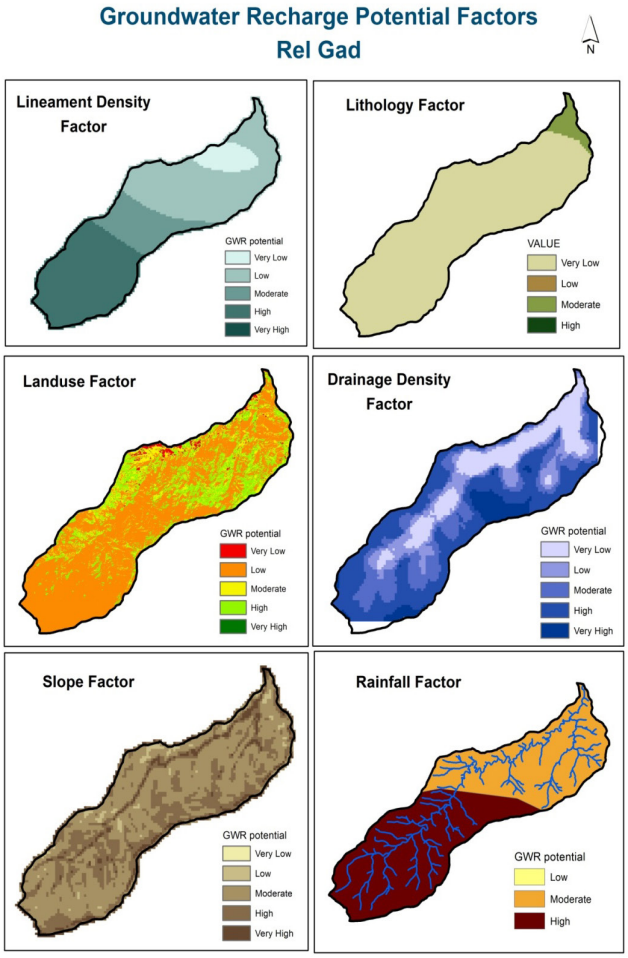


Figure 3b. Groundwater recharge potential factors in Rel Gad, Doti

4.2 Spatial Distribution of GWR Potential and Location of Springs

The study found that most of the study area is under moderate GWR potential comprising nearly 48% spatial coverage (Table 3). The result shows that only 16.2% of the total area of two watersheds area have very high recharge potentiality while 31 % area falls under very low recharge potentiality. Almost total very high GWR potential is confined to Dhung Gad watershed whereas only 0.2% area in Rel Gad watershed is of very high GWR potential. The spatial concentration of very high GWR potential area is towards the northern part of both of the watersheds (Figure 4). Conversely, the lower GWR potential area is found in the southern part of Dhung Gad but the north-western part of Rel Gad watershed.

Table 3. Spatial coverage of GWR Potential in the study area

GWR Potential	Percent		
	Dhung Gad	Relgad	Total
Very High	16.0	0.2	16.2
High	29.3	2.8	32.1
Moderate	31.6	16.3	47.9
Low	19.7	52.8	72.5
Very Low	3.1	28.0	31.1
Source: calculation from GWRP GIS layers			

The identified groundwater recharge potential area map was validated through the location of springs across different potential zones. There is 90 spring occurrence in two watersheds of which, 59 are located in Dhung Gad and 31 are located in Rel Gad (Table 4). It is found that the distribution of existing spring sources is random concerning GWR recharge potentiality. In Dhung Gad, relatively uniform distribution of springs is found in all potential classes whereas, in Rel Gad, the major concentration of springs is in low to very low GWR potential zones. Spring distribution in moderate GWR potential zones of both watersheds is uniform. However, in Rel Gad 77% concentration of springs is in low to very low GWR potential zone and no spring is very high and only 1 spring in high GWR potential zone is found. The location of a fewer number of springs with high flow discharge is noted at the very low GWR potential zone of Dhung Gad. Conversantly, flow discharge of springs located in high and very high GWR potential zone is relatively low.

So far as spring source users are concerned, 57% HH resides in the moderately to very low GWR potential zone in Dhung Gad whereas, in Rel Gad, nearly 95% of users reside in the same zones. Water stress in Rel Gad watershed in particular is evident which accentuates the proper management of existing recharge potential areas.

Table 4. GWR Potential and Location of Springs

GWR potential	Spring distribution	Percent Share of Spring	Average Discharge	Spring users HH	% Spring users HH
Dhung Gad, Southern Slopes					
Very High	14	23.73	0.43	356	17.3
High	17	28.81	0.21	521	25.3
Moderate	12	20.34	0.52	441	21.4
Low	14	23.73	0.5	555	27.0
Very Low	2	3.39	0.75	183	8.9
Total	59	100		2056	

DOI: https://doi.org/10.30564/jgr.v3i3.2160

Rel Gad, Northern Slopes					
Very High	0	0	0	0	0.0
High	1	3.23	0.11	53	5.3
Moderate	6	19.35	0.19	186	18.6
Low	12	38.71	0.73	412	41.2
Very Low	12	38.71	0.31	348	34.8
Total	31	100		999	

Source: Field survey, 2017-18.

The type of springs based on outflow in the study area show that most springs are an intersection between topography and a geological phenomenon. Common characteristics of springs type are found in the study area which matches springs in other parts of the country [2,9,26]. Among 90 springs, the most common type is a depression or contact springs comprising 75% (Table 5). However, their location regarding lithology is variable. Of the total springs in Rel Gad, 90% are in Phyllite/ Phyllite Quartzites area whereas only 2 springs are located in the same lithology in Dhung Gad. Spatial distribution characteristics of springs regarding lithology and slope gradient show that 63% springs are located within 20-35 degree slope while only 3 springs are located in less than a 10-degree slope. Similarly, 61% springs are located within 1000-1500m altitude and 29% are located within 1500-2000m range. Only 9% is located below 1000m altitude.

Table 5. Spring source type and Lithology

Lithology	Depression or Contact Spring	Fissure or fracture Spring	Stream surface flow	Total
Dhung Gad				
Calcacareous Slate/ Sandstones	15	1	8	24
Calcareous Quartzites/ Dolomitic Limestones	23		8	31
Phyllite/ Phyllite Quartzites	2	1	1	4
Rel Gad				
Calcacareous Slate/ Sandstones	0	0	0	0
Calcareous Quartzites/ Dolomitic Limestones	0	0	0	0
Phyllite/ Phyllite Quartzites	28	0	3	31
Total	68	2	20	90

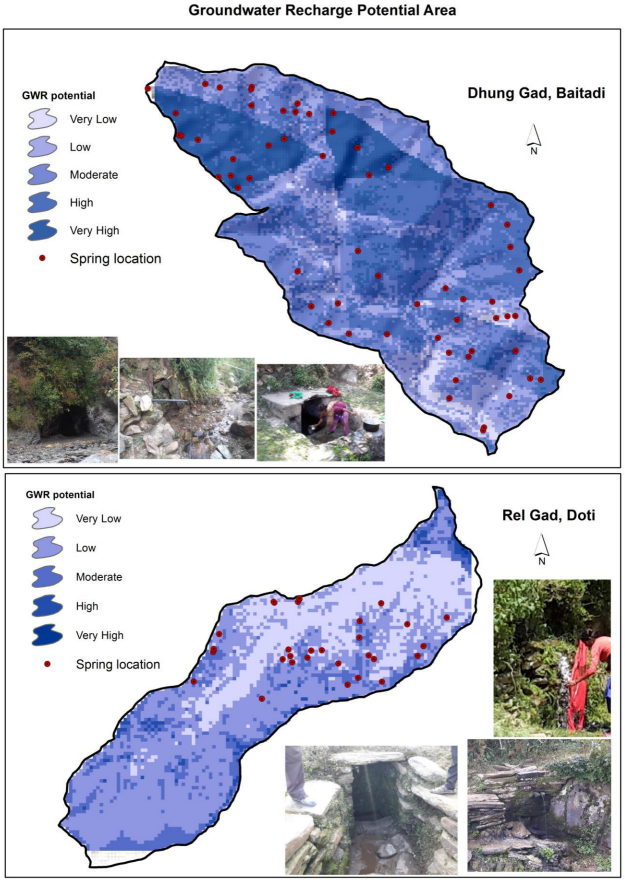


Figure 4. Spatial distribution of GWR potential in the study area

4.3 Data and Method for GWR Potential Mapping: Importance and Challenges

Various statistical methods that were adopted for groundwater potential zone mapping such as weights-of-evidence method [9], multi-criteria decision evaluation method [19], frequency ratio method [3]. Field-based Geological, hydro-geological and Geo-physical surveys using different techniques are used for groundwater exploration and aquifer investigation/ identification [13,37]. Mapping and identification of GWR Potential area using geo-information tools and techniques through analysis of hydrogeological and geological and other information aids such exploration saving time and resources. Geological, hydro-geological and geophysical methods, and related techniques are *in situ* method for groundwater exploration and recharge potential mapping with extensive field investigation [27]. GIS and RS based methods are well accepted for the assessment of availability and status of groundwater resources for developing a map of groundwater typologies. One approach to adopt GIS and RS method for groundwater

DOI: https://doi.org/10.30564/jgr.v3i3.2160

recharge potential mapping is due to readily available data with limited field investigation whereas another approach is to map areas with no or poor field data/sample availability [35.40]. Integrated GIS/RS and quantitative estimation of mean relative recharge for a hydrologic research unit were carried out using the GIS tool based on the mean annual precipitation records [13]. Physical attributes like surface geology, soil type, impervious land cover (buildings, roads, etc,)and drainage density were regarded as the most significant influence and primary indicators for assessing recharge.

Collection of data on the characteristics of the spring and its catchment for poorly understood spring sources and groundwater systems are also emphasized [22]. Importance of groundwater recharge potential and spring mapping is highlighted in several studies [3,13,22,25]. Such studies help to address location-based water management planning and new infrastructure development, maintaining and regulating water supply and surface and groundwater flow. The GIS/RS based GWR potential mapping result may be useful for decision-makers to formulate appropriate groundwater management strategies in the data-poor and economically poor nations.

A study carried out in the central middle mountain region of Nepal applying weighted evidence method with eleven influencing factors in a GIS environment and the validation of groundwater spring potential in the field concluded that the method can be replicated in a similar biophysical environment, where the hydro-geological or geophysical surveyed data is not available [17]. Gentle slope, low relative relief, high flow accumulation, north- and east-facing slopes, denser lineament density, altitude class of 1500-2500 m, high vegetation density, and forest demonstrated a higher likelihood of spring occurrence which implies availability of groundwater recharge potential. Groundwater potential mapping in the Nepalese context is limited particularly in the hill and middle mountain regions. The studies carried out so far in the country have included both controlling and influencing factors like lithology, drainage density, land use/land cover, lineament density, slope, and precipitation [28]. The studies on groundwater mostly carried out in the Southern plain (Terai) region of Nepal have focused on availability and use of groundwater, groundwater aquifer and geological formations, groundwater environment, recharge potential, and the factors that have control over it [36]. Most of these studies have concluded varying depths and amounts of availability of groundwater in the country. Very few studies have been carried out in the far western hill and mountain region of the country [11,20,23]. These studies have outlined the limitation of geo-hydrological data and detailed geo-lithological surveys and maps, which is imperative for understanding the complexities of the geo-hydrological process of springs and spring water recharge potentials [20].

5. Conclusion

Two major approaches to GWRP mapping and analysis are prevalent in contemporary groundwater recharge research namely, a data-driven method with an intensive desk study, and site-specific observation and exploration with extensive field survey.

A very high GWR potential zone is located downstream in the northern slope (Rel Gad) but is located upstream in southern Slope (Dhung Gad). In Rel Gad watershed annual average rainfall is higher and has lower slope but spatial coverage of high/high GWR potential is low as compared to Dhung Gad only because it is located in the northern aspect of a similar slope gradient. Springs distribution is relatively uniform in all GWR Potential classes in Southern Slope but clustered to moderate-very low classes in Northern Slope. The average spring discharge is relatively higher in Northern Slope but lower in Southern Slope. Variable GWR potential in two watersheds with relatively similar altitude zone, land cover land use, slope, and geology but the difference in rainfall e.g. Southern slope with less rainfall has a large area under high to very high GWR potential while and northern slope with higher rainfall has a very limited area under the same. This finding implies that a combination of factors play a different role in different geographical setting and groundwater recharge potential is localized in the area of complex geographical and geological setting.

The finding also implies the importance of high-resolution spatial data and detailed study of the smaller spatial unit for GIS/RS based GWR potential research. Both of these are perhaps the utmost limitation in current time particularly of spatial data of different physical factors and spatial scale at which the recharge potential is mapped. The GWR potential mapping is, therefore, important for planning and management of water security. Such mapping apprehends to spatial coverage gaps and helps manage and monitor resource development and use. Proper management of recharge potential area and spring water sources will direct the future water availability in the watersheds to fulfill the increasing water need of the communities.

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ARTICLE

Integrated Urban Development Plan (IUDP) as a Guiding Tool to Municipal Development: Insights from Dudhauli Municipality, Nepal

Kedar Dahal*

Department of Geography, Tri-Chandra Multiple Campus, Tribhuvan University, Kathmandu, Nepal

ARTICLE INFO

Article history
Received: 22 June 2020
Accepted: 23 July 2020
Published Online: 30 July 2020

Keywords:
IUDP
Land use
Strategies
Lead sector
Infrastructure
Urban growth
SWOT

ABSTRACT

Several planning tools and approaches such as action plan, period plan, physical development plan have been applied for planned development for municipalities including other small and medium-sized towns of Nepal. Among them Integrated Urban Development Plan (IUDP) is the latest approach that focuses integrated sectoral development envisioning long-term spatial development by adopting strategic actions, which is backed by lead development sectors of that town. This study is based on field level data collection through municipal and community level interactions, observation and field mapping. Dudhauli municipality, which is located in the hilly region of Bagmati province Nepal has been selected for this study, which reveals an array of diverse patterns and challenges of municipal development. Present scenario of urban growth in Dudhauli has been taking place at and around Dudhauli bazzar, Dakaha and Sirthauli area and main roadsides in the form of compact and linear development pattern in unplanned way, which has resulted increasing built-up area and decreasing agriculture land. Rapid spatial expansion of residential buildings construction and densification of built-up areas have been increased by 56% within the time period of 10 years in Dudhauli area. Consequentially, fertile agriculture land has been converted into constructional area significantly. To regulate urban development in a right direction, a planned urban development of Dudhauli is needed. IUDP, in this context would be an appropriate tool to guide as a framework of municipal development by considering vision, goals, strategies, key activities and land use zones for regulated urban development.

1. Introduction

Urbanization is a good indicator of economic development of the country and it has always been an accelerator of growth and development, bringing about enormous changes in the spatial distribution of people and resources, and in the use and consumption of land [1]. The level of urbanization has considerably increased in the last four decades in Nepal [2] and it has practiced to analyze urbanization in terms of the number of municipalities and people living there. In this respect, about 63% people are living in the urban area (what we called municipalities) in 293 municipalities in Nepal [3]. Urbanization in Nepal has mainly occurred due to three interrelated factors:

**Corresponding Author:*
Kedar Dahal,
Department of Geography, Tri-Chandra Multiple Campus, Tribhuvan University, Kathmandu, Nepal;
Email: kedar.geog@gmail.com

 DOI: https://doi.org/10.30564/jgr.v3i3.2031

(1) Emergence of new towns

(2) Expansion of existing urban areas, and

(3) Migration (rural to urban and ridge-top to valley)

Over 65% of urban growth in Nepal over the recent past can be traced to migration [4]. In the recent years, internal migration particularly rural to urban and ridge-top to valley or hill to Terai (plain) have increased significantly in the many hills and mountain towns of Nepal.

However, the present scenarios in the context of urbanization (through incorporated/emergence of large number of places as municipal town in Nepal) is yet to be assessed [5] and this scenarios of the increasing number of urban center (municipalities) and people living in them does not mean that the country has accelerated rate of economic development through the transformation of agriculture economy into processing and services. Urban growth in hill and mountain region have determined by combination of factors, such as, local topography and environment, natural population growth and migration, infrastructure development, (local) elite's voice and choice, availability of space and land use. Particularly, in the case of (physical) infrastructure development and facilities, local elites and their decision shapes the city's future expansion (growth). Besides, as the Nepal government has declared 293 municipalities; most of them have poor provisions of municipal services and facilities. Such municipalities neither have basic physical and social infrastructure nor strong economic resources that could be invested in the prioritized sectors of development. In addition to this these municipalities pose poor data base, urban development regulation (bye-laws), development vision, mission, objective and strategic planning. It is thus, apparent that local government bodies, particularly newly formed municipalities are needed to enhance their skills and capacities more on their service delivery, planning and monitoring.

Lack of local level land use plan and zoning, among other factors, is probably one of the most persuasive factors to the haphazard urban development in most of the towns in Nepal. However, there have been some impressive practices over the planned urban development including widening of inner roads and streets by proportionate contribution of land by the landowners of adjoining plots [6]. There have been changed in the planning practices from action plan to periodic and integrated approach. Integrated approach of urban development is also called Integrated Urban Development Plan (IUDP) in general. In the few years, there have been shift towards a new paradigm in urban development through promulgated IUDP concept, as an effective tools of sustainable urban development in Nepal, which focused the long-term thinking about spatial development by adopting strategic view and by supported by a common vision [7] correspond with the local situation.

IUDP has sought to provide a roadmap for the spatial transformation towards livable, inclusive and resilient towns and cities; and to guide the future growth and management of urban areas [8]. Therefore, the IUDP is about process and participation, which has focused on:

(1) A comprehensive SWOT analysis of a town

(2) Defining goals, objectives and strategies, and setting up a vision for the town

(3) Preparation of planning framework, Multi Sector Investment Plan and implementation modality.

In this context, IUDP is considered as an effective planned document to guide newly incorporated towns and municipalities. There are six main reasons why a municipality should have an IUDP [9].

(1) *Effective use of scarce resources:* The IUDP will help the local municipality focus on the availability of resources and cost–effective ways of providing services at the local level, and to address the local level problems.

(2) *Helps to speed up delivery:* The IUDP helps to develop realistic project proposals based on the availability of resources. It identifies the least serviced and most impoverished areas and points to where municipal funds should be allocated.

(3) *It helps to attract additional funds:* Government departments and private investors are willing to invest where municipalities have clear development plans.

(4) *Strengthens democracy:* Through the active participation of all the important stakeholders, decisions are made in a democratic and transparent manner.

(5) *Rural-urban linkages:* Municipal resources are used to integrate rural and urban areas and to extend services to the poor.

(6) *Promotes co-ordination between local, provincial and national government:* The different spheres of government are encouraged to work in a coordinated manner to tackle the development needs in a local area.

Moreover, IUDP is a participatory process, which emphasizes community involvement in the planning process at different level. Participatory process of strategic planning and management ensures use of its stakeholders' knowledge, resources, and commitment [10]. Department of Urban Development and Building Construction (DUDBC) (2018) [11] has also focused participatory approach for IUDP that could reflect issues and problems not only in sectoral basis but through community as well as broad development framework that would guide municipal development in the long-run. Broadly, present IUDP process involves through the following process (Figure 1).

DOI: https://doi.org/10.30564/jgr.v3i3.2031

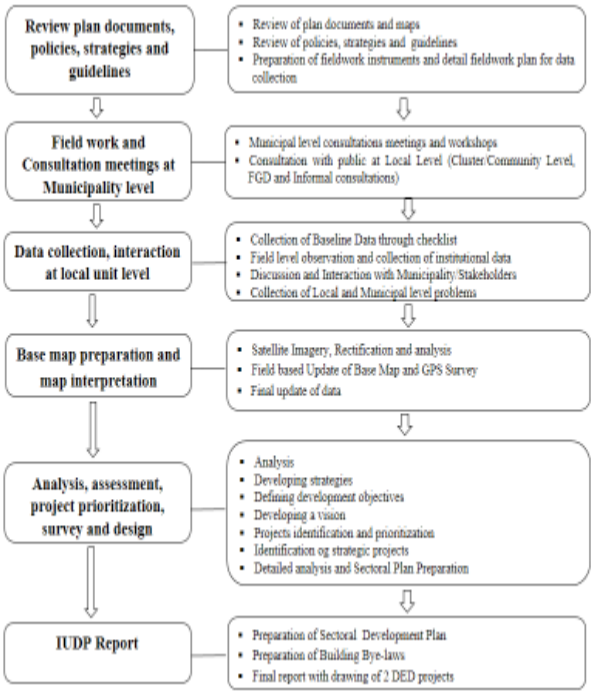

Figure 1. IUDP Process in General

2. Present Federal Context

With the promulgation of Constitution of Nepal-2015[12], Nepal is a federal democratic republic with federal set up that constitutes federal, provincial and local government. There are seven federal states that governed six metropolitan cities, 11 sub-metropolitan cities, 276 municipalities and 460 rural municipalities. The constitution provides a framework and legal mandates for the devolution of powers to the federal and local level governments for governance, development activities and resource mobilization for the provincial and local governments. As such, the municipal government is assigned a larger functional, semi-judicial and fiscal authority. The constitution has empowered municipality a number of constitutional power of roles under the section 8 of Local Government Operation Act 2017 [13]. These powers and duties are flexible and include the followings:

(1) Constitution, operation, management and regulation of municipal police.

(2) Formulation, execution, and regulation of cooperative policy and law.

(3) Approval and Regulation of F.M Radio.

(4) Fixation and collection of local taxes.

(5) Management of local services.

(6) Local data center.

(7) Identification, planning, and implementation of local development projects.

(8) Primary and secondary education.

(9) Mandates of the new laws are very wide and the municipality has tremendous duties and powers.

In this federal governance system, municipality can have the right to formulate plans, allocate budget in their own priority sectors, implement resource generation plans and act as primary actors in the development process. This context has also justified to the need of IUDP for urban development as municipalities themselves can formulate plans for implementation.

3. Methods and Materials

This study is based on primary and secondary data and information. Field study has been conducted to collect primary data through applying a checklist which includes physical infrastructures (road and transportation, water supply and sanitation, electricity and alternate source, communication, irrigation, environmental situation etc.), social infrastructures (education, health, security, entertainment, parks and recreational area, etc.); and economic infrastructure (Haat Bazzar, cold store, agricultural and fruits processing center, etc.). In addition to this, information on existing government and non-governmental institutions within the municipality were also collected and located in the maps. During the field study, basic infrastructure, urban development pattern, development scenario were thoroughly observed and analyzed. Similarly, discussion and interaction with municipal officials and municipal elected representatives, service-providing agencies and local communities have been conducted to identify local and strategic issues for the municipal development. Observation of the urban expansion sites and environmental sensitive areas of the municipality have been done to get insight about the future expansion of the municipality and potential sites of further infrastructure development. In addition, key informants interview including the mayor, deputy mayor, and representative of civil society, political parties, local teachers, technical persons and local aged people were interviewed to get insights in the municipal information.

A number of articles, previous plans and policies, international case studies have been reviewed. National Urban Development Strategy 2017 [14], Land Use Policy 2015[15], The Planning Norms and Standards 2013 [16] have been reviewed. Spatial and situation analysis, SWOT analysis and trend analysis were acknowledged, as some of the important parts of the IUDP have been conducted to see different prospects and hindrances of municipal development.

 DOI: https://doi.org/10.30564/jgr.v3i3.2031

4. Result and Discussion

4.1 Sites and Situation of the Municipality

Dudhauli municipality is located in Sindhuli district Bagmati province and has designated in municipal status in 2014 covered 390.39 square km of land with 14 wards [17]. The municipality lies in between Mahabharat Range (mountain region) in the north and Chure (Siwalik) range in the south, ranging its height from 158m to 2106m mean sea level (Figure 2). Topography of the municipality is rugged with steep to gentle slopes. It consists of sedimentary to low-grade meta-sedimentary rocks. Topographically, the Mahabharat Ranges is markedly higher than the Siwalik hill. It forms rugged terrain with sharp crest and steep slope. The northern slopes are generally steeper than the southern ones. Southern gentle slope as Kamala river basin is more populated.

The Chure hills are characterized by low terraces, alluvial fans, badlands, and thin sandy soil covers. Tawa Khola river valley and Kamala river are filled up by the alluvial and fan deposits. These river valleys are cultivated and are encroached in some places by the people resulting in the degraded forest, overgrazing pasture lands, and badlands topography. A great amount of sediments are contributed to these rivers. Other small streams and rivulets originating from the Chure hill remains nearly dry during most of the year except in the monsoon period.

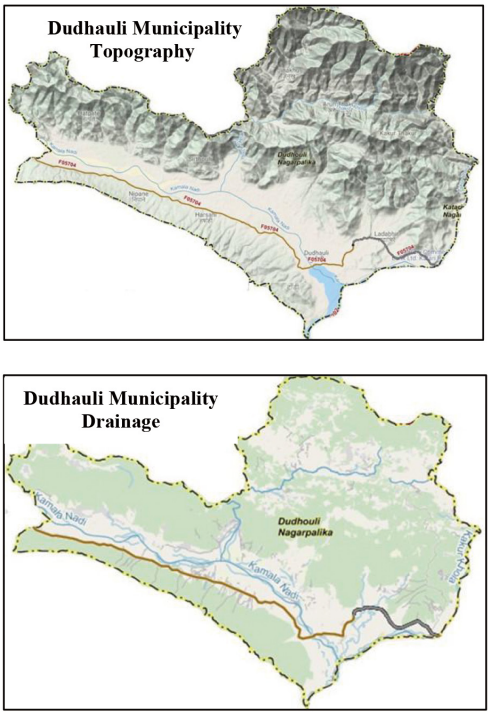

Figure 2. Topographical variation and drainage pattern of Dudhauli Municipality

4.2 Socio-economic Characteristics

As of National Population Census 2011, Dudhauli Municipality had 65,203 populations with an average household size 5.03. Out of this, 47.5% were male and 52.5% were female with gender ratio 90.54. Population density of the municipality was 119.12 persons per sq. The literacy rate (about 80%) of Dudhauli Municipality is above the national average of 66% [17]. However, more focus still needs to provide educational facilities to northern side, as these areas are still remote from the core market area. Future population projections on the basis of existing growth rate have been done. If the population growth rate remains same (present population growth rate 0.92 % annual), the population of Dudhauli municipality in the next five year would be 72,888 (2023AD), and 79,878 in the next 15 years (i.e. 2033AD). As being a newly emerging municipality located at south-east of Sindhuli district and left side of Mirchaiya-Katari-Okhaldhunga road corridor, it seems that physical infrastructure, inter-intra linkages and connectivity of the Dudhauli will grow significantly; as a consequence, the municipality will attract more population from surrounding district, municipalities and rural municipalities in the future.

4.3 Existing Infrastructure and Connectivity

Dudhauli Municipality is located about 14 km north of Mirchaiya Bazzar at east-west highway (Dhanusha District). The municipality has also connected by Bhiman-Dudhauli road which is partly gravel and partly earthen (Figure 3).

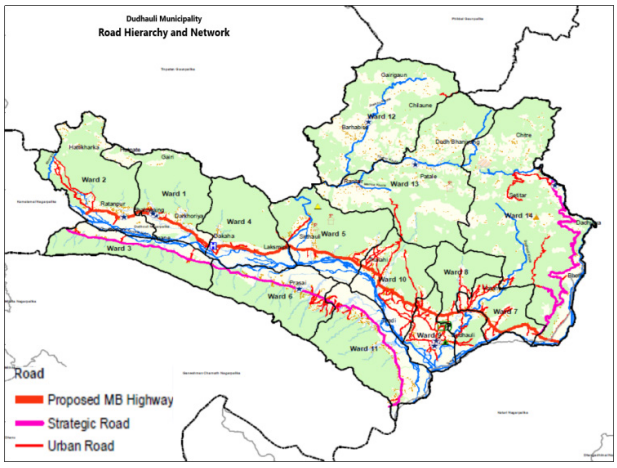

Figure 3. Road networks and road hierarchy

Dudhauli Bazaar, Dakaha, Dhansari, Maraghatte, Panchagachhi, Thakurdaman, Bitriya, Thapatar, Fakritar, Jyamitar, Bansbote, Chitre, Jiganu Phat, Pariyatar, Jinaju Phat are the major settlement of the municipality. There

DOI: https://doi.org/10.30564/jgr.v3i3.2031

are three periodic markets which are providing trading opportunities to the local people living in the surrounding areas. Among them, periodic market located at Dakaha Hatechock (ward no 4) opens every Wednesday. Gaagat Bazaar (ward no 2) and Sirthauli Bazaar (ward no 5) are other periodic markets open in every Thursday and Monday. Besides these, there are five agricultural market centers providing goods and services to the local people as well as buyers and traders of nearby villages and market centers.

5. Urban Growth and Future Scenario

Dudhauli municipality has a number of settlements. These settlements are mostly scattered and some are semi-compact form. Dudhauli, Dakaha, Hatpate, Nipane, Sankhatar, Dandatol, Khiriyani, Harsai, Sirthauli, Arunthakur are major semi-compact settlements. Among other, Dudhauli and Dakaha are main market centers and are developing in the linear patterns on both side of the roads. These are small newly growing market centers but it is observed that urbanization seems to be concentrated high in and around these areas. Migration seems to be high in the recent years, and physical infrastructure for example roads, bridges are constructing connecting to other settlements. Other socio-economic infrastructures are also expanding rapidly at these two settlements. Many traditional houses made with local materials are rapidly replaced into modern one and narrow roads and street are widening significantly. There is also increasing trends of building construction in the recent years. It was also observed that people are constructing new building with concrete structure with multi-story buildings. These indicate an increasing trend of urbanization which seems to be high in the next couple of years in Dudhauli and Dakaha areas of the municipality. Data also reveals that agriculture land has been rapidly converted into residential plots and construction in the last decade. Nearly 56% built-up area has been increased in the period 2008-2018 in the municipal area [18] (Figure 4). It includes residential plots, roads and other physical infrastructure, market places etc.

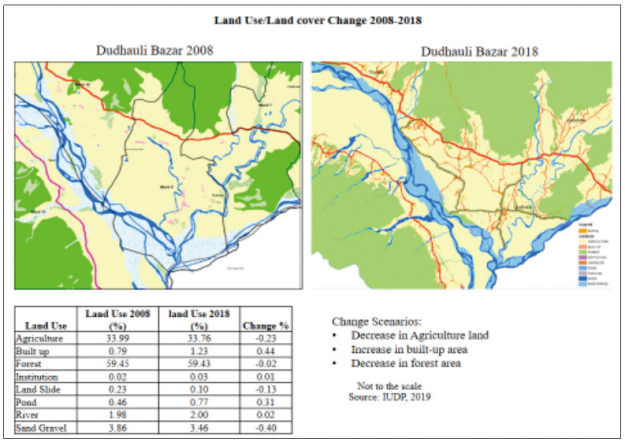

Figure 4. Land use changed 2008-2018 (main Dudhauli Market area)

Settlement pattern of municipality is found semi-compact, linear as well as scattered. Dudhauli and Dakaha bazaar area have compact as well as linear settlement pattern. These market center are developed on both side of the roads. Linear settlements are increasing in ward no. 8, 9 and 10 at the low lying basin of Kamala river and Tawa River. Rest of the areas of the municipality have scattered settlements.

At the nodal points and road juctions, some cluster settlements have been developed to serve as small market centres such as Dakaha, Hatpate, Harsai and Nepane. These market centres serve as suppliers of goods and services and collection of local production. Figure 5 shows that there has been significant changed in the urban form of Dudhauli in the year 2000-2018.

 DOI: https://doi.org/10.30564/jgr.v3i3.2031

Figure 5. Urban Expansion Scenario, Dudhauli Bazzar Area 2000-2018

Source: *Google Earth Archive.*

6. Lead Sector and Vision of Municipal Development

Being about 79% people are still dependent on the agriculture and allied activities, it is one major sector of development. Paddy and maize are the major cereal crops; and fruits (mango and sweet orange), vegetables (potato and others), and spices (zinger, big cardamom) are major cash crops. Importance of Dudhali for agriculture development has laso been recognized as it has been selected for paddy block, mango and zinger pocket area for Prime Minister Agricultural Modernization Project, one of the focussed project of Nepal Government. Agriculture, thus, has been leading sector of economic development of the Municipality. Similalry, the municipality is also known for its ethnic, cultural and religious diversity. There are more than 40 ethnic groups, who have their own cultural and religious practices, traditions and dilects. Likewise, the municipality is also rich in its flora and fauna of sub-tropical climate. Municipality has hot to cool climate lying on the Chure and Mahabharat region. Therefore, people who are living in the southern hot climate zone can enjoy with cool climate of Mahabharat region within short distance. Site scene and trekking are also potential in the municipality. Therefore, tourism has considered as a sub-sector of municipal development.

Taking consideration into above lead sectors of development, a municipal vision has been finalized through participatory consultations. The vision reflects municipal development dream in the long-run, it gives guides and track to the municipality to address the existing problems through phase wise interventions. The vision statement for Dhudauli municipality is: "agriculture, tourism and infrastructure are the main basis of prospeours Dudhauli". It indicates that agriculture and tourism are the major leading sectors of development which should be backed by infrastructure development to make prosperous and livable municipality.

7. Potentials and Problems Analysis

SWOT is a strategic planning technique that helps to identify strengths, weaknesses, opportunities and threats of institution related to project/planning. Strengths and weakness are generally defined in terms of internal factors; whereas, opportunities and threats are commonly known as an external factor. Based on the interaction with the local communities and municipal officials, impressions of detailed fieldwork and municipality profile (2017), data and literature, Dudhauli municipality has some potentialities and weakness of developement which are presented below (Table 1).

Table 1. SWOT Analysis (Municipal level)

Positive	**Strengths**	**Weakness**	**Negative**
	• Road connectivity and accessibility (309 km of roads and connected by Mirchaiya-Katari road and Bhiman-Dudhauli strategic road) • Diversified ethnic composition-multi-cultural and multi-ethnic communities. • Ample land available for infrastructure development. • Good share of economically active population (53%). • Presence of forest (59%) and water resources • Availability of flat and fertile land for agriculture and irrigation facilities (47 irrigation schemes)	• Lack of planned urban development initiatives. • Poor irrigation and agricultural support programs/incentives. • Weak institutional capacity (human resources, technical expertise and logistics). • Low revenue generation and poor spending capacity. • Poor urban infrastructure and services (poor road condition and market infrastructure, no bus park, drainage network and landfill site). • Outward migration of youth for employment	
	Opportunities	Threats	
	▪ Increase accessibility by upgrading existing roads including Madan Bhandari highway (proposed), and bridges over Kamala and Tawa Khola ▪ Larger markets in adjoining areas e.g. Mirchaya, Katari and Bhiman ▪ High potentiality of commercialization of agriculture e.g. Ginger, Junar, Paddy ▪ Potentiality of natural and religious tourism-Madhuganga	• High dependency on external funds for infrastructure development. • Flash food and inundation (Kamala and Tawa rivers). • Depletion of productive land (Change in land use). • Forest Encroachment (Chure region) • High cost for infrastructure development • Outsourcing the technical exerts • Youth outmigration • Chure degradation and climate change impacts	

8. Planning Issues and Strategies for the Municipality

From the detailed field work, major issues of Dudhauli municipality have been identified. As explained above, the issues were identified through the interaction with the municipal officials and local communities as well as field observation and informal conversations at different areas and sectors in the municipality. Identified planning issues are listed out as follows:

(1) Kamala River, Tawa River and seasonal river and rivulets are major problems for Dudhauli causing flooding and inundation. These issues need to be addressed by river

DOI: https://doi.org/10.30564/jgr.v3i3.2031

embankment and implementing flood control mechanisms.

(2) Poor physical infrastructure development (road, bridge, sewerage, electricity and irrigation), insufficient community infrastructures (health, educations, community halls etc) need to be implemented on phase-wise basis.

(3) Having insufficient water supply, many people are depended upon tubewell and well even river which are unsafe for health. Different schemes of water supply projects should be implemented.

(4) Encroachment of public land, forest and Chure area and increasing squatter settlement are other issues which need to be addressed incorporating in annual plans and programmes of the municipality.

(5) Institutional strengthening through capacity development (skills and knowledge enhancement, provisions of infrastructures and municipal assets and data base management etc.) should be priority in institutional development for the municipality.

(6) Rapidly conversion of agriculture land, public land and open space into built-up form in an unplanned development causing haphazard urban growth need to be controlled from the beginning to develop a healthy urban development. Land use planning and implementation of building bye-laws [19] for urban growth regulation should be implemented in the municipality.

(7) Increase social facilities and infrastructures to enhance accessibility to education and health and economic opportunities in a balance way that would bring municipal people in a proximity of easy service delivery system.

(8) Conservation of natural resources including Chure conservation, conservation of traditional culture may enhance tourism promotion and economic development which need to be addressed in annual plans and programmes of the municipality.

(9) Agriculture incentives, pocket area development, promotion of high value crops, livestock development and market infrastructure development will be important strategies for agriculture development and employment generation in the municipality which could be intervene in the annual plans and programmes of the municipality.

(10) Tourism promotion, tourism infrastructure development with tourism route development linking important tourism sites is an important strategy to develop tourism activities in the municipality.

9. Land Use Zones and Regulation

In Nepal, Land Use Policy (2015) has emphasized the safe and secure settlement along with the environmental protection, food security and it has mandated for designation of land use zones/classes [20]. Based on the existing land use pattern of growth and considering increasing trend of land use changes, which was quite visible during the field visit, growing urbanization and growth trends lead demand of land for non-agricultural uses, land use zoning of the municipality has been prepared. The land use zoning has been proposed to regulate controlled land use zoning so that unwanted haphazard urban development would be discouraged and urban development would be regulated in a right direction.

Agriculture area which has been identified and demarcated on the basis of quality of land, land capability, and irrigation facilities which would contribute to increase agriculture productivity. Dudhauli (ward 9), Rajbas, Khariyani, Thalaha, Patayani, Narkate, Jitpur, Dudaha, Daman, Jagadi, Laxmipur, Khuttepani and Dandagaun falls in this zone. Based on its potentiality, the agriculture zone further classified as fruit, paddy and zinger pocket areas with other mixed agriculture zones. Potential area for future residential expansion has been identified and demarcated on the basis of proximity to existing residential area, access road and infrastructural services and facilities avoiding fragile topography including low land and flood prone areas. The following areas are categorized as residential areas in the municipality:

(1) High density residential area: Dudhauli, Dakaha, Sirthouli,

(2) Medium density residential area: Tandi, Thalahi, Sirthouli, Dakaha, Majhuwa

(3) Low density residential area: Arundana, Saldanda, Barhabise, Ranitar, Phulbari, Hattikharka, Katahare

Commercial zone comprising of areas occupied by existing government institutions, community services and commercial activities. Dakaha, Dudhauli, Jhankritar and Sirthauli area are categorized in this zone. Existing industrial areas as well as areas identified and demarcated as potential area for future expansion of commercial activities which would likely to take place in near future because the area lies in the proposed highway. There is huge coverage of forestland in the municipality, which shall be protected and developed as forest zone (Figure 6). Besides barren lands, flood land and wetlands are also identified and demarcated in the forest zone. Other land use zone is identifying and demarcating public land containing man made and historic features, public utilities, natural and cultural heritage sites and environmentally sensitive areas like water sources, rivers and streams, canals, ponds etc. which need to be protected against encroachment.

The land use zoning has also been guided by urban infrastructure and service provisions. Road hierarchy with 50m (Madan Bhandari Highway), Bimad-Dudhali feeder road (22m), municipal strategic roads (11m-15m) and other municipal roads (6m to 8m) has been proposed for

 DOI: https://doi.org/10.30564/jgr.v3i3.2031

long-term development. Besides, other infrastructures provisions have also been guided by bye-laws for restriction and ease to municipal development in the long-run.

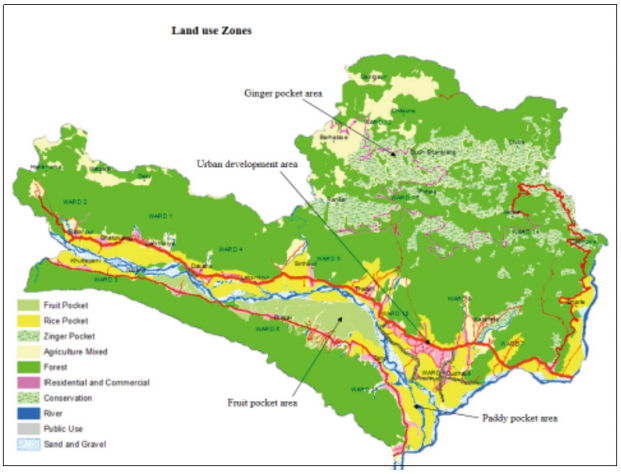

Figure 6. Land use zones and potential sites of development

10. Prioritized Key Sectoral Strategic Projects for IUDP Implementation

This IUDP consists of various sectoral development plans including physical infrastructures, social, economic, tourism and cultural development, environmental management, disaster risk reduction, institutional development plans. Integration of these sectoral development plans thereby promote sustainable development of the municipality is the main concern. To summarize major sectoral strategic activities that need to be implemented as project level planning in the municipality, following activities should be municipal major focus and priority:

Physical Development: Physical development plans consists of upgrading of 200 km road and construction of 150 km new roads which will connect low land and highland area/settlements to integrate important settlements in the municipality. Five overhead tanks are needed to provide water supply in the major settlement areas. Construction of drainage and sewerage network at Dudhauli Bazar, Dakaha and main market areas needs to be expanded. Expansion of irrigation canals in agricultural pocket areas is also important to develop in the municipality. Conservation and promotion of traditional ponds and drinking water source at 5 different locations are proposed. Similarly, construction of one bus park and a slaughter house at Tandi, convention/city hall at Dudhauli Bazar area, cremation and cemetery/burial ground, etc., are some of the prioritized physical development projects. Besides, land use zoning and provisions of Right of Way (RoW) have also been proposed as physical development plan.

Social Development: social development activities consist of uupgrading and improvement of school infrastructures (school building, class room, library, science/computer lab, toilet, playground, etc.) at 10 different schools is needed. Construction of one technical institution (skill promotion) at Sirthauli area, reduce school dropout rate and increase school enrollment to targeted groups and community through community campaign and providing them different economic opportunities, construction of one hospital (50 beds) and birthing centers at each ward, one community library at each ward, four urban service centers at Dudhauli bazar, Dakaha Bazar, Sitthauli and Tandi; construction of two public toilet at each ward and three community recreation parks at Dudhauli Bazar, Dakaha and Sirthauli; construction of old age home are major projects to be implemented within the municipality.

Economic Development: Economic development activities constitutes agriculture related infrastructure development, promotion, market development, skill development to youths, entrepreneurships, farmers incentives and subsidies and market access to them. Major priority project activities within economic development consists of one integrated market centre at Tandi, five collection centres and hat-bazzars, two cold storages at Dudhauli and Dakaha, training to farmers, establishment of fruit processing plant, soft loan provision through banks etc.

Tourism and Cultural Development: Tourism and cultural development activities create peoples' involvement in employment and economic earnings. As tourism has been a lead development sectors, tourism promotion connecting it with cultural connection will be important. Therefore, construction and management of tourism centre, promotion and broadcast on tourism significance, development of tourism route connecting different tourism sites, cultural home stay, agro-tourism are major activities identified.

Environment Management: Major environment management activities prioritized by the study are the development of landfill site, waste collection and disposal, forest area conservation, strengthening of community forest users' groups, environmental sanitation, water reserves through community ponds, river management, etc.

Disaster Risk Reduction: Major disaster risks to Dudhauli municipality are flooding, inundation, and land slide hazards. To minimize the disaster risks, river bank protection of Kamala River (26 km both sides at Duhdauli area), Tawa river protection, establishment of flood early warning system, forest protection and plantation are identified as major priorities.

Institutional Development: institutional development as such is important to Dudhauli Municipality, as it is

DOI: https://doi.org/10.30564/jgr.v3i3.2031

very poor in municipal human resources, poor skilled and trained personnel in the municipal governance, poor infrastructures and logistics, very low internal resource capacity for project investment. For this purposes, key activities such as skill development training to municipal staffs, recruitment of technical experts, revenue generation campaign, community awareness, construction of municipal office building, equipped with logistics and facilities in the municipality and each ward offices have been prioritized.

The projects and strategies of municipal development have been planned in a way that these would be tied up to each other to meet targeted vision, goal and objectives. Sectoral integration and connections have been done through different aspects of planning principles.

To make vision operationalize, agricultural development; and trourism promotional activities have been prioritized. Infrastructure development has been proposed as backup of agriculture; and tourism development to foster prosperous Dudhauli. Main attention has been given to connect between lower level social communities to upper class communities and spatially poor geographically backwarded areas to comparatively fair developed geographical areas.

11. Conclusion

Current swift in urbanization and growth has demanded the immediate need of planned intervention in Dudhauli municipality. The town has largely agro-based activities and has initiated new physical infrastructure development in the fertile agriculture land. Its locational advantage attracts more people, goods and services in the recent years; consequently, traditional form of town has rapidly been replaced into modern one by use of modern constructional materials in buildings and houses. Moreover, towns in other hill region like Dudhauli have generally to be considered as risk sensitive particularly of flooding, inundation and landslide in urban planning context. Recent growth trend has resulted the conversion of agriculture land into built-up area leading to unprecedented hapazard urban growth. Settlement expansion mainly found in and around the main market centers and along the strategic road corridors. The growing settlemtns has already started showing chahotic urban growth that demands plan interventions from the beginning. But the initiatives are lagged behind to proper management as the municipal local governance seems poor in its capacity interms of investment, human resources enhancement and service delivery to its people.

To regulate unwanted hapazard growth and development, a proper planning with long-term development vision is needed not only to regulate development but guiding to municipal authorities lead into right directions. In this context, IUDP approach of urban planning has to be considered as an effective tool of planning. IUDP is one of the most effective tools to regulate the urban development by envisioning future, targeting to the goals and strategies, utilizing the potential resources integrating different sectoral development. The IUDP through proposed land use zoning, ROW, bye-laws will regulate the town for sustainable development as an appropriate tool to emerging towns like Dudhauli. Being a newly formed and emerging municipality, urban forms of Dudhauli has not been reached to an unmanageble yet. Nevertheless, it needs a planned course of actions as guided by IUDP.

However, there is always challenge that plan itself does not make a sense if it is not implemented properly. IUDP is a guiding tool to Dudhauli municipality for best achievement integrating physical, social, economic, environmental and institutional development. Success and failure of this plan all depend on how the municipality will adopt its vision, mission, goal, objectives and the direction and consequent formulation of annual plans and programme in the coming years.

Acknowledgement

I would like to thanks to the DUDBC for providing opportunity to conduct IUDP study. I also thanks to K. P. Timilsina and S. C. Jha for supporting field data collection and mapping works.

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DOI: https://doi.org/10.30564/jgr.v3i3.2031

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ARTICLE

Biogas Technology Adoption as an Alternative Source of Energy in Domboshava Communal Area of Zimbabwe: Benefits and Challenges

Thomas Marambanyika Shingirayi Sakarombe Tatenda Musasa* Rameck Defe

Department of Geography and Environmental Studies, Midlands State University, Zimbabwe

ARTICLE INFO

Article history
Received: 15 July 2020
Accepted: 23 July 2020
Published Online: 30 July 2020

Keywords:
Biogas
Sustainability
Renewable energy
Rural communities

ABSTRACT

The research examines challenges and opportunities of biogas technology adoption to achieve sustainable household energy in Ward 4 of Domboshava communal area, Zimbabwe. The research adopted both qualitative and quantitative research techniques. A total of 65 questionnaires were randomly distributed to households using biogas. Purposive sampling technique was employed to select key informants from the Environmental Management Agency, Netherlands Development Organisation, Zimbabwe Energy Regulatory Authority, Environment Africa and the Ward Councillor. The study revealed that the level of education attained do not influence biogas adoption ($p > 0.05$) whereas funds availability, awareness, promoters and gender of the household head were seen to have a major effect ($p < 0.05$). The benefits of biogas technology noted by households were that it cooks fast, provides clean energy and at the same time reducing the frequency of fire wood collection in the forest. Challenges such as lack of adequate knowledge about the technology and lack of required financial and material resources compromised the adoption of biogas technology by the households in Ward 4. The study recommends that relevant government agencies should provide accessible technical services and set up demonstration centres in every ward with a view of encouraging rural households to adopt biogas technology.

1. Introduction

Scarcity of sustainable energy solutions, accompanied by over dependence on wood energy has remained one of the challenges faced by developing countries [15,19,22]. This has therefore, placed great need for sustainable alternatives of energy such as biogas. Biogas technology is generally defined as the use of biological processes in the absence of oxygen (anaerobic digestion) to degrade and stabilise organic matter and other biodegradable raw materials to create a mixture of methane and carbon dioxide that can be utilised as fuel [13,15,16,17]. Biogas technology has great potential to reduce wood energy consumption since it provides sustainable household energy, thus enabling household members to meet their increasing energy demand [3,15,16]. Unlike wood energy [22], shanchu biogas burns without smoke thereby improving indoor air quality and thus saving household users from respiratory distress and ailments.

The need for sustainable energy remains a very criti-

*Corresponding Author:
Tatenda Musasa,
Department of Geography and Environmental Studies, Midlands State University, Zimbabwe;
Email: tatendamus14@gmail.com

 DOI: https://doi.org/10.30564/jgr.v3i3.2151

cal issue in Africa's efforts to meet the increasing energy demands [6,14]. To support this, Scarlet [18] stated that with increasing population densities access to energy is a prerequisite in order to improve the quality of life. This explains why the provision of sustainable, affordable, clean, adequate and efficient energy remains at the core of sustainable development goals (2015 -2030). In spite of the efforts in place so far to provide sustainable energy for all, nearly 1.3 billion people globally do not have access to modern sources of sustainable energy [1,14,17]. The number of people living without access to renewable energy has been increasing in Africa constituting approximately 57% of the World's population [21]. This compounded with other social and economic challenges has left poor people marooned in poverty which frustrates efforts to attain the Sustainable Development Goals (SDG) in Africa.

In sub-Saharan Africa, biomass energy in the form of firewood, charcoal and crop residues accounts for 70 - 90 per cent of primary energy supply [2]. Due to acute energy poverty in sub-Saharan Africa firewood and charcoal have emerged as important sources of energy for lighting and heating [12,17]. In another fascinating development, the US Department of Energy concluded that over 75% of wood harvested in Africa is used for household energy needs [6]. This situation poses a great threat to human and environmental security and also constitutes a major stumbling block to progress towards growing economies as well as realising goals of sustainable development agenda in Africa [12,17,18].

Zimbabwe has a growing understanding of sustainable energy supply as a critical factor for national development [8]. Currently, the country's energy requirements are met through a combination of biomass energy, thermal and hydro-electric power plants as well as imports. ZERA [25], noted that Zimbabwe has a national power generating capacity of 1 400 megawatts (MW) against a national peak demand of 2 400 MW. This situation clearly indicates that there is a mismatch between power supply and demand. The capacity of electric power stations in Zimbabwe has therefore been compromised due to reduced water levels which impact negatively on the power generating capacity. In the same way, the available thermal power stations have passed their lifespan and the equipment is now obsolete resulting in serious inefficiency and frequent breakdowns. For these reasons, prospects of fast connecting rural households with electricity has henceforth remained inconceivable. To this end Zimbabwe's energy consumption has been dominated by wood based energy, agricultural residues and cattle dung thus presenting a disastrous threat to environmental sustainability.

According to Hivos [8], wood based energy consumption in Zimbabwe is particularly high and unsustainable accounting for up to 95% of total energy consumption in rural households. Most rural communities are now facing acute shortage of household energy supply mainly because of unsustainable firewood harvesting and land clearance for agriculture [10]. Another worrying development as observed by Mbulayi [10], is that people in rural areas mainly women travel long distances to collect firewood at the expense of engaging in other productive economic activities. Other than this, continued reliance on firewood for energy has been linked to increased respiratory ailments among users due to incomplete combustion and smoke emissions in poorly ventilated houses common in rural areas [5]. In a study on indoor air pollution from biomass combustion and acute respiratory illness in pre-school ages in Zimbabwe, Mishra [11], found out a worrying high incidences of respiratory related deaths. This therefore calls for an urgent shift to other alternative sources of energy which are clean, affordable and sustainable with biogas technology being one of the best option.

Efforts to disseminate biogas technology amongst rural communities in Zimbabwe were reignited in 2012 following a partnership between the government and development agencies. The National Domestic Biogas Programme was thereafter launched with an aim to establish a vibrant biogas sector set to benefit many rural households across the country. Given the inter-related challenges of poverty and energy demand, climate change, indoor air pollution and human health, accelerated and large scale dissemination of biogas technology is now necessary more than ever [8]. Regrettably though, benefits and challenges of adopting and using the technology have never been comprehensively documented from the users' perspective, information that is critical to guide sustainable adoption and implementation of biogas initiatives. This paper therefore seeks to understand the challenges and opportunities of biogas technology adoption in communal areas of Zimbabwe to achieve sustainable development goal seven (SDG7) which seeks to ensure access to affordable, reliable, sustainable and modern energy for all.

2. Study Area

The study was carried out in Ward 4 of Domboshava (31^0E and longitude 17^0S), a peri-urban communal area in Mashonaland East province of Zimbabwe (Figure 1). Administratively Domboshava falls under the local authority of Goromonzi Rural District Council and lies approximately 29 km northeast of Zimbabwe's capital city, Harare.

DOI: https://doi.org/10.30564/jgr.v3i3.2151

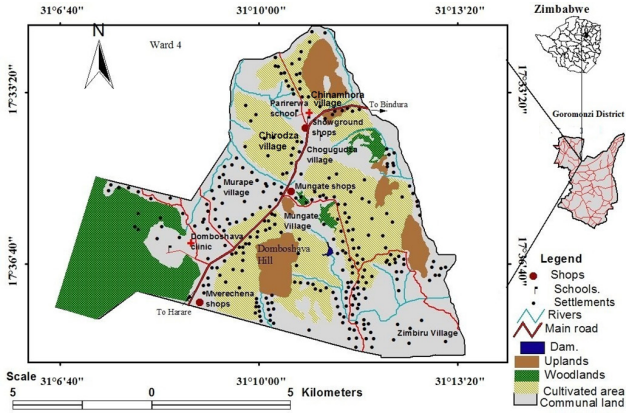

Figure 1. Ward 4 of Domboshava Communal Area in Mashonaland East Province, Zimbabwe

Goromonzi District has a total of 15 wards and a population of about 227 987 people [26]. The district is divided into three political constituencies which are Goromonzi North, South, and East. Domboshava itself is made up of five wards and falls under Goromonzi North constituency which has a total of eight Wards [9]. Ingwani [9], further stated that two of the wards (ward 6 and 7) of Goromonzi North constituency are commercial farms. Ward 4 is found on the boundary of Harare and stretches all the way to Makumbe Mission along the Domboshava road.

The study area is found at an altitude of 1 080 m above sea level. The area is largely a rugged terrain with a drainage dominated by dendritic river patterns, draining to the north-east into Mazowe Catchment. Soils in the area are dominantly sand veld, red clay soils, black turf and sandy soils which are derived from the same parent material but differ in properties as they occupy different topographical positions. The area lies in agro-ecological region 2b of Zimbabwe which receives good rains although subject to frequent droughts, dry summer spells and short rainy seasons [9]. Rainfall averages 650-800 mm per annum with temperatures averaging around 26-29 degrees Celsius in summer [27]. In winter the temperatures drop to as low as 10-15 degrees Celsius. Zvigadza et al. [27], further pointed out that frequent mid-season and unusual rainfall variations are threatening many livelihoods in some parts of the area. Vegetation is sparsely distributed with shrubs and mature trees severely subjected to deforestation. This situation limits the potential use of wood as a source of fuel.

Population has been increasing in ward 4 of Domboshava and is estimated to be around 7 100 households [26]. Increasing population increases demand on energy sources including biogas, thus it is imperative to comprehensively examine the challenges and opportunities of biogas technology adoption. The average poverty prevalence in the area ranges between 61% and 72%. Poverty is more prevalent on the northern peripheral areas of Goromonzi District in wards 1, 2, 3, 4 and 5 which forms the huge part of Domboshava area. This leaves the local communities with no option except to use the available raw materials such as wood and dung for energy.

Major economic activities in the area ranges from market gardening, grain production and livestock rearing. In general terms most people in Domboshava are subsistence farmers who grow groundnuts, maize and other small grains for food security. However, Zvigadza et al., [27], mentioned that for decades' families in Domboshava has been relying on market gardening activities for survival but things seem to be changing as the area is facing serious deterioration of water levels, expanding population, economic stagnation and a flooded market for some of its agricultural products. In terms of ethnicity, Domboshava communal area is largely dominated by people who speak Zezuru, a Shona dialect which is one of the main vernacular languages of Zimbabwe [9].

3. Data Collection Methods

A mixed methods research approach combining both quantitative and qualitative research techniques was adopted in this study. Field surveys were carried out between January and March 2017 using questionnaires and semi-structured interviews to gather information on challenges and opportunities of biogas adoption in ward 4 of Domboshava area.

The study targeted individuals and institutions involved in biogas technology implementation such as households, traditional leaders, local political leaders, Domboshava Community Development Association, Netherlands Development Organisation (SNV), Environment Africa, Environmental Management Agency (EMA) and Department of Renewable Energy in Zimbabwe. The households were chosen because they had first-hand information on challenges and opportunities that are arising from biogas technology adoption and use. Sixty-five households using biogas drawn from all villages making up Ward 4 of Domboshava communal area participated in the questionnaire survey. A register of households using biogas was obtained from the ward councillor and verified with the development agency funding adoption of the technology. Household heads or the eldest person who makes decisions in the absence of a household were asked to complete the questionnaire. Household heads provided information on socio-economic characteristics of households (e.g. size, age of head and sources of income), level of awareness and attitude towards biogas technology, factors influencing adoption and use of biogas technology.

DOI: https://doi.org/10.30564/jgr.v3i3.2151

Key informants were purposefully selected from traditional leaders, local political leaders, Domboshava Community Development Association, Netherlands Development Organisation (SNV), Environment Africa, Environmental Management Agency (EMA) and Department of Renewable Energy in Zimbabwe for semi-structured interviews. With the participants' consent interviews were audio recorded and notes were taken at the same time to capture important cues and relevant points. Field observations aided by a checklist assisted to document how biogas practice was undertaken in the area. Ethical issues were considered before and during the study. Prior to fieldwork ethical clearance were sought from the Department of Geography and Environmental Studies at Midlands State University. Thereafter, permission to enter Ward 4 of Domboshava was granted from the Rural District Authority.

4. Data Analysis and Presentation

Quantitative data obtained from closed-ended questionnaires was cleaned to check for errors and completeness. This data was coded in Microsoft Excel spreadsheet before exported to the Statistical Package for Social Scientists (SPSS) Version 25.0. Descriptive statistics and inferential statistics were generated to show patterns in biogas adoption and associated challenges. Chi-square tests were carried out at 95% confidence interval to determine the association between households' characteristics and level of biogas adoption as well as households' awareness and attitude to use of biogas. Qualitative data obtained from semi-structured interviews, field observations and open-ended questions in the questionnaire were analysed using content analysis method. Content analysis involves coding and categorising of verbal or behavioural data in a manner that differences and similarities can be recognised.

5. Results and Discussion

5.1 Level of Awareness on Biogas Technology

The study results show that a few of the adopters' neighbours, friends and relatives in the Domboshava community are well appraised of biogas technology. The majority of the household respondents, that is, 56.6% were in disagreement with the fact that people in Domboshava are well aware of the biogas, a situation that has potential to compromise adoption of the technology in the communal area despite having several benefits (Table 1). In addition, while 22.2% of the questionnaire respondents are not sure (undecided) of the level of biogas technology awareness, only 13% maintained that people in the communal area were fully aware of the technology. However, it is not clear whether the knowledge encompasses both existence, operation, maintenance and efficiency of the technology since awareness of the existence of the technology does not point to the technical awareness of the technology itself. Therefore, knowledge and awareness towards a certain technology may have an influence on its adoption, a situation also observed by Adeola *et al.* [2].

Table 1. Responses on the level of awareness on biogas technology

Level of agreement	Frequency	Percentage
Strongly Agree	4	8.9
Agree	6	13
Undecided	10	22.2
Disagree	25	55.6
Strongly Disagree	0	0

Wawa [24] proposed that awareness of biogas technology should encompass people getting to know finer details of the technology, that is; what it is, how it functions, its services and financial aspects for it to be able to influence people's decision on adoption. Findings from the study indicated that only 37.8% of the respondents had received training on biogas technology while 62.2% indicated that they have never received some form of training or attended a meeting on biogas technology. This relates with the discovery that a substantial number of the respondents have learned about biogas technology from their neighbours and friends. However, the implication of the result is that biogas adopters who have never attended meetings or receive some form of training on biogas technology may fall short of the adequate knowledge on the benefits, operation, maintenance and services offered by the technology hence low awareness.

Chi-square test results show that employment status and level of education attained do not influence biogas adoption ($p > 0.05$). Thus regardless of the level of education attained households can implement the technology depending on local skills acquired either through community meetings.

5.2 Source of Information about Biogas Technology

As indicated in Figure 2, NGOs (33.3%) and existing biogas adopters (friends/neighbours) 40% served as the main sources of information about biogas technology. Only 13% of the biogas users have heard about the technology from government while less than 12% mentioned media

DOI: https://doi.org/10.30564/jgr.v3i3.2151

publications. The results relate to the findings of Wawa [24], who observed that in Tanzania NGOs are more active than the government in the promotion and awareness raising of biogas technology. In addition, it was observed that existing biogas users with the largest representation stands to be tools for biogas technology promotion and use in Domboshava. The explanation to this, is that both friends and neighbours often relay information to each other as they meet more frequently during domestic chores such as fetching water and through community based food security projects. The role of media (12%) is not much visible given location of the study area in the outskirts of urban areas which hence inhibits access to information and media publications. To support this, results from interviews also revealed that media plays a minimal role in raising awareness given the rural set up of the area. In fact, most people are engaged in agricultural activities during the day and pledges no time to radio, reading newspapers or watching television. The prime effect of this situation is that there is limited awareness yet the technology presents numerous opportunities as local communities often do not spare their time but rather seek to improve their livelihood status.

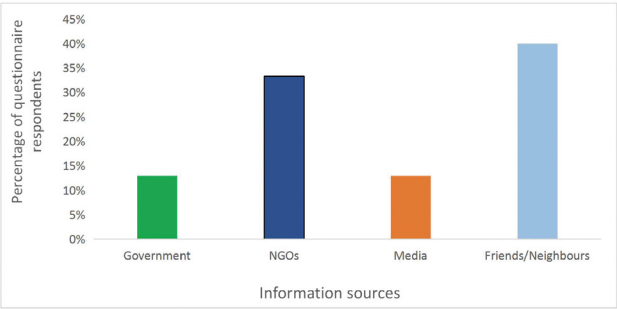

Figure 2. Sources of information on biogas technology in Domboshava Communal Area

5.3 Attitude towards Biogas Technology

The results from the survey revealed that, the majority that is 56% agreed to the fact that biogas technology reduces the rate of deforestation a situation that creates a positive attitude towards adoption of the technology. Households are also intensifying biogas technology activities in Domboshava in a bid to relieve women work load and reduce time spent in collection of firewood. This was confirmed by 44% of households using biogas technology in Domboshava communal area (Table 2). Households in Domboshava either recommended as the best alternative energy source which pointed out that the technology benefits completely outweigh its weaknesses. Scores for strongly agree and agree are higher than those of disagree, undecided and strongly disagree combined together. This is a clear indication that overally respondents have a positive attitude towards biogas technology. However, further enquiries indicate that many people were not very sure (undecided) if the technology can help reduce smoke inhalation given higher frequency (38%) of neutral responses.

Table 2. Respondents attitude towards biogas technology

Statement	SA	A	UD	D
Biogas will reduce the rate of deforestation	15 (33)	25 (56)	4 (10)	1 (2)
Biogas will relieve women workload	7 (15)	16 (36)	15 (33)	5 (11)
Biogas will save time spend on fire wood collection	12 (27)	20 (44)	8 (18)	4 (10)
Biogas will reduce inhalation smoke	9 (20)	11 (25)	17 (38)	9 (20)
Biogas technology will help improve soil fertility	13 (29)	31 (69)	4 (10)	0 (0)
Biogas is recommended as the best alternative energy source	33 (73)	9 (20)	2 (4)	1 (2)
Benefits of biogas overweighs its weaknesses	5 (12)	18 (40)	13 (29)	9 (20)

(Bolded figures indicates frequency and those in brackets is the percentage frequency)

***Key: SA** Strongly agree; **A** Agree; **UD** Undecided; **D** Disagree*

Also, high frequency of neutral responses was noticeable on the ability of biogas to relieve women workload (33%) and outweighing its weaknesses (29%). This is attributed to the fact that most of the biogas adopters have not yet fully utilized all the benefits offered by biogas technology. However, on a general note, neutral responses could not dilute the general trend of a clear positive attitude towards biogas technology expressed by the household respondents.

5.4 Factors Influencing Adoption and Use of Biogas Technology for Household Energy

Results from the study revealed that motivation from promoters and other users in the area, environmental, economic and health considerations contributed towards the adoption of the bio gas technology in Domboshava. This was confirmed by 91% of the households who revealed that biogas is the main contributor for household technology which they have adopted as a result of motivation from various promoters. This result concurs with findings by Wawa [24], who observed that various promoters are key in adoption of biogas technology adoption since they provide funds and any related material towards the adoption of the technology so as to ensure sustainable and clean energy for all. Additionally, it was revealed that various promoters such as Netherlands Development Organisation (SNV) contribute towards the adoption of the technology through sponsored cooking stoves.

DOI: https://doi.org/10.30564/jgr.v3i3.2151

Table 3. Respondents' motivation for biogas technology adoption

Factor	Frequency %
Motivation from promoters	91
Motivation from other biogas users	69
It cooks quickly	60
Produce less smoke	51
Health benefits	28
Non availability of cheap fuel sources	9

Results from the survey also revealed that biogas adopters (69%) motivated the adoption of biogas technology. This relates to the findings that friends and neighbours were also crucial sources of information in terms of awareness in Domboshava communal area. Ability of the technology to cook quickly was mentioned by 60% a gesture that promoted the adoption of biogas technology in Domboshava communal area. About 51%, confirmed that biogas produces less smoke as compared to other sources of fuel such as wood. This makes it clear that biogas is a clean source of fuel a factor that motivated households to adopt the technology. Households in Domboshava communal area adopted biogas because of the associated health benefits received as confirmed by 28% of the respondents. To support this, during an interview, it was highlighted that most people are lured into biogas technology because of the need to have an alternative source of energy which is sustainable, environmentally friendly and cost effective in nature. This therefore makes it clear that adoption of the technology is critical since it ensures access to affordable, reliable, sustainable and modern energy for all thus attainment of SDG goal 7. The results of the study are in agreement with studies carried out in Kenya where people's involvement in biogas technology was mainly due to the need to enjoy multiple services that it provides a situation observed by Bonnke [4].

5.4.1 Cost of Biogas Digester Installation

From the results obtained in the field, a small number of respondents (4.5%) highlighted that the installation process is reasonably affordable. The estimated cost of installing a domestic biogas digester and its appliances ranges from US$600.00 to US$ 1 500 depending with the size of the plant. About 93.5% of the household heads expressed that the cost of acquisition and installation of the technology was high and they find it very difficult to raise the required funds in time. This implies that cost of biogas technology is an important influencing factor with high initial cost of installing the technology being a limiting factor in Domboshava as revealed during field observations. This finding concurs with Bonnke [4], who observed that in most developing countries high initial costs of access to modern energy sources are often exorbitant and inhibitive for poor rural populations. The results therefore indicate that while biogas technology maybe expensive as expressed by the biogas adopters, people are motivated by other factors superior than the expensive nature of the technology.

Chi-square test results revealed that there is a relationship between employment status and affordability of installing a biogas plant (p=0.000). This indicates that people who are employed are better positioned to adopt biogas technology in Domboshava than those who are unemployed. Employed household heads can afford initial installation costs of biogas technology and have better access to information when they migrate to various urban centres in pursuit of their occupations.

5.4.2 Adequacy of Biogas for Daily Energy Needs

Few adopters (32.2%) stated that biogas produced from their digesters was enough for their daily energy needs, whereas the majority (67.8%) pointed on its inadequacy. Most households mentioned that they still need to supplement their biogas plants with other energy types as the majority showed that they are still using firewood to supplement biogas. As a result, it was reported that fast cooking with biogas is only possible for simple meals like porridge, vegetables and tea using stoves in figure 3. For heavy meals and especially for larger families, most biogas technology adopters are reportedly resorting to firewood (Figure 4). During interviews it was revealed that most people in the area are surely energy stressed. This was further augmented by sparse vegetation and distances travelled to the nearest forest observed during field work. Results from the survey also revealed that several government efforts have been launched so as to connect rural households to the national grid through rural electrification programs. However, it emerged that not all segments of the population benefited from this initiative with majority still languishing in energy stress. One of the elderly biogas adopter in the community revealed that when he first heard of biogas technology, it was said the technology will provide energy for cooking, heating, lighting, ironing as well as refrigeration. However, this has never been the case as most households, if not all rarely use biogas for other uses except cooking.

DOI: https://doi.org/10.30564/jgr.v3i3.2151

Figure 3a. Self purchased biogas cooking stove

Figure 3b. SNV sponsored cooking stove

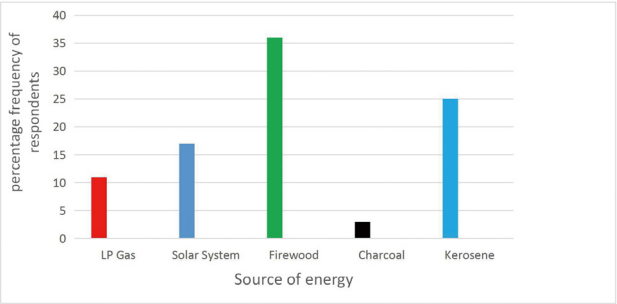

Figure 4. Energy types being used together with biogas by adopters

Although there are a number of energy sources being used, firewood scored highest frequency (36), followed by kerosene (25) definitely used for lighting. Other households have since secured and installed solar systems as observed during field work although it registered a low frequency due to its expensive nature and hence cannot be afforded by low income households. Due to the proximity of Domboshava to Harare, it emerged that some households are using liquefied petroleum gas (LPG) to meet increasing household energy. The proportion is however limited owing to issues of affordability as confirmed by 22.7%. This finding concurs with Bonnke [4], who in a separate study observed that the cost of household energy sources determines the number of people who are likely to adopt the technology.

5.4.3 Benefits of Using Biogas Technology

From the survey the majority of the households (60%), highlighted that biogas is an efficient and fast technology with limited smoke. To support this, during an interview it was emphasized that biogas technology is an effective source of energy as it offers multiple services at household level. Besides provision of gas for energy, field observations conducted revealed that biogas technology provides well rotten organic manure that is free from pests and diseases. Maize and beans grow very well from this organic fertilizer a situation that has increased crop production for biogas adopters in Domboshava communal area. Questionnaire survey results also show that the time spend collecting firewood has been reduced significantly as shown in Table 4. This implies a reduction in deforestation levels in the area, reduced indoor air pollution and of course subsequent reduction in emission of carbon dioxide into the atmosphere.

Table 4. Comparison of time spend collecting firewood before and after biogas technology adoption

Variables	Frequency	Percentage%
Less time	39	86.6
More time	0	0.0
Same time	7	15.6

The study findings revealed that a minority (15.6%) are still using same time after installing a biogas plant. This is despite the majority (86.6%) conforming that they have observed a difference between times spend collecting firewood before and after adopting biogas technology. During interviews it was highlighted that: "*...the adoption of biogas has reduced the rate of firewood collection in Domboshava communal area since the majority have now resorted to this new technology over other sources of energy. As a result, firewood is now used for cooking heavy meals like beans"*

About 32.2% of the biogas adopters highlighted that despite reduced frequency of firewood collection there is

DOI: https://doi.org/10.30564/jgr.v3i3.2151

need to supplement biogas especially in winter when temperatures are low therefore causing low biogas production. The proportion of those not seeing difference in terms of frequency of firewood collection before and after adopting biogas technology may be explained in terms of different household sizes and an engraved culture of being used to firewood as a parent source of firewood. During field observations, the researchers observed quantities of firewood piles per each household. The general observation is that firewood quantities seems to correlate with household size. Less quantities of ashes pointed to reduced use of firewood as observed during field work.

5.5 Challenges and Constraints to Biogas Use and Adoption

Construction of large digesters was limited by lack of resources as the majority could not afford construction of large digesters as confirmed by 33% of the households. Those with large digesters are at liberty to use gas for different purposes given the amount produced. To support this, during interviews it was highlighted that if all things are held at constant, a $4m^3$ plant digester should be able to support a family of about 6-10 people. The challenge therefore as revealed by the interviewee is that of failing to feed the plant as persistently and constantly as required. This hence points to lack of understanding on the operation and maintenance of the plant by adopters. This finding concurred with Collins et al. [6], who also observed the similar challenge in a separate study conducted in Uganda. Constant need to ensure sufficient supply of cow dung for the digester was also raised by other respondents as labour intensive although the proportion is low (22.2%) in comparison with the issue of appliances. This is despite many households acknowledging that the task is easy when compared to firewood collection.

Chi-square test results revealed that there is an association between biogas plant size and adequacy of biogas for daily energy needs ($p=0.02$). This means that the bigger the plant size the higher the chances of getting adequate biogas sufficient to meet daily energy needs.

Table 5. Constraints to biogas technology adoption in Domboshava

Constraints to biogas technology adoption	% Frequency
Ignorance	95.5
Lack of required resources	91.2
Additional labour	17
No cattle	77.8
Lack of technical personnel	46.7
Lack of post installation support	21

The majority of the households that is (95%), revealed that lack of adequate information (95.5%) complicated the adoption of biogas technology in Domboshava. About 91.2% pointed lack of required resources as another set back towards the adoption of biogas technology in Domboshava communal area. This was not surprising as results with key informants revealed that biogas technology is associated with high initial costs of installation a situation that has potential to compromise adoption of the technology among rural populations. To support this, field observations conducted by the researchers revealed that households with biogas digesters are richer in comparison with other households in the area. The findings are similar to those of Waqah et al. [23], who proposed that households that are relatively rich have higher likelihood of adopting biogas than low income earners households.

Furthermore, interviews conducted revealed that available information to the people is insufficient to convince them to adopt biogas. Lack of information by the public was also attributed to failure by the biogas adopters to understand the technology. In addition to this, one of the biogas technology adopters mentioned that there are no trained experts, fabricators and building masons in their proximity to assist with information to both biogas users and potential adopters. In the face of this challenge, key informants pressed for more training of some individuals who stay within Domboshava. Questionnaire survey results revealed that almost all the household respondents (95.5%) are of the view that ignorance is one of the major constraining factor to biogas technology adoption.

About 77.8% of the respondents were of the view that adoption of biogas technology is being hindered by lack of cattle for the supply of cow dung. It was highlighted that many households were left without cattle in the past two years following an outbreak of a deadly disease that forced many households in Domboshava to close their pens. Lack of technical personnel for the construction of the digesters presented challenges to the adoption of biogas technology. Lack of technical personnel registered a substantial frequency of 37.8% indicating that a sizeable number of biogas technology adopters could have faced this challenge in the process of biogas installation. About 21% of the respondents highlighted lack of post installation support as a challenge faced and threatening sustainability of the technology in the area. This relates to the findings of Parawira et al., [17], where they mentioned that most biogas units installed in the early 1980s in Zim-

DOI: https://doi.org/10.30564/jgr.v3i3.2151

babwe were left dormant following the withdrawal of the promoting donors. This was mainly because the biogas units were left in the hands of people with no proved technical competence in the face of a challenge a situation that resulted in malfunctioning of the plants.

6. Conclusion

The research examined challenges and opportunities of biogas technology adoption for sustainable household energy in Domboshava. The research findings revealed that adoption of biogas technology has been largely influenced by motivation from promoters, adequacy of biogas for daily needs as well as employment status. Biogas technology presents several benefits which include ability to cook fast, save firewood and health benefits. In addition, the study revealed that biogas is effective in terms of saving firewood, cost effective and reduced time spend collecting firewood. Notably, the research findings revealed multiple services provided by biogas technology which are critical for the conservation of the environment as well as the provision of sustainable household energy. In this case, the study revealed significant reduction of frequency of firewood collection by many households with biogas digesters. This points to reduced cases of deforestation, expenses on other fuel sources and amounts of emitted gases from burning wood. Above all biogas technology adopters appreciated effectiveness of organic manure, an end product of the technology which is said to increase agricultural yields. Ignorance and lack of required resources were the major constraints compromising the adoption and use of biogas. The challenge of meeting initial costs of biogas plant installation as linked to lack of required resources was widely pronounced by the respondents. Chi-square test results revealed that there is a relationship between employment status and affordability of installing a biogas plant ($p=0.000$). Therefore, many households are failing to diversify the use of biogas due to financial constraints.

Recommendations

In light of the study findings there is need for a coordinated approach to conduct massive awareness campaigns so as to raise awareness on the technical aspects with regards to the use and adoption of biogas technology. This should be spearheaded by the Ministry of Energy and Power Development (MoEPD) together with other currently involved stakeholders particularly NGOs. This will go a long way in improving adoption of the technology by local communal people. In order to increase the number of biogas plants the government through the Ministry of Energy and Power Development together with NGOs must install at least five demonstration biogas plants in each Ward for rural households to replicate and learn from. MoEPD in partnership with the Ministry of Higher and Tertiary Institutions, Science and Technology Development should provide funds for more research on biogas technology to generate more innovative ideas on efficiency so that clean, sustainable and safe energy is made available to all thus attainment of Sustainable Development Goal number seven.

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DOI: https://doi.org/10.30564/jgr.v3i3.2151

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ARTICLE

Hidden Map of North America in "Bacchus" by Leonardo da Vinci

Grigol Keshelava*

Helsicore Clinic, Georgia

ARTICLE INFO

Article history
Received: 13 July 2020
Accepted: 24 July 2020
Published Online: 30 July 2020

Keywords:
Geography
Renaissance
Tree of life
John Baptist

ABSTRACT

The object of this research is a "Bacchus" created in 1510-1515 by Leonardo da Vinci. By moving the detail of the painting, the map of North America is obtained, on which the present United States and Mexico are imprinted. The detail was drawn along the pale lines.

The map we have shown in the painting is almost identical to the modern map of North America. The right part of the map shows a tree. In our opinion, Leonardo symbolically painted a tree of life, associated with the newly discovered land at that time.

1. Introduction

Bacchus, formerly Saint John the Baptist, is a painting based on a drawing by Leonardo da Vinci. It is presumed to have to have been executed by an unknown follower, perhaps in Leonardo's workshop. The drawing is assigned to Leonardo da Vinci's second Milan period [1]. The painting shows a male figure with garlanded head and leopard skin, seated in an idyllic landscape. He points with his right hand off to his left, and his left hand grasps his thyrsus and also points down to earth.

2. Methodology/Methods

The object of this research is a "Bacchus" (Figure 1). The painting with dimensions 177 cm X115 cm is created in 1510-1515.

Through the program Paint X, we moved one detail to the top left of the painting (Figure 2). The detail was drawn along the pale lines.

Figure 1. "Bacchus" by Leonardo da Vinci

**Corresponding Author:*
Grigol Keshelava,
Helsicore Clinic, Georgia;
Email: gagakeshelava@gmail.com

 DOI: https://doi.org/10.30564/jgr.v3i3.2146

Figure 2. The moving detail is represented by a red outline

3. Results

By moving the detail given in Figure 2, the map of North America is obtained, on which the present United States and Mexico are imprinted (Figure 3). The map we have shown in the painting is almost identical to the modern map of North America.

Figure 3. Image after drawing detail moving

The map accurately depicts the contours of the Gulf of California and Mexico. The right part of the map shows a tree. In our opinion, Leonardo symbolically painted a tree of life, associated with the newly discovered land at that time.

4. Discussion

The discovery of new land by Columbus has always been considered a milestone, even though Leif Ericsson had previously reached the American coast five centuries earlier.

On October 12, 1492, Columbus set foot on American soil (the Bahamas), though he thought it was East Indies.

In 1502, a Florentine explorer Amerigo Vespucci came to the conclusion that Columbus was mistaken and that it was not India. The new land was later renamed America in his honor [2].

It is logical that cartography was relevant in Europe for this period. Maps were inaccurate in the Renaissance era. But the maps drawn by Leonardo were distinguished by accuracy. An example of this is the town plan of Imola created in 1502. Leonardo also produced a map of Chiana Valley (1502), which he surveyed, without the benefit of modern equipment [3]. In 1515, Leonardo created a map of the Roman Coast. Leonardo da Vinci complied this map to dry the swamps.

Donato Pezzutto studied Leonardo's works in a geographical aspect. He determined and found that the landscapes in the individual paintings reflect specific geographical locations using a cartographic perspective [4].

Although Leonardo is considered to be the greatest man of the Renaissance, he was not recognized as the creator of the world map. It should be noted, however that Leonardo created the map, which is one of the first to show America. At that time, there were many attempts to reflect the round surface of the earth in a plane. Leonardo solved this problem quite originally. He depicted the surface of the earth as an eight octant petals in two florets [5].

The source of the data on the world map created by Leonardo da Vinci is probably information from the travels of Amerigo Vespucci. An accurate description of Antarctica and the Arctic on this map is noteworthy [6]. The name of Florida (Terra Florida), correctly placed opposite Cuba, was used for the first time on Leonardo's globe, one year after Ponce de Leon's expedition to Florida [7].There is a version that Leonardo may have received information about Antarctica from a Portuguese traveler Tristao di Cunha who in 1514 was the ambassador to Rome [5].

The first map of North America was created and published in 1566 by Zaltieri (Figure 4). Italy played a

DOI: https://doi.org/10.30564/jgr.v3i3.2146

leading role in cartography during this period, which was mainly due to the travels and discoveries of Marco Polo, Columbus, Vespucci, Cabot, and Verrazano, who explored the America's east coast.

Figure 4. The first map of North America published in 1566 by Zaltieri

It follows from the above that Leonardo painted "Bacchus'' during the period when he was engaged in cartography. The contours on the map discovered by us in this painting are more accurate than on the first map of North America printed in 1566 by Zaltieri.

The right part of the map shows a tree. In our opinion, Leonardo symbolically painted a tree of life, associated with the newly discovered land at that time. The tree of life first appears in Genesis 2:9 and 3:22-24 as the source of eternal life in Garden of Eden.

Our attention is drawn to Leonardo's allegorical drawing (1508-1516) (Figure 5). This drawing shows an animal sitting on a ship with a compass pointing at an eagle perched on a globe. The emblem of Isabella, the Queen of Spain in that era, has been inset for comparison, supporting the suggestion that the navigation target represents the Spanish throne (which was actual patron of Columbus' voyages to the Indies) [5]. Slightly to the left of the center of the drawing is a tree that we think has the same content as the tree on the map. In our view, Leonardo in both cases painted a tree of life, associated with America.

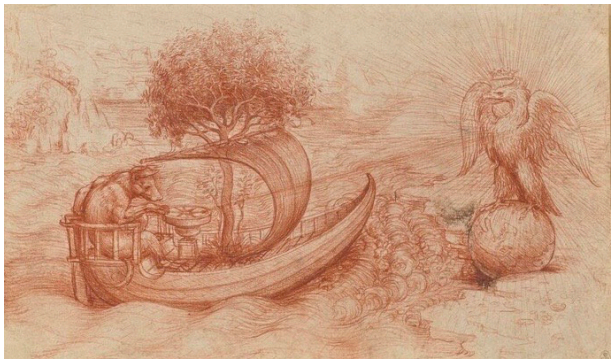

Figure 5. Allegorical drawing of river navigation (1508-1516) by Leonardo da Vinci

5. Conclusion

Our research shows that by moving one detail of the painting a map of North America is obtained that is almost identical to the modern map.

The tree depicted on the map is, in our view, the tree of life associated with America.

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ARTICLE

Challenges of the Use of Instructional Materials in Geography Classroom in Secondary School: Nepal

Keshav Raj Dhakal*

Central Department of Education, Tribhuvan University, Kirtipur, Kathmandu, Nepal

ARTICLE INFO

Article history
Received: 13 July 2020
Accepted: 31 July 2020
Published Online: 19 August 2020

Keywords:
Instructional materials
Geography lesson
Qualitative research
Quality teaching
Local materials

ABSTRACT

Geography is an optional subject in the secondary schools in Nepal. This paper is an attempt to examine the challenges of using instructional materials in the geography classroom in community secondary schools in Kathmandu district of Bagmati Province. Geography teachers were selected by purposive sampling offering geography as an optional subject in secondary school. The semi structured interview method was used for data collection. The interviews were recorded on an audio recorder and transcribed. After collecting data, analysis of the data was made through the interpretations of the raw data by interpretative method. The results reveal that the challenges of using materials are non-availability of materials, laziness of the teachers, lack of skill and strategies, financial constraint, lack of appropriate materials in textbook, time constraint, lack of support from authority, lack of geography resource room etc. The remedies of the challenges of using materials are the organizing of training and workshop for teachers on how to use instructional materials, provision of funds by the authorities and government, regular supervision, the improvisation of the local materials and the provision of the various instructional materials which are necessary for teaching etc.

1. Introduction

Education attainment of any nation depends upon the quality of teaching. Quality teaching learning process more requires the use of different kinds of instructional materials in teaching. The materials are as objects or devices that help the teacher to make learning meaningful to the learners [1]. Instructional materials are those materials that teachers need to incorporate in the teaching learning processes, to help the students benefit maximally from the learning experiences [2]. Materials as things or materials that can be seen or touched, places or persons that establishedconditions which enables learners to acquire knowledge, skills and attitude [3]. Teaching learning in secondary schools can only be effective through the use of different types of materials that guide the teacher in explaining topics to the students effectively and efficiently [4].

These materials could be different forms which include printed, graphic, objects, audiovisual, boards, local materials and many more. Instructional materials to be used meaningfully and effectively, they must meet some characteristics i.e. variety, economy, adaptable and accuracy[5]. These materials must be well designed, instructionally

**Corresponding Author:*
Keshav Raj Dhakal,
Central Department of Education, Tribhuvan University, Kirtipur, Kathmandu, Nepal;
Email: dhakalkeshav@hotmail.com

DOI: https://doi.org/10.30564/jgr.v3i3.2144

recognized, address the learners need, portable, durable, relevant and economic. The language of these materials should be simple, unambigious and communicative to the all type of learners.

Geography one of the branches of social sciences encompasses a lot of topics in our life on earth such as physical and cultural geography and topical, regional and systematic geography [6]. Being the bridge between physical science and social sciences, geography depends on the use of different type of materials and resources in classroom. The purpose of use of materials is to improve the quality of teaching and reinforce effective teaching and learning. Implementation of any curriculum depends on the quality and quantity of materials available to teachers and students for use in schools [7].

These materials assist the teacher in promoting teaching and learning in geography classroom. The use of adequate materials provides platforms for delivering information for teacher and they motivate learners to learn more. The use of materials can also help to reduce the length of time to concretize the concepts of the subject matter. Low extent of use of materials has hindered the teacher's effective presentation in classroom. When the students learn through more materials in classroom, learning becomes real, practical, effective and meaningful. The use of materials would make learning real, permanent and promote retention [8]. The use of these materials play the important role in the teaching and learning process. However, they are not ends in themselves but they are means to an end [9].

These materials provide the teachers with a kit of tools to carrying out diagnostic research and remedial work demanded by up to date instructional purpose[10]. For effective and purposeful teaching and learning activities, the teacher has to make and use of the appropriate and adequate materials [11]. Generally it is said that one picture is equal to thousand words. These materials are limited and scarce, for the teaching of geography, and this necessitates challenges for the achievement of the set objectives of the subject.

The essential materials for teaching learning are often unavailable in most of community secondary schools. The unavailability of such materials in secondary schools lead the teachers to talk and chalk in the teaching and learning. When the these materials are unavailable, learners cannot do well. This implies that when learners are not doing well the defined objectives of education and geography curriculum cannot be realized [12]. When the materials are not properly utilized and well managed, they pose a lot of challenge to the teaching and learning of geography. The main purpose of this study is to find out the challenges of using different materials in the teaching of geography in community secondary schools in Kathmandu district of Bagmati province.

2. Methods and Materials

Qualitative research method has been used in this study. Qualitative research is grounded in interpretivist philosophical position in the sense that it is concerned about how the social world is interpreted, understood, experienced or produced [13]. This study is a descriptive study to gather the information on teacher's perceptions and experiences about the challenges of using instructional materials in geography classroom in secondary schools. The main purposes of descriptive studies are describing, explaining and validating research findings. Eight geography teachers were selected on the basis of purposive sampling out of community secondary schools offering geography as an optional subject in Kathmandu district. Information on the secondary schools offering geography as optional subject in secondary level was acquired from different official records.

The primary data were collected using semi structured interview with geography teachers. Semi structured interviews are commonly used in qualitative and interpretive research. This method is conducted according to an interview guide that focuses on certain themes and may include suggested questions [14]. The interview were recorded on an audio recorder to avoid data loss and then after transcribed. The secondary data were acquired from the published, unpublished and electronic materials. The data were categorized from the raw data and tables were constructed with frequency. After collecting data, analysis of the data acquired was made through the interpretative method by interpretations of the collected data.

3. Results and Discussions

The survey was responded by eight geography teachers in different sampled secondary schools in Kathmandu district. The number of male teachers dominate all the posts and had at least bachelor degree in geography from Tribhuvan University. It is found that 50 percent teacher had a teaching experience over 10 years, 25 percent had teaching experience less than 5 years and 25 percent had teaching experience between 5-10 years. All teachers got different teacher training program as a secondary geography teacher.

3.1 Utilization of Instructional Materials

The researcher wanted to explore the use of instructional materials in teaching geography classroom in secondary schools. The geography teachers were asked to state the extent using instructional materials in geography

 DOI: https://doi.org/10.30564/jgr.v3i3.2144

classroom. This question had a goal to findout the use of teaching materials by geography teachers in teaching in community secondary school. Table one below represents the responses of the most widely utilized materials by teachers in the geography classroom in secondary schools.

Table 1. Utilization of instructional materials in geography classroom

Instructional materials	Frequency
Printed materials (textbook, reference book, journal, magazine, teachers manual, newspaper, dictionary etc.)	8
Graphic materials (map, atlas, globe, chart, graph, diagram, poster)	8
Audio visual materials (video, mobile, computer, tape, cassette, radio, overhead projector, television, photo, slide)	5
Local materials (mud, stone, stick, brick, floor, culture and traditions etc.)	0

Source: Field Survey, 2018.

According to the findings all geography teachers have used different printed materials (textbook, reference book, journal, magazine, teachers manual, newspaper, dictionary etc.) in teaching geography in secondary schools. All teachers in study area used graphic materials (map, atlas, globe, chart, graph, diagram, poster) in teaching geography. Audio visual materials (video, mobile, computer, tape, cassette, radio, overhead projector, television, photo, slide) in geography class room is occasional. Table 1 shows that all of the teachers don't want to improvise local materials (mud, stone, stick, brick, floor, culture and traditions etc.) for teaching in geography classroom in the study area.

3.2 Challenges of Using Instructional Materials

The researcher wanted to investigate on the challenges that teachers face in use of instructional materials. The geography teachers were asked to state the challenges using materials in teaching geography. This question had a goal to determine the challenges of materials by geography teachers in teaching in community secondary school. Table 2 represents the teacher's response of the different challenges of using materials in the geography class room.

Table 2. Challenges of using instructional materials

Challenges	Frequency
Non-availability of materials in school	7
Laziness amongst the teachers	5
Lack of skills and strategies	5
Financial constraint	4
Lack of appropriate materials in textbook	3
Time constraint	2
Lack of support from administration/ authority	2
lack of geography resource room	1

Source: Field Survey, 2018.

Teachers in community secondary schools face some challenges in using materials in the geography classroom. Most of the teachers state that schools do not have instructional materials in school. According to finding other challenges of using materials in teaching of geography in community secondary schools showed that laziness of the teachers, lack of skills and strategies for improvisation and use of instructional materials, financial constraint, lack of appropriate materials in textbook, time constraints, lack of support from administration / authority and lack of geography resource rooms.

3.3 Remedies for Challenges of Using Instructional Materials

Semi structured interview on the remedies of the challenges of using materials in the teaching of geography in community secondary schools. Table 3 represents the response of the remedies of the challenges of using different materials in the teaching of geography in secondary schools.

Table 3. Remedies for the challenges of using instructional materials

Remedies	Frequency
Organizing of workshop on how to use instructional materials	7
Provision of funds by the school authorities and the government	5
Regular supervision by the authorities	5
The improvisation of the local materials for teaching by the teacher	4
The provision of the instructional materials needed for teaching by the authorities	3

Source: Field Survey, 2018.

From the findings the remedies of the challenges of using materials are the organizing of workshop for teachers on how to use instructional materials, provision of funds by the school authorities and the government, regular supervision by the authorities, the improvisation of the local materials by the teachers and the provision of the various instructional materials needed for teaching by the authorities.

4. Conclusions

The instructional materials are important tools for achieving educational objectives of the country. The study has been revealed that in secondary schools there is lack of more materials used in the teaching of geography. The administrators and authorities should make available the necessary materials for teaching in classroom. Similarly, it was observed that the causes of the challenges of using materials are very many. Therefore, workshops should be conducted to educate the teachers on the challenges of

DOI: https://doi.org/10.30564/jgr.v3i3.2144

using materials during teaching. The importance of use of instructional materials in teaching, should not be neglected. Therefore the challenges encountered during the use of the materials, should be tackled for effective use of these materials. When necessary materials for geography teaching are provided in schools and the challenges of using materials are solved, the aims of secondary level geography curriculum may be achieved and the performance of the students may be improved.

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