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Impact on water sources due to land use and land cover change in Chitwan district, Nepal

Moti Poudel[a,b], Subodh Sharma*[a,b], Anish Ghimire[c], Guy Howard[d], and Prayon Joshi[b]

[a]Department of Environmental Science and Engineering, Kathmandu University, Dhulikhel 45200, Nepal.
[b]Aquatic Ecology Centre, Kathmandu University, Dhulikhel 45200, Nepal.
[c]Department of Water Resources and Environmental Engineering, Asian Institute of Technology, Pathum Thani 12120, Thailand.
[d]Cabot Institute for the Environment & Civil, Aerospace & Design Engineering, University of Bristol, BS8 1TR, United Kingdom.

Abstract

Rapid urbanization and unplanned infrastructures are stressing the drinking water sources, primarily due to land use and land cover changes (LULCC). Rapid population increases water demand and is straining water resources. This study aims to analyze LULCC from 1991 to 2020 and explore its impact on 23 regular used drinking water sources in Ratnanagar and Kalika municipality in Chitwan district. ArcGIS 10.8 classified five different classes in the images compiled from Landsat 5 and 8. Supervised classification with Maximum Likelihood algorithm was used with 30 signatures for each class as training samples. After the calculation of producer's accuracy and user's accuracy, accuracy assessment of classified images based on the ground truth points in 2020 Google earth images shows that kappa coefficient was 0.892 and overall accuracy was 91.67%. Over a period of 30 years, tree cover, agricultural, and water body areas have decreased by 15.18 %, 2.94 %, and 0.08 %, respectively while built-up and barren land have increased by 7.09 % and 11.11 % correspondingly. Secondary data from 30 years shows the population growth in study area was about 400% and 337.12 mm per decade reduction of precipitation. Increased built-up area has reduced the surface area for percolation of water. Uncontrolled LULCC, urbanization, and local climatic phenomenon have threatened the drinking water sources. Implementing the principles of resilient and sustainable urbanization, sustainable land use practices, climate resilient water safety tools and adequate investment in water sources protection can be a sustainable approach to address LULCC.

Keywords: Land use land cover changes; Supervised classification; Precipitation; Population; Water sources.

1. Introduction

Earth surface is dynamic which affects the environment from local to global scale [1]. The scientific tools enable the detailed observation of real-time changes on earth, capturing vital data through satellites that facilitate the analysis of environmental dynamics on a global scale [2, 3]. The continuous phenomenon of change in the Earth's surface, particularly due to factors such as urbanization and population growth, is effectively identified using these technologies [2]. The monitoring of land use and land cover change (LULCC) has significantly advanced with the advancement of the GIS technologies and availability of satellite images [4]. While there are various tools for quantifying the change in LULCC, use of satellite images in combination with GIS has been preferred because of its accuracy and efficiency [3, 5–7]. Inevitably, the change in the land use of any area directly or indirectly affects the water resource of the area [8, 9]. For example, increase in concretized built-up reduces the area for percolation and infiltration of the rainwater and thus increasing the surface runoff [10]. This change in the land use surface needs to be studied for better understanding of the land use dynamics and the status of water resources [11]. This aids to understand the impact on resources not just for the sake of research but also for planning, geography, and policy formulation sectors [12].

While rural areas in Nepal are converted to the urban area in rapid way within short span of time [13] the ground water sources needs a sustainable actions to meet the demand of the growing population. Our study area lies in the center of the Terai region (southern plain lands with high productivity) with multiple connectivity of roads to all parts of the country and population growth by nearly 400% [14, 15]. These drivers will inevitably lead to change in the land cover of these regions but limited studies have been conducted on LULCC. Increase in population with limited water resources leads to reduced quality and quantity of water in the urbanized area [16]. Furthermore, the over extraction of water in the urban area might led to the lowering the water table and subsequently land subsidence due to the pressure on the ground water aquifer [17]. Due to the change in landscape and increasing the impervious surfaces has directly impact on the hydrological cycle due to decreased infiltration, increase runoff, and decrease recharge of groundwater[18]. These drivers will inevitably lead to change in the land cover of these regions but limited studies have been conducted on LULCC. Hence, our study aims to assess the change in LULC in these two municipalities in Nepal and further quantify the stress on the prime water sources available in Ratnanagar and Kalika municipality within the time frame of 1991 to 2020 AD.

*Corresponding author. Email: subodh.sharma@ku.edu.np

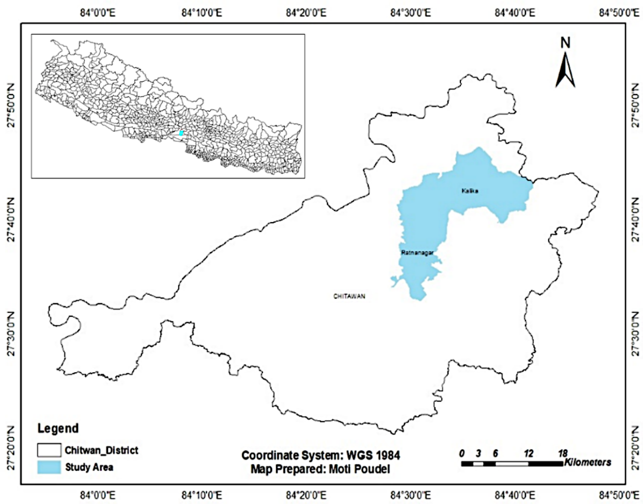

Figure 1: Municipal level map of Nepal highlighting Ratnanagar and Kalika Municipality.

2. Materials and methods

2.1. Study area

The study area lies in Chitwan district of Nepal. Both the municipality lies 150 meter above the average mean sea level. Ratnanagar municipality lies at 27°37' north and 84°30' east while Kalika municipality lies at 27°69' north and 84°57' east (Fig. 1). The study area encompasses a major portion of the vegetation canopy along with the agricultural land while the area has been a major choice for settlements too. Ratnanagar and Kalika municipality has the total land area of 69.01 and 149.27 sq. km respectively. The recent census data shows that the total population of Ratnanagar municipality is 89,905 with an average population density of 1,322 per sq. km. Similarly, the total population of Kalika municipality is 52,164 with an average population density of 354 per sq. km [15] (Table 1). Due to the better availability of the physical facilities and easy access to economic activities, internal migration towards low land of Nepal has been preferred [19].

The major source of water for drinking or for the agricultural purposes in the study area is the ground water extraction [20]. However, this study is more focused for the protected water sources used for drinking and household chores. Since the selected water schemes listed in Table 2 of drinking water covers 61.34 % of the total population in the study area [15], these sources are the primary sources being used at the study area.

2.2. Weather station installation

Real time data of precipitation was collected from the Campbell scientific automated weather station installed at Chitwan. The weather station was installed based on Campbell© installation guidelines, world meteorological organization guidelines and United States Environment Protection Agency protocols [21, 22].

2.3. Data acquisition

The multispectral images of 1991 and 2020 used for this study were retrieved freely from an online portal of United States Geological Survey©(USGS) [https://earthexplorer.usgs.gov]. The specification of the data used for this study has been shown in Table 3. The images of Landsat 5 for the year 1991 and Landsat 8 images for the year 2020 were used for the study of LULCC detections. The selection of the images was done with the due consideration for cloud covers, hazes, and fogs free [3, 23]. Since the days of October and November are clear and sunny in Nepal images used for the image interpretation for both the year were taken during the autumn seasons. Also, the cloud percentage on the images was found less than 3.5 % on both the images while the required area of the study was 100 % free from the cloud cover.

2.4. Image processing and classification

The raw images downloaded from the USGS were first clipped with the study area boundary and all the bands of the images were made into a composite of a single layer. As Landsat 8 had more bands than Landsat 5, only bands that were common in both were taken for classification. Six bands were taken for classification which are Blue, Green, Red, Near Infrared (NIR), Shortwave Infrared (SWIR)-1 & 2, and Thermal Infrared (TIRS)-1. Further details on the bands and their respective wavelengths have been provided in Table 4. These images were processed using ArcGIS 10.8 by Environmental System Research Institute (ESRI) [23]. The images were projected to UTM Zone 44N and area of these municipalities were compared with the data provided by the Survey Department, Government of Nepal to check for the accuracy of area [15].

In process of the data collection by the sensors on the satellites, the images have to pass from the atmosphere. The images were distorted by the fogs, aerosols, and haze in the atmosphere. So, the correction of the sun angle and the radiance (top of atmosphere) of the images is must. The images of Landsat-5 (1991) and Landsat-8 (2020) were further corrected through the radiometric and atmospheric correction methods. The same images were further orthorectified with the help of study area Digital Elevation Model. The DEM image was retrieved from USGS. The corrected images were classified by applying maximum likelihood algorithm of supervised classification techniques. Major five classes which were the most prevalent in the area of interest were taken during the classification (Table 5) based on the previous research [24, 25] as well as from the observational knowledge. To avoid any biases or over fitting, the classification of each class was done by selecting 30 signatures on the image as practiced by previous research [23].

3. Results and discussions

The classified image of 1991 shows 60.20 % (131.4 sq.km) canopy covered by forest area, bushes or the trees in the study area (Fig. 2). The major reason behind huge area covered by the trees is due to the less population in the study area as proven by the population history record [15]. Agricultural land area comes to the second major classification with the total land area of 27.88 %. (60.85 sq.km). As Nepal is more based on the agricultural products for the livelihood, the period of 90's is well justified by the percentage of the agricultural land area. The agricultural land can be observed spreaded in the lower southern part of the study area than in the upper northern part. Similarly, the bare land represents the unused and abandoned land in the study area. Since the images were taken from the autumn, the season itself could be one of the factors to be dry to spot more bare lands. In total, bare land, builtup and water bodies cover 6.56, 5.16 and 0.21 percent of the classified image.

Similarly, the classified image of 2020 (Fig. 2) shows that the tree cover is still the maximum area in the study area with 45.02 % (98.26 sq. km). The classified agriculture land was 24.94 % (54.43 sq. km) followed by the bare land area i.e. 17.67 % (38.56 sq.km). So, in total, built-up area and water body covers 12.25 and 0.13 percentage of the total land.

While comparing the land cover changes between 1991 to 2020, we can record the significant changes of tree cover. In total 15.18 % of tree area from 1991 has transformed to other features either to builtup, bare or agriculture area. On the same way, the percentage of agricultural area has decreased from 27.88 % to 24.94 % be-

Table 1: Population information.

Data Source and Year	Nepal Population	Ratnanagar Municipality	Kalika Municipality(Was reformed by merging Shaktikhor, Kalika and Siddhi VDC)	Total Population (Ratnanagar +Kalika municipality)
National Statistics Office, 1991	18491097	18885	Shaktikhor:5260 Kalika:3438, Siddhi:1501	(18885+5260+3438+1501) = 29084
National Statistics Office, 2021	29192480	89905	52164	(89905 + 52164) = 142069

Table 2: Salient features of selected schemes in the study area.

S.No	Drinking Scheme	Latitude	Longitude	Approx. Dependent Population	Types of Sources	Address (Municipality)
1	CD_TW	27.61306	84.49778	50	Tubewell	Ratnanagar
2	LP_TW	27.61501	84.48251	25	Tubewell	Ratnanagar
3	MCBP_TW-1	27.58389	84.50306	25	Tubewell	Ratnanagar
4	MCBP_TW-2	27.58361	84.50306	25	Tubewell	Ratnanagar
5	MCBC_TW_1	27.58528	84.50056	125	Tubewell	Ratnanagar
6	MCBC_TW_2	27.61861	84.50028	125	Tubewell	Ratnanagar
7	RTN_1	27.62889	84.52222		Deep Bore well	Ratnanagar
8	RTN_2	27.62833	84.52250		Deep Bore well	Ratnanagar
9	Bagdevi_1	27.65444	84.51083		Deep Bore well	Ratnanagar
10	Bagdevi_2	27.65444	84.51167	72500	Deep Bore well	Ratnanagar
11	Bagdevi_3	27.65389	84.51167		Deep Bore well	Ratnanagar
12	Ghegauli_1	27.63639	84.50333		Deep Bore well	Ratnanagar
13	Ghegauli_2	27.63611	84.50222		Deep Bore well	Ratnanagar
14	TW_Dugwell	27.68611	84.56306	150	Dugwell	Kalika
15	JS_TW	27.68694	84.56417	212	Tubewell	Kalika
16	Korean_TW	27.68222	84.56028	150	Tubewell	Kalika
17	24_TW	27.68667	84.56333	120	Tubewell	Kalika
18	3_Dharey	27.68278	84.56250	150	Spring Source	Kalika
19	Agingarey	27.69639	84.59139	1000	Spring Source	Kalika
20	Jutepani_1	27.68722	84.56444		Deep Bore well	Kalika
21	Jutepani_2	27.67278	84.54944	12500	Deep Bore well	Kalika
22	Jutepani_3	27.68722	84.56417		Deep Bore well	Kalika
23	Jutepani_4	27.68722	84.56417		Deep Bore well	Kalika

Table 3: Data specification of satellite imageries used in LULC classification.

S.No	Satellite Data	Spatial Resolu-tion (m)	Temporal Resolution (days)	Total Band	Data Acquired	WRS Path	WRS Row	Sensor Identifier
1	Landsat 5	30	16	7	28/10/1991	142	40	Thematic Mapper
2	Landsat 8	30	16	11	28/11/2020	142	40	Operational Land Imager and Thermal Infrared Sensor

Table 4: Band and wavelength details of Landsat 5 and Landsat 8.

Band	Wavelength in Landsat-5 (μm)	Wavelength in Landsat-8(μm)	Spatial Resolution (meter)	Remarks
Coastal aerosol		0.43 – 0.45	30	-
Blue	0.45-0.52	0.45 – 0.51	30	Band used
Green	0.52-0.60	0.53 – 0.59	30	Band used
Red	0.63-0.69	0.64 – 0.67	30	Band used
NIR	0.76-0.90	0.85 – 0.88	30	Band used
SWIR 1	1.55-1.75	1.57 – 1.65	120, 30	Band used
SWIR 2	2.08-2.35	2.11 – 2.29	30	Band used
Panchromatic	-	0.50 – 0.68	15	-
Cirrus	-	1.36 – 1.38	30	-
TIRS 1	10.40-12.50	10.60 – 11.19	30, 100	-
TIRS 2	-	11.50 – 12.51	100	-

Table 5: Classification of the land features.

S.No.	LULC Class	Description
1	Agricultural Land	Cultivated surface. Includes cropping in both valley and terrace.
2	Water Body	Surface covered with water
3	Bare Land	Surface without vegetation and exposed soil
4	Builtup Area	Urban and rural human settlements, construction areas
5	Tree cover (Forest cover)	Surface covered with trees and bushes

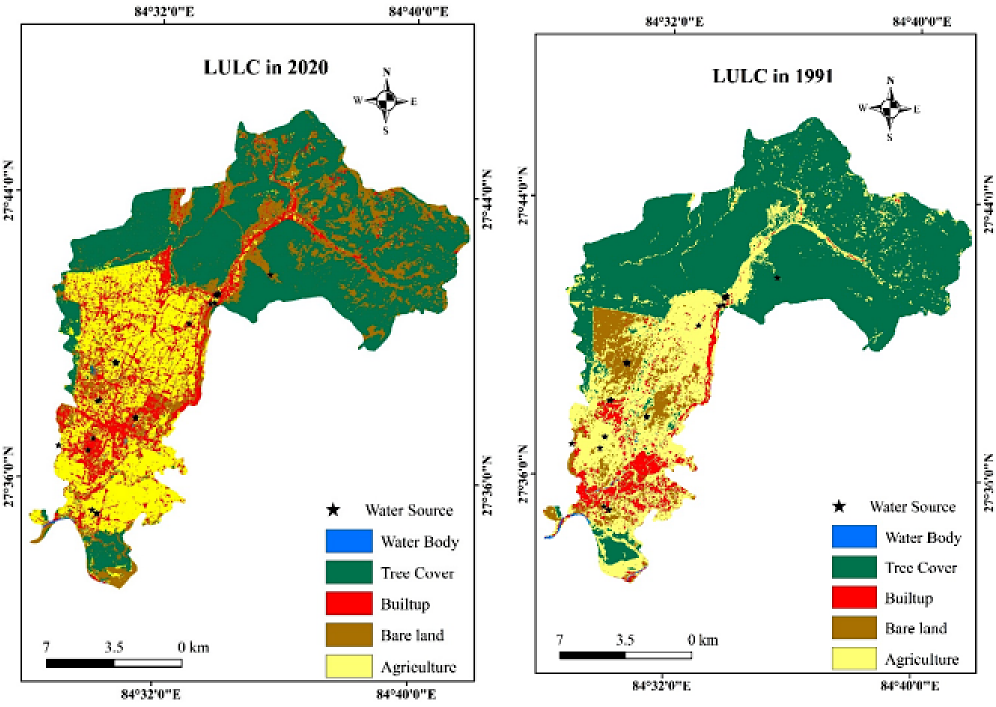

Figure 2: Classified study area for 2020 and 1991 AD with water source points.

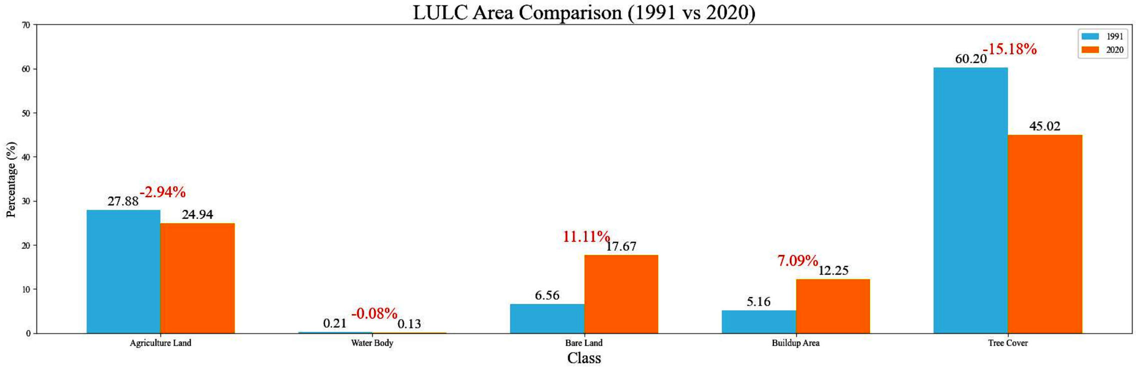

Figure 3: Area comparison between 1991 and 2020.

Table 6: Kappa coefficient categorization [24].

S.No.	Kappa statistics	Strength of agreement
1	<0.00	Poor
2	0.00 - 0.20	Slight
3	0.21 - 0.40	Fair
4	0.41 - 0.60	Moderate
5	0.61 - 0.80	Substantial
6	0.81 - 1.00	Almost perfect

tween the periods of analysis. The builtup and bare land area has increased by 7.09 % and 11.11 % respectively (Fig. 3). The area coverage of the barren land has also changed significantly from 1991 to 2020. The impact of the urbanization can be easily noticed on the classified image. Compared to 1991, percentage of builtup area has increased significantly. The water bodies were found slightly decreased in 2020 classified images. The possibilities of decrease in water bodies could be the seasonal change in the water bodies [26].

The LULCC has been widely observed in Nepal which has been attributed to the economic activities, internal migration and better availability of commodities for daily life [5–7, 19]. In contradiction, the forest area in Nepal has been increased during 1990-2020 [27] while this research has recorded the decreased forest cover.

3.1. Accuracy assessment

The accuracy assessment of land classification is vital indicator to ensure the quality of data processing. The higher the accuracy, more accurate the data classification is. So, kappa coefficient equals to 1 means the perfect selection of the land types during the training assignment while zero means the agreement is poor [28]. This study has compared kappa coefficient with Table 6 [24] which has been highly referenced. The strength of agreement in this research shows the kappa statistics of 0.89 results the selection of land use classification was 'almost perfect'.

3.2. Meteorological data analysis

Real time data of the weather variability was retrieved from the weather station installed at the study area which shows significant reduction of precipitation to 998 mm from 2992 mm within the last four years (Fig. 4). Data received from the department of hydrology and meteorology, Kathmandu for 1991 to 2000 shows 337.12 mm per decade decrease of rainfall. So, decrease in the rainfall and increase in the demand of the water shows the stress on the dependent water sources.

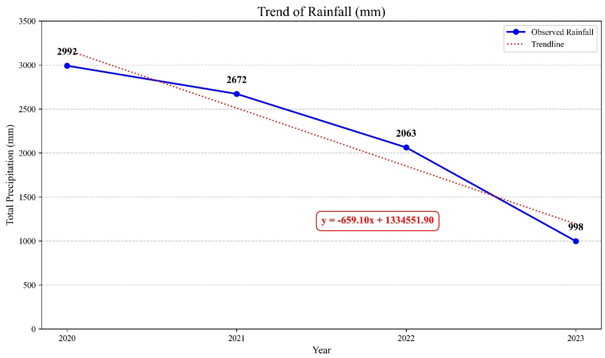

Figure 4: Precipitation data recorded at the weather station in Chitwan.

3.3. Impact on water resources

The population data record received from the central bureau of statistics shows that population at the study area has increased to 400% from 1991 to 2020 [14][15]. Total served household by the water supply scheme has increased by 27.25 % where water demand has amplified by 47.27 %. During the group discussion with the water users and sanitation committee at Ratnanagar, the ground water table has been depleted by 6 meters within last four years. While at Kalika water supply system, no such records was recorded though they have felt the reduced yield during the peak dry seasons, i.e., March and April.

The impact of increased urban area, decrease in recharge zone for the water infiltration obviously disconnect the ground water aquifer leading to the decrease in water capacity in the watershed [16]. The consequent effect of reduced recharge may lead to permanent loss of the ground water sources. The increase in the built-up area with the over extraction of ground water has shown an evidences of ground water table reduced up to 9 meter in watershed of India [10].

3.4. Resilience of water supply systems

The pressure on the water sources has been significantly identified in this research. Similar research in Chitwan area has shown the decrease (-0.9 %) in the water bodies during 2000 to 2010 and increase by (1.15%) from 2010 to 2020 [29]. While these 23 water sources has been assessed through water sanitation and Hygiene (WASH) framework in 2022, which shows the sources are under the pressure of climate change and are moderate to weak resilient to climate change [30]. The study recommended to implement the actions to improve the resilience of water schemes for sustainability of the water sources. So, to improve the resilience of the water supply systems and to address uncontrolled urbanization, climate resilience water safety plan can be an effective tool. In addition, local level can formulate the policy of resilient urbanization action plan to meet the demand of rapid population growth [31].

4. Conclusion

Remote sensing techniques has been very efficient tool to study the change in land cover and its impact on water sources for two different time scale. The identification of changes has been made more convenient through the software. As we are facing the impact of climate change, scarcity of the water resources at the research area can be a major treat. The impact of climate change has been attributed to the increasing population for increasing the urban heat index. The immediate address for the groundwater recharge can be through the recharge ponds in the study area. The resilience of the schemes selected in this study can adopt the climate resilient water safety plan which has been made mandatory by government of Nepal.

This study provides a better understanding on impact of LULCC on water sources in last 30 years. The results can be important for the policy makers to address the impact of unscientific land classifications. The major portion of the classified images shows major portion covered is tree/green canopy followed by the agricultural land. So agricultural land has provided the sufficient space for the ground water recharge. The precipitation data shows drought can be a major issue in the near future. Since the built-up area was observed significantly increasing, resilient urban development plan is recommended. The carrying capacity of the municipality needs to be considered for sustainability of development. A methodological framework needs to be developed to make a resilient recharge plan for the water sources allocated in core city area. The accuracy test of this research is highly reliable to understand the changes in the land topography in study area. The depletion of the ground water table by six meters is an alarming situation. So immediate recharge plan to support the aquifers needs to be implemented.

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