Use of earth observation data for disaster mitigation planning in an Inner Terai watershed of central Nepal
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ABSTRACT

The problem of mass wasting, landslide and soil erosion is common in hills and mountain areas while the plain area is affected by flood and sedimentation problem. In addition to this, the failure of timely formulation and implementation of land use regulation as well as increased human intervention have further deteriorated the watershed. The problem can be addressed by preparation of integrated watershed management plan and its effective implementation. It is always desirable to have well managed watersheds including conservation of downstream areas. This is required to minimize degradation in the watersheds for reducing sediment deposition as well as flashfloods in downstream areas. The earth observation data can be used to access the geological disaster, prepare management plan thereby implement it through participatory integrated watershed management. Watershed management is necessary to have an environmentally sustainable watershed through watershed rehabilitation and disaster reduction activities. The present study identifies issues/problems/threats and underlying causes behind degradation of the Riu watershed. Landslide susceptibility map of the watershed and flood hazard map of the Riu River shows the areas vulnerable to landslide and flood, which is a vital tool for watershed management through appropriate planning to reduce the disaster risk in the watershed.

Keywords: Earth observation data, disaster mitigation, Riu watershed, Inner Terai, Nepal.

1. Introduction

The mountains of Nepal Himalayas are geologically young and tectonically active with steep and unstable landscape. Intense and prolonged rainfall causes erosion, slope failure, river bank erosion and flooding during the monsoon period. The result is the loss of agricultural lands damage of properties, infrastructures and loss of lives each year (Aryal, 2012). The Siwalik region at the southernmost part of the Himalayas, has been constantly suffering from the problems of degradation (natural and anthropogenic) and over exploitation. This lead to the overexploitation of valuable watershed resources of Siwalik region and has become unable to meet the demand of natural resources of a growing population in and around Siwalik region (also called Churia region in Nepali).

The extensive soil erosion and landslide from the Siwalik watershed leading to sediment deposition on riverbed as well as desertification of agriculture land at the downstream has taken place. In addition, it has caused flashfloods thereby damaging the agriculture land, which eventually reduces the fertility and productivity of farm lands. In comparison to the erosion rates of other regions of the Himalaya these rates are significantly higher (Ghimire et al., 2013; Ghimire et al., 2006). This disastrous consequences and other cross cutting issues (loss of biomass and biodiversity, inappropriate agriculture practices, overgrazing, forest...
encroachment, haphazard settlements etc.) has resulted in the reduced sources of livelihood and deprivation of the people.

A proper management of river basin is the only solution for reduction of soil erosion, landslide mitigation, sedimentation control and disaster mitigation, which will eventually support for better livelihood and overall development of the area. In order to identify the critical area to the landslide and flood hazards as well as vulnerable areas and proposing appropriate preventive and mitigation measures the earth observation data can best be utilized (Pathak, 2014a; Pandey et al., 2007; Khan et al., 2001). The present study carried out study on gully erosion, landslide susceptibility and flood hazard mapping that are quite useful for the disaster mitigation planning in the watershed.

2. Study area

The study area lies in the southern part of Chitawan district, central Nepal. It is a part of the Churia range (also known as Siwalik) that extends along the south of the Mahabharat range from the east to west continuously. The study area is traversed by Riu River through Madi valley, which borders India in the south (Figure 1).

Figure 1: Location of Riu River watershed in the Chitawan district. The position of Chitawan district in Nepal is shown in the index map at top left.

The Riu River valley (Madi valley) is situated within the Chitawan National Park. Forest area lie at the right bank of the river while four Village Development Committees (VDCs), namely Gardi, Baghauda, Kalyanpur and Ayodhyapuri VDCs lie at the left bank. The protected area (Chitawan National Park) covers an area of 960 km² and hence is quite important from wild life conservation and touristic aspects. The four VDCs (Ayodhyapuri, Kalyanpur, Baghauda and Gardi) lie within the Buffer Zone of the national park and hence the people are continuously threatened by the wildlife. The population densities of Ayodhyapuri, Baghauda, Gardi and Kalyanpur VDCs are 87, 261, 251 and 181 per square km,
respectively with an average of 196/km$^2$, which is very close to the national average of 197/km$^2$ for the year 2014 (The World Bank, 2015).

The study area lies in the humid tropical climatic zone with very hot summer. The monthly rainfall pattern observed in Rampur meteorological station (near Bharatpur) from the year 2001 to 2005 shows the usual trend of Nepal with the highest rainfall between June and August. The highest maximum temperature recorded at this station ranges from about 33 degrees to 37 degree in the months of April to June and the lowest minimum temperature ranges from 4 degree to 9 degree in the month of December and January. More than 80% of rainfall occurs during the months of June-Sept associated with the summer monsoon. The proportion of summer monsoon to total precipitation is around 85%. The monthly rainfall pattern observed in Rampur meteorological stations from the year 2001 to 2005 also shows similar national trend.

2.1 Drainage

The SE-NW flowing Riu River originates at Someswor hill in Siwalik range and discharges to the Rapti River. The Riu River Basin covers an area of 460 km$^2$ at Confluence with Rapti River in the west. Several tributaries that originate from the Siwalik range covered by dense Sal forest joins the Riu River at left bank, while few tributaries are at the right bank (Figure 2).

The width of the river varies from 1300 m at upstream to 200 m in the downstream part (near the confluence with Rapti River). There is about 230 m elevation difference between the originating point and Riu-Rapti River confluence point. The slope varies from 1:320 at the upper reaches to 1:3000 at the lower reaches. Around 28 km long stretch of the river (upstream of Rapti-Riu confluence) is the critical stretch that occupies an area of 285 km$^2$. The higher catchment areas are represented by high drainage density showing the significant presence of gullies at those localities (Figure 3).
The drainage density in the catchment area has significant role in the soil erosion and landslide activities in the area when the other parameter favors the situation.

2.2 Geology of the study area

The Riu River catchment is consisting of rocks of Siwalik Group, aged between Mid. Miocene to Lower Pleistocene (DMG, 1998; Gansser, 1964). The Siwaliks thrust over the Quaternary sediments of the Indo-Gangetic Plain in the south along the Main Frontal Thrust (MFT), and is separated from the Lesser Himalaya in the north by the Main Boundary Thrust (MBT). The whole Siwaliks consist of an alternation of mudstone, sandstone, and conglomerate, but at varying proportions and textures. This Group is sub-divided into Lower Siwalik, Middle Siwalik and Upper Siwalik. The Lower Siwalik is characterized by fine grained sandstone with inter-bedding of red coloured mudstone, shale and siltstone, while the lower part of Middle Siwalik is dominated by fine to medium grained sandstone with inter-bedding of siltstone and mudstone. The upper part of Middle Siwalik consists of medium to coarse grained pebbly sandstone. Conglomerate with subordinate sandstone and mudstone occurs in Upper Siwalik. Besides, surficial material of alluvium in origin (Quaternary to Recent in age) the Siwalik Group of rocks are exposed at several locations.

Lower Siwalik rocks are exposed at the mountainous parts in the upper reaches of Riu River, mostly in the southern part of the area, near Indo-Nepal border (Figure 4). The alluvial materials ranging in size from clay to boulders are widely distributed in the lower elevation areas, mostly covering the right bank of the river. The area between Riu River and Rapti River is entirely covered by these materials. The Upper Siwalik rocks are exposed in easternmost part of the watershed while the Middle Siwalik is distributed around the left bank of the River. The Siwalik rocks are thrust/faulted and folded with the development of joint sets and differential erosion is one of the reasons for contributing significant sediment load to the river during monsoon season.
The Lower Siwaliks is exposed around right bank of the Riu River and the Middle Siwaliks consisting dominantly of thick-bedded, massive, medium- to coarse grained, ‘salt and pepper’ sandstone and subordinately of mudstone, siltstone, and conglomerate occupies southern part of the Riu watershed. The Siwalik Group on the whole displays a coarsening upward sequence, forming an archive of the Himalayan uplift. There are many faults within the Siwalik. Central Churia Thrust (CCT) that passes through the Churia Range is mainly responsible for the formation of Dun Valley. Such geological control is playing dominant role in the drainage network, physiographic condition, natural hazard (landslide, flood, bank cutting etc.) and biodiversity/ecological units. The flora and fauna are also varying in different physiographic regions. The Dun Valley Occupies recent sediments derived from the surrounding mountains. It is a tectonic valley formed due to the presence of faults. The Riu River Valley represents the southern part of the Chitawan Dun Valley. The sediments are relatively coarser along the mountain foothill that gradually becomes fine towards the valley centre.

3. Materials and methods

A general assessment of the Riu River watershed was done through the study of available literature as well as satellite imageries. The Riu River watershed has been assessed through the utilization of primary data collected in the field, information extracted from the satellite image and secondary information. The data used in the study are geological map of the area, digital topographic map and satellite imageries. The geological map of the area published by Department of Mines and Geology (DMG, 1998) was digitized in GIS. This map consists of different geological formations with rock types and geological structures. Various thematic layers like slope, aspect, drainage density, land use, landslide distribution, physiography etc. were prepared from the digital topographic data as well as the information extracted from the satellite images and field data. The data were integrated in GIS and bivariate statistical method was applied to prepare the landslide susceptibility map of the area.

Hydrological analysis was carried out followed by hydraulic modelling to prepare flood hazard map of the Riu River. The results form vital source of information regarding geo-
hazard condition in the area. Appropriate mitigation measures have been proposed to reduce the impact of geological disaster in the study area.

4. Results and Discussion

4.1 Watershed characteristics

The Riu watershed is represented by a typical doon valley, which is surrounded by mountainous regions. The watershed area is mostly covered by hill slope with less than 15 degree (92%), while the area covered by hill slope between 25 and 40 degree is less than 1%, indicating that the watershed is having low to moderate hill slope (Figure 5).

![Figure 5: Slope map of the Riu River watershed](image)

The Riu watershed is dominantly covered by forest area (76%) followed by cultivation (16%), grass land (4%) and sand deposition (3%). The remaining 1% of the watershed area is covered by water body, barren land and settlements (Figure 6). This parameter is useful because the landslide occurrence and land use changes have direct connection (Glade, 2003). Fortunately, the mountainous areas are mostly covered by the vegetation, which is playing positive role for the soil erosion and landslide control. However, the left bank of the valley region is mostly occupied by the agriculture land. It has been annually affected by the Riu River flood during the monsoon season.

![Figure 6: Land cover map of Riu watershed](image)
4.2 Basin morphology

The Riu River is sixth order stream. The total length of the first order stream in the Riu watershed is 770 km, while the lengths of second, third, fourth and fifth order streams are respectively 324, 187, 100, and 49 km (Figure 7). The length of highest stream order (i.e. sixth order) is 43 km.

![Figure 7: Stream network and order in the Riu watershed.](image)

Majority of the tributaries of Riu River are of the order up to third at the right bank while it is up to fifth order at the left bank. The mean bifurcation ratio of the Riu watershed is 1.94, stream frequency is 7.7, and drainage density is 3.21. The bifurcation ratio generally ranges between 3 and 5 for natural drainage basins without differential geological controls and only reaches higher values where geological controls favor the development of elongated narrow basins (Strahler, 1964). Chorley (1969) had noted that the lower the bifurcation ratio, the higher the risk of flooding, particularly of parts and not the entire basin. The low bifurcation ratio of the Riu watershed of 1.94 is an indication that parts of its segments are liable to flooding. Likewise, the circulatory ratio 0.41 is an indication that the basin is not circular in shape. Chow (1964) had noted that strongly elongated basins have circularity ratios of between 0.40 and 0.50.

4.3 Landslide susceptibility mapping

Delineation of the landslide susceptible zones in an area is helpful towards landslide disaster risk reduction. Various methods are in use for the preparation of landslide susceptibility map (e.g. Pathak, 2016, Pathak, 2014b; Park et al., 2013; Dahal et al., 2012; Regmi et al., 2010; Yalcin, 2008; Dahal et al., 2008; Chen and Wang, 2007; Van Westen et al., 2003). The present study carried out knowledge based landslide susceptibility mapping in which weight for each theme and rank for each class within the theme were assigned. Each thematic layer was given weight ranging from 0 to 10 depending upon the degree of their effect for the occurrence of landslide. Likewise, in each thematic layer, the ranks to individual classes were also assigned within the value of 0 to 10 (Pathak, 2016). The derived map was validated with the existing landslides and mass wasting data. The resulting map shows that the north eastern part and southern part of the study area is having high landslide susceptibility (Figure 8).
The landslide susceptibility condition within the watershed is important for watershed management purpose, which is required to reduce the disaster risk in the area.

4.4 Flood hazard mapping

Flood hazard mapping was carried out through hydrological and hydraulic analysis, the later was carried out in GIS platform. The river is ungauged so the flood flow estimation was carried out using three different methods, namely Water and Energy Commission Secretariat (WECS, 1990), Department of Hydrology and Meteorology (Sharma and Adhikari, 2004) and Modified Dickens methods.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Computation Method</th>
<th>Riu River Discharge (m³/sec) at Various Return Periods</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>2 years</td>
</tr>
<tr>
<td>1</td>
<td>WECS Method</td>
<td>429.37</td>
</tr>
<tr>
<td>2</td>
<td>DHM Method</td>
<td>467.86</td>
</tr>
<tr>
<td>3</td>
<td>Modified Dickens Method</td>
<td>471.05</td>
</tr>
</tbody>
</table>

It is realized that the WECS method gives low discharge in comparison to other methods and the other two methods gives very close discharges. Since the Modified Dicken’s Method is widely used, the discharge value obtained from this method for 50 years return period has been used as the design discharge for the hydraulic modeling of Riu River. HEC-RAS software has been be used for hydraulic analysis and the output is the flood level on the cross-section of the river, which was used to generate flood hazard (in terms of flood depth) using HEC Geo-RAS application. The flood hazard map shows that the entire stretch of the Riu River is having flood problem (Figure 9).
The settlements at the left bank of the river are prone to river flooding and hence required mitigation measures are required for flood disaster risk reduction in the area.

5. Conclusions

Riu River originates from Siwalik range in the south western part of the Chitawan district and flows through the Chitawan National Park, with settlements at the left bank of the river. The Riu River watershed is very fragile as it completely lie within the Churia (Siwalik) Region. The river is of aggrading nature, which is braided in the upper reaches while it is meandered at the lower reaches in the study area. Channel shifting of the river is a common phenomenon. The river is narrower at the upper reaches and becomes wider as it approaches the valley part thereby depositing the sediment derived from the upper catchment. The river is inflicting damages to the settlements lying at the left bank thereby causing damages to houses and agriculture fields lying on the river bank. The damages by the river are mainly in terms of bank erosion, sediment deposition and flooding or inundation during the monsoon period. Landslide susceptibility mapping of the watershed and flood hazard mapping of Riu River has been carried out which has identified the areas vulnerable to landslide and flood. This information is useful for planning the required mitigation measures so as to reduce disaster risk in the watershed.

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6. References


