Universität für Bodenkultur Wien

Evaluation of old and recently built farm roads in the selected watershed of Bhutan-an evaluation from the prospective of assessing environmental impacts.

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Submitted by

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Declaration

I hereby declare that this master's thesis is my own work and effort. It has not been submitted in any other University for any other award. Due acknowledgements have been made to all materials cited in the text.

Place: Gregor Mendel Straße 33, 1180 Wein *Tashi Norbu Waiba*

Date: August 2015

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Abstract

Rural accessibility being the defining issue of developments in the country, the construction of farm roads is promoted and prioritized amongst other development goals by the government. Over 5255km of farm roads has been constructed in the country as of 2013. However, this aspiration of the government was realized largely at a cost of considerable environmental impacts on the natural environments due to substandard works and weaknesses in the construction methods. In view of the above context, this study assessed the efficacy of farm road constructions from technical competencies, environmental impacts and social utility point of view in Dagana Critical Watershed. Subsequently, the study comes out with suitable recommendations for further improvement of the existing farm roads in the watershed from the prospective of minimizing environmental impacts. A total of eight farm roads measuring 42 600m were evaluated by laying 213 sample plots at a distance of 200m along the road transect. Approximately 70% of the total farm road length is in good condition and 30% is in bad condition. About 9372 m and 6390 m of road length have very steep (> 12%) and flat (<3%) road gradient respectively. The road networks also substantially lack road drainage facilities with about 30% of the road length without side drains. Further, almost all the roads lacked adequate road pavements and other vital road infrastructures. The combination of all of the above factors have led to massive road surface and slope erosions. Moreover, almost 72% of the total farm road length runs through the government reserved forests which certainly has adverse environmental impacts on the surrounding natural vegetation. Despite adequate road connectivity of the households with a road density of 10.6m/ha, some of the farm roads have relatively low social utility.

Key words: Environmental impacts, Road surface erosion, Road gradient, Social utility

Kurzfassung

Die Erschließung ländlicher Gebiete ist ein zentrales Entwicklungsthema in Bhutan und genießt deswegen einen hohen Stellenwert in der Prioritätensetzung der Regierung. Bis 2013 wurden im Land 5255 km Güterwege gebaut. Diese Zielsetzungen wurden jedoch aufgrund minderwertiger Arbeitsqualität und ungeeigneten Baumethoden größtenteils unter erheblichen Umweltschäden verwirklicht. In diesem Zusammenhang untersucht die vorliegende Studie in einem kritischen Einzugsgebiet in der Provinz Dagana die Wirksamkeit des Güterwegebaus hinsichtlich technischer Standards, Umwelteinflüssen und sozialer Wirksamkeit. Als Ergebnis leitet die Studie Empfehlungen zur Verbesserung des Güterwegenetzes im Einzugsgebiet ab mit dem Ziel Umwelteinflüsse zu minimieren. Insgesamt wurden acht Güterwege mit einer Gesamtlänge von 42600 m anhand von 213 Probepunkten in Abständen von 200 m untersucht. In etwa 70% des Güterwegenetzes ist in einem guten und 30% in einem schlechten Zustand. 9372 m Straßenlänge haben einen sehr steilen (> 12%) und 6390 m einen sehr flachen (<3%) Gradienten. Der Ausbau von Straßengräben fehlt entlang von 30% des Erschließungsnetzes und der Belag und andere Elemente der Straßeninfrastruktur fehlen beinahe zur Gänze. Die Kombination dieser Faktoren haben zu einer massiven Erosion des Straßenkörpers, bzw. der Straßenböschungen geführt. Da ca. 72% des Erschließungsnetzes durch Wälder verlaufen, hat der Straßenzustand auch erhebliche negative Effekte auf die Vegetation. Trotz einer hohen Erschließung und einer hohen Straßendichte mit 10.6 m/ha haben einige Güterwege relative geringe soziale Wirksamkeit.

Schlagworte: Straßengradient, Strassenoberflächenerosion, Umwelteinflüsse, Soziale Wirksamkeit

1. Introduction and Research Objectives

Bhutan is located on the eastern Himalayas mountain ranges sandwiched between the two world giants viz, China and India measuring 38 394 km2 in area, falling within the geographic co-ordinates of 27˚30'N and 90˚30'E (National Soil Service Center 2012). The country has a population of 634 982 with a growth rate of 1.3% per annum (PHCB 2005).

1.1 Socio-Economic Developments and Environmental Conservation.

Bhutanese economy as such is highly depended on nature and environment with hydropower as the major contributor of GDP in the country. Further, Bhutanese culture and tradition are intricately woven with nature and its components since long time (National Environment Commission 2008) . Besides the economical and cultural importance of the environment, the very location of the nation in one of the most fragile Himalayan mountain ecosystem makes it imperative for sustainable environmental conservation in Bhutan, which culminated in making mandatory to maintain atleast 60% of the total geographic area of the country under forest cover for all times to come (Constitution of the Kingdom of Bhutan 2008).

However, over the years environmental conservation has become increasingly challenging to keep in pace with the development needs of a growing and modernizing Bhutan. And the challenges are even more with the onset of democracy in the country in early 2008. Developmental aspirations of the rural poor, which constitute a major proportion of the country's population, for basic modern amenities like road, schools and hospitals will venture the government into a tough decisions and tradeoffs between socio economic developments and its environmental conservation objectives as these two often contradicts with each other in absence of sound strategies, technologies and mechanisms in place.

1.2 Rural Livelihood.

Bhutan is generally an agrarian country with about 69% of its population living in rural areas, largely dependent on subsistence farming (PHCB 2005). Given its rugged and hilly terrains , agricultural land cover accounts for only 7.8% of the total geographical area and two third of the farmers have land holdings below two hectares (National Soil Service Center 2012). Agriculture food production contributes to about one third of the GDP and also the sector provides majority of income, food security and employment to most of the rural poor in the country (Planning Commission 2000) .

1.3 Poverty

Approximately 29 percent of the rural population and 2.4 percent of the urban population lives below the absolute poverty line (ADB 2007), geographical isolation of communities being the single most factor for rural poverty and underdevelopment in the country (ADB 2006). Almost 98% of the poor live in rural Bhutan and that the incidence of rural poverty is about 31% as compared to 1.7% percent in urban areas (ADB 2007). In these remote areas, people make their livelihood working from dawn to dusk in agricultural fields and their lives are still characterized by vulnerability and uncertainty. These communities are most vulnerable to some of the worst adverse impacts of climate change like famine, drought, malnutrition and food security besides being completely forbidden to the most basic modern amenities like health and education (Wangdi, Lhendup et al. 2013). In such areas, legitimate expectations and aspirations are not yet being fulfilled let alone ensuring equitable access to basic services and infrastructures, one of the primary visions of Bhutan 2020 (Bhutan 2020 2000). Thus, to ensure that these disadvantaged and vulnerable groups are able to fully harness the benefits of social and economic developments in the country, rural road constructions had been one of the main priorities of the government and it will be so in the years to come as well (Tenth Five Year Plan 2008).

1.4 Rural Accessibility

Market opportunities for farm products and access to public services are highly restricted in remote areas of the country, mainly due to the absence of proper road accessibility. Most of these villages are located at several days walk from the nearest motor road. Nearly half of our population lives in villages which are more than a half a day's walk from the nearest motor road despite the rapid expansion of the road net-works in the country. Communities living in the more remote areas of the country are still dependent on trails, mule tracks and ropeways for transportations (Planning Commission 2000). Rural poverty is largely a result of poor road accessibility to these rural areas (Planning Commission 2000). Accessibility has been emphasized as the defining development factor in Bhutan, the only means to increase access to opportunity, enterprises, markets or any other modern services for the rural poor. The Bhutan 2020 vision lays an ambitious task of ensuring at least 75% of the total population live within half days walk from the nearest motor road by 2020 with the formulation and implementation of the Road Sector Plan (Tenth Five Year Plan 2008).

1.5 Farm Road construction: Purpose, Objectives and Commitments of the Government.

The millennium declaration declared during the millennium summit held at the United Nations in 2000 to which Bhutan is a signatory nation articulated a strong commitment to create an environment which is conducive to development and the elimination of the poverty. One of the eight major MDGs goals thus identified is halving the extreme poverty and hunger by 2015 from the baseline year of 1990. In an effort to achieve this goal within the set time frame, the 10th FYP of the government has emphasized and prioritized poverty reduction from 25% to 15% by the end of the plan period, one of the primary goals of the government. In doing so, rural road connectivity was felt crucial in tackling under development and poverty in Rural Bhutan (Tenth Five Year Plan 2008). This goal of the government was further supported by the Vulnerability Assessment and Mapping Study 2005, which concluded that 37% of the most vulnerable Gewogs (blocks) indicated that the improvement of road accessibility would enhance food security in their Gewogs (Visser, Augustijn et al. 2005). Besides addressing the problems of food security, the rural road network was also expected to bring about greater integration of the rural areas into national domains of socio-economic developments through rural industrialization, farm mechanizations, marketing opportunities and establishment of non-farm enterprises in these rural areas.

1.5.1 Tenth Five Year Plan (2008-2013)

One of the macro strategies of the tenth FYP adopted by the government to achieve the goal of maximum road connectivity to rural areas was through national spatial planning. Some of the policy objectives of the government with regards to the road connectivity laid in the FYP are:

1. To provide road accessibility to all Gewog centers in the country.
2. To reduce poverty and improve the quality of life in rural areas through rural accessibility.
3. Implement and practice environment friendly construction practices to minimize impact on the environment.
4. Professional capacity building of the human resources in areas of planning, design, monitoring, quality control and cost-effective construction of road and bridge infrastructure works.

The tenth five year plan laid an ambitious goal of ensuring that at least three fourths of the rural population lives in less than a half days walk from the nearest road head and the government did so through various activities such as double- laning, realignment, resurfacing and construction of thousands of feeder roads and farm roads. In doing so a total budget outlay of USD$ 215 million (Nu. 13,707.861 million) was kept for the plan period and a total of 3388 km of farm roads were constructed nationwide (Tenth Five Year Plan 2008)

1.5.2 Eleventh Five Year Plan (2013-2018)

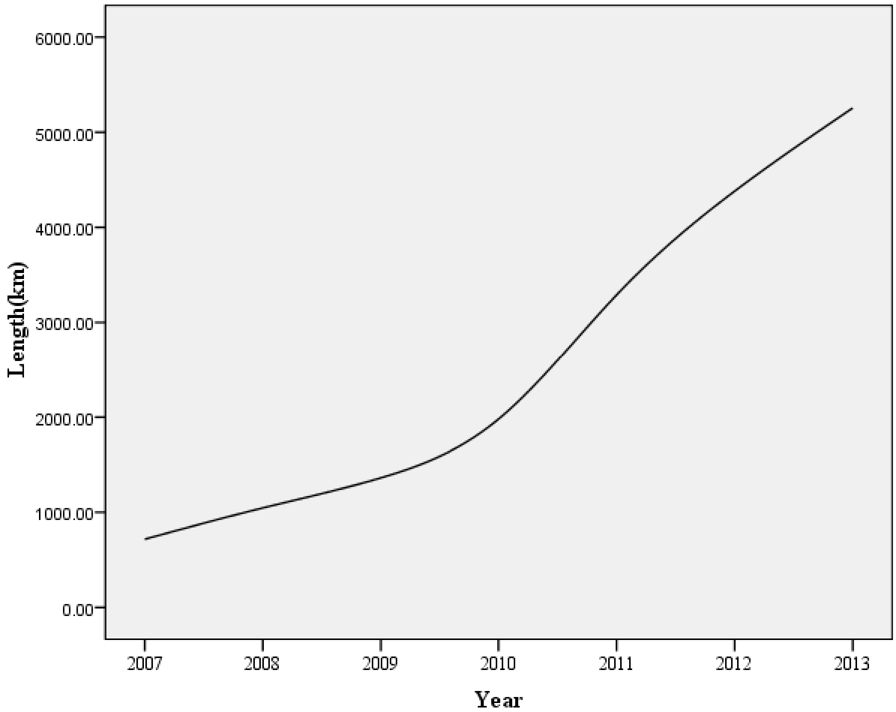

Figure 1: Line Graph showing the number of farm roads constructed since 2007 till 2013 in Bhutan (National Statistical Bureau 2014)

In the 11th five year plan, the government has a proposal to construct 1000 new farm roads along with the maintenance of 800 existing farm roads for an efficient transport network. Also the current government has plans to construct an additional 500 more farm roads. A total of approximately $ 100 million would be incurred for road maintenance and construction of new farm roads in the country (Eleventh Five Year Plan 2013). Thus, farm road construction in Bhutan has been set as top priority by the government, and will continue to be so until all rural villages in the country is connected with road networks (Bhutan 2020 2000). Currently there is over 5 255 kilometers of farm roads built in the country (National Statistical Bureau 2014).

1.6 Problem Statement

Despite the extensive networks of farm roads built in the country so far, there have not been major emphasis on an elaborative monitoring and evaluations of these farm roads taking into account the technical and environmental aspects, except for a couple of reports compiled by NGOs and task force. The findings and observation thus highlighted by these agencies do merit an evaluation of farm roads construction works, both from technical and environmental impacts point of view. Several substandard works with the construction of farm roads have been reported in these reports, which resulted in wastage of huge government's resources. Most of the farm roads have been found to be built with insufficient budget, resulting in incomplete and below standard roads. This has subsequently resulted in huge maintenance costs and destruction to the environments (Sustainable Environment Support Programme 2012). Also as a general current trend in the country, farm road construction lacks professional/ technical expertise in the field. The construction works are generally tendered to local contractors who lack technical expertise in constructing an environment friendly roads[1]. As per the reports complied by the Royal Society for the Protection of Nature, an NGO based at Thimphu, of the 688 roads investigated, over 5% was found to be not useable at all and 51 % of the roads were functional only on seasonal basis. Most of the roads were found defunct, posing threats to the environment by triggering massive mudslides and turbidity issues in downstream rivers and water sources (Tshering and Dorji 2013). The findings of the RAA (Royal Audit Authority) further elaborates on the poor conditions of the farm roads, highlighting some of the major weakness in constructions and technical expertise. The annual audit reports, 2009, highlights almost a third of farm roads defunct, causing environmental degradations in the country (RAA Annual Reports 2009).

Some of the major environmental impacts due to farm road construction in Bhutan are land scape scrapping, total removal of vegetation from the steep land surface thereby leaving the terrain vulnerable to soil erosions and landslides, wild life habitat fragmentation, indiscriminate surface runoff and sedimentation of water channels (Tshering and Dorji 2013).

With the ever increasing demands for farm roads, and a firm commitments of the government to connectify all rural areas by 2020, it becomes imperative that the farm roads that have been already constructed are well maintained and that the future farm roads are built to technical standards taking into considerations the environmental and social impacts (Multi-sector task force on farm roads 2011).As for the current trends, and with the onset of democracy in the country, the focus seems to be more on the quantity rather than on the quality of farm roads constructed. In most of the cases, during the construction of farm roads, the local authorities and the contractors involved have entirely focused just on reaching their end point destinations by any means, not adhering to engineering and environmental requirements of the farm road construction process. In some cases, the road alignments have been found to be adjusted and compromised in favor of the elites in the communities (Sustainable Environment Support Programme 2012).

Further it has been reported by NGOs, and also in several media reports that the implementation of farm road construction works in the field is hardly aligned with the guidelines, in that most of the farm roads are constructed without even having done a proper EIAs.

However, the socio-economic impacts of the farm road have been considerable and positive. And due to its contribution to the overall growth of the rural economy, the demand for farm roads has been growing exponentially over the years, especially with the onset of democracy in the country (Figure 1)

1.7 Research Objectives

This study aims at studying the efficacy of farm road constructions from technical competencies, environmental impacts and social utility point of view, in Dagana Critical Watershed. The outcome of this study will contribute towards quantifying the current technical gaps and inefficiencies in construction of farm roads, the farm road utility status, the subsequent benefits to the communities and the concomitant impacts on the environment. Further, the study is expected to come out with suitable recommendations, for further improvement of the existing farm roads in the watershed, from the prospective of minimizing environmental impacts. Therefore the study was carried out with the following objectives:

- To assess the efficacy of farm road constructions from **Environmental Impacts, Technical Competencies** and **Social Utility** point of view in the Dagana critical watershed.
- To come out with **better recommendations** for further improvements of the existing farm roads in the watershed, from the prospective of minimizing environmental impacts.

2 Literature Reviews

2.1 Rural Roads/ Farm Roads

Even today about 1.4 billion people living under extreme poverty despite a massive global efforts towards alleviating poverty. A majority (70% or 1 billion) of them lives in rural areas making poverty largely a rural phenomenon and this is true for most of the developing countries majority of which are in East Asia (International Fund for Agriculture Developments 2011). Lack of accessibility has been regarded as the major factor for poverty in rural areas (Binswanger and Khandker 1995; Fan, Hazell et al. 2000; Lebo and Schelling 2001; Lokshin and Yemtsov 2005), where geographical isolations sustains poverty and perpetuates vulnerability (Chambers 1997; Minot, Baulch et al. 2003)

Road construction has always been one of the most important tools for rural developments and is one of the basic infrastructures that enormously benefits the rural poor (Creightney 1993; Lipton and Ravallion 1993). It serves as an important catalyst for economic developments (Rostow 1960). It plays and had played a vital role in any civilizations. Developments in any forms would be difficult without roads and is one of the key factors that determines access to markets opportunities, employments, enterprises and any others modern facilities (Lugo and Gucinski 2000) and has the potential to create opportunities for economic growth and poverty reduction through a range of mechanisms (Lokshin and Yemtsov 2005). Accessibility being one of the factors of production in any kind of industry has the potential of reducing transportation costs, subsequently reducing the costs of consumption and production of goods and services. Roads can also enhance and diversify rural industries and enterprises through increased availability of resources and lower input costs (Binswanger and Khandker 1995; Lokshin and Yemtsov 2005). Household level productivity and demand for labor also increases considerably with the increased earning opportunities brought about by road developments (Khandker, Bakht et al. 2009). The increased household income in turn boost the household consumption and reduce poverty. Other subsequent benefits that follows are improved education and health, especially for the women and girls (Porter 2002). Higher school enrolments of rural youths was also observed with the rural road developments (Binswanger and Khandker 1995) . Poverty impacts brought about by the investments in rural roads was found to be relatively higher than the investments made on other areas like irrigation, soil and water conservations, health , and rural and community development (Fan, Hazell et al. 2000). However, due to the complex mixture of tradeoffs involved in road constructions, notably the strong friction between the conservation of wild lands that protect the native flora and fauna and the road that fulfills the basic necessities of the rural poor, often the decisions on road alignments, building, maintenance or not constructing at all becomes complicated and difficult (Lugo and Gucinski 2000). Off late, road infrastructure development has become a highly professional discipline demanding meticulous skills and knowledge in planning and executing road infrastructures. Designing and implementing road infrastructures in ways that would best fit to fulfill both the objectives of enhancement of road utility and at the same time ensuring environmental sustainability by reducing environmental impacts has become an ideal paradigm for road construction methods (Sessions 2007).

2.1.1 Farm Road Construction, Vegetation Loss and its Subsequent Environmental Impacts

Lately road constructions have been an important topic of discussion among environmentalists and government agencies including publics with concerns about their short and long term effects on the environment. (Cole and Landres 1996). Besides promotion of economic developments in rural areas, constructing rural roads also facilitates deforestation, habitat fragmentation (Chomitz and Gray 1996) and interrupting natural ecological flows in natural environment (Forman and Alexander 1998). It's the natural vegetation like forests that are at high risk of depletion and degradation due to road construction. Long term conservation strategies should necessarily consider measures to mitigate roads as permanent landscape features and drivers of deforestation and forest fragmentation (Freitas, Hawbaker et al. 2010). The deforestation in particular is mainly a result of enhanced accessibility to anthropogenic disturbances leading to illegal felling and forest fires. For instance, nearly 50% of the total forest covers were completely wiped out in the aftermath of opening the forests with roads in the western Baso valley of Pakisthan, largely due to illegal felling in the area (Ali, Benjaminsen et al. 2005) . Also it is not a wise decision, both economically and ecologically, to construct farm roads in areas with poor soils for agricultural cultivation and low population densities. It is a "lose-lose" scenario for both the government and the people causing environmental degradation and providing low economic returns (Chomitz and Gray 1996).

Disruption of landscape processes and loss of biodiversity are the major environmental impacts of a road network in addition to deforestations at a landscape scale(Forman and Alexander 1998). Some of the major landscape processes that are hampered due to road constructions are disruption of natural hydrological processes leading to increased surface runoff which in turn leads to increased erosions, reduced infiltration rates and disturbed subsurface flow. These effects become more pronounced and severe with the increasing terrain gradients (Brink, Slate et al.). Also road building is the main destabilizing activity in the forestry and wild land management (Weaver and Hagans 1994). Road design and alignments considerably affects the intensity and the kind of environmental impacts on water quality, plants and wildlife habitat. Poorly designed roads can have significantly adverse impacts on these aspects of the natural environment reducing habitat value for the wild life by acting as a barrier to wild life movements (Nunamaker 2007). The intensity of habitat fragmentation of wildlife due to road construction is considerably more than that of clear cuts (Reed, Johnson-Barnard et al. 1996) These effects of roads on the wildlife and the vegetation is not restricted within the confines of road alignments but extends far beyond the road edge into the forests bringing about a change in microclimates and the vegetation dynamics(Murcia 1995; Spellerberg 1998). The influences of microclimatic edge effects were felt as far as 50 meters away from the immediate vicinity of the road edge which had an impact on the natural processes of germination and establishment of seedlings .This will in turn certainly impact the forest dynamics.(Young and Mitchell 1994). Such changes in the forest dynamics will alter the community composition and abundance of indigenous faunal groups(Laurance, Goosem et al. 2009). Also with the construction of roads, the likelihood of native indigenous vegetation being taken over by the alien exotic species increases considerably.(Caro, Dobson et al. 2014). Further, the impacts of the invasion by alien species on the native species is even more on hilly and rugged terrains where vegetation are more habitat confined due to narrow altitudinal belts(Young 1994). Solutions to many of these economic, social and environmental impacts are through participatory and sound engineering practices.(Fannin and Lorbach 2007). Planning and reconnaissance surveys are the best means to identify and mitigate potential construction and environmental issues. Proper and meticulous planning done in the office is worth the time wasted in the field trying to find the proper alignment based on some physical features. (Gilmore 2012). Besides greater reliability and lower maintenance cost , a well-designed road have fewer impacts on the environment (Kocher 2007). If done in a right and competent way, the result is always a low-maintenance, low- impact road. If done in a wrong way with inadequate planning, the results is always a high-maintenance, high-impact roads (Weaver and Hagans 1994). Often it is insufficient awareness of the adverse impacts on the forest ecosystem than the financial constraints which leads to improperly designed roads. Environment friendly roads may incur high initial construction costs but its benefits are later harnessed through lower maintenance cost, longer road sustainability and avoidance of social conflicts (Klassen and Hasbillah 2006). Long term commitments both in terms of cash and human resources is necessarily required while building a road. It would be wiser to forgo the construction of road in the absence of both of these commitments. (Weaver and Hagans 1994).

The environmental impacts of development activities has always been emphasized globally in many international conventions subsequently coming out with guidelines and strategies. The Convention on Biological Diversity has emphasized on the importance of assessing the environmental impacts thoroughly prior to implementation of any development projects or activities.

2.1.2 Impacts of Farm Road Construction on Landscape Hydrology and Soil Loss

Rural road networks along with unsustainable agricultural practices especially in the mountains are the two major anthropogenic activities that contributes substantially to downstream environmental impacts mainly through sedimentation. Easy generation of runoff in combination with loose soil particles on the road surface are the main factors that leads to sedimentation of streams and water resources which in turn affects the aquatic systems (Forman and Alexander 1998). Generally the road surface erosion is relatively higher in locations where the slopes are steep, runoff distances are long and the traffic volume is high (Ziegler, Giambelluca et al. 2004). Where roads are not maintained and constructed properly, concentrated ditches can transport sediments to the nearby channels and plugged culverts can cause fill slope washouts and gullies. Further, landslides and erosions may be triggered on a steep and unstable slopes. (Nunamaker 2007). Sedimentation in water channels can alter the morphology and ecology of the channel completely in a long run.(Wood and Armitage 1997).

Road also alters the natural hydrological patterns of an area by diverting the subsurface flows to surface flows. Erosions from the cut and fill slopes in combination with the erosion from road surface can significantly contribute to river and stream sedimentation which will certainly have potential ecological impacts on water quality and aquatic life.(Sessions 2007). Re-vegetation or bio-technical stabilization measures can significantly reduce the sediment yield from cut and fill slope (Akay, Erdas et al. 2008). Sedimentation results in increasing the turbidity of the stream water which sometimes takes a long time to get cleared during rainy seasons. Poorly designed roads have a higher risk of failures than a well-designed roads during event of extreme storms. Adequately sized culverts, free-flowing ditches, and properly drained road surfaces are the key elements of a good road network in absence of which even small rainfall events will render the road impassable. Thus, road drainage is one of the most essential components of a good and reliable road (Kocher 2007). The environmental impacts of a single road analyzed in isolation to a particular region may not be significant enough taking into account the socio-economic benefits that it renders to a community. But cumulative environmental impacts of hundreds of such roads being constructed concurrently must be looked into not simply in the context of local regions but from the national context too. (Nature 1996).

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3 Material and Method

3.1 Description of Study area.

3.1.1 Physical Features.

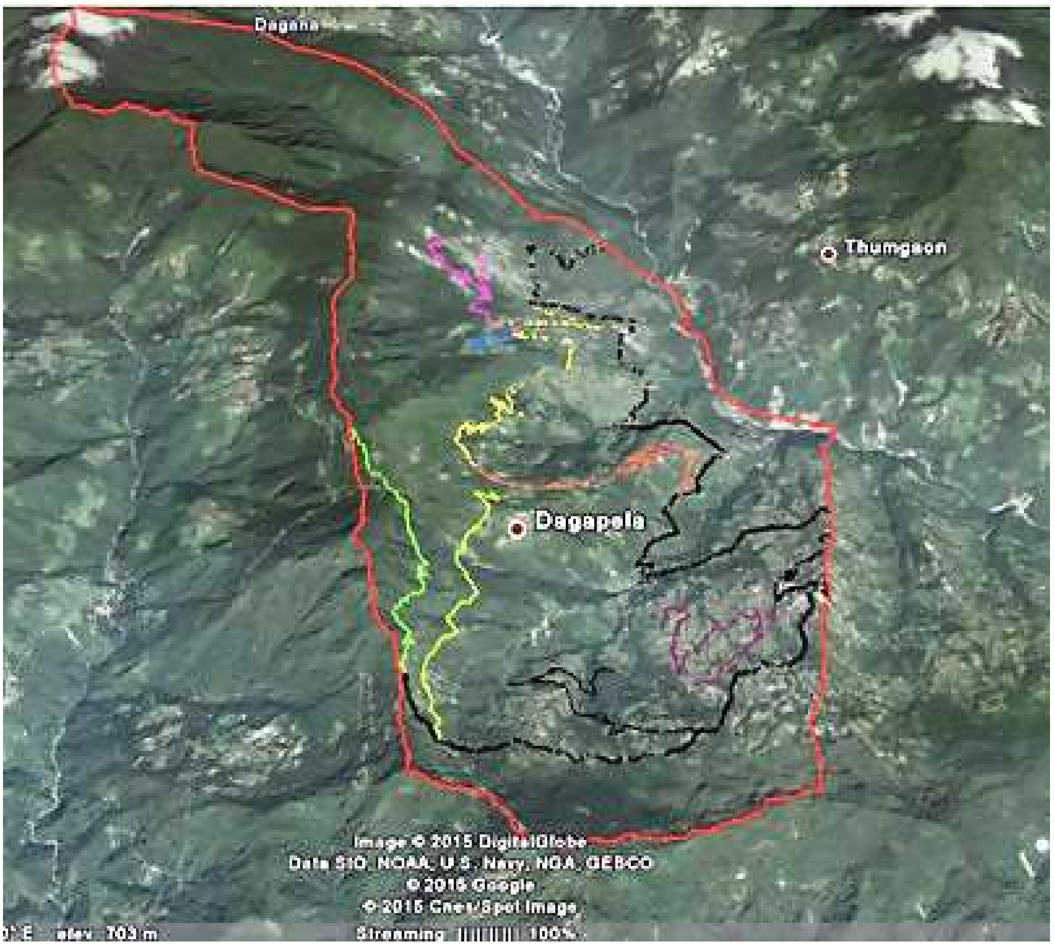


Photo 1: Google Image of the Study Area

The study area is located within geographical co-ordinates of 27° 1'33.08"N, 89°51'23.45" in Dagana Dzongkhag , one of the southern districts of Bhutan , which is approximately 6 hours drive from the capital city, Thimphu (Figure 2). Spread over an area of 6421.73 ha with altitude ranging from 500 msl to 2250 msl , it covers three Gewogs of Dagana Dzongkhag viz Kana , Goshi and Geyserling Gewogs. Topographically, the terrain is almost entirely hilly with terrains having a significant impact on land use patterns and settlements (Photo 1).The area has been identified as one of the critical watersheds of the country by the Watershed Management Division, Department of Forest and Park Services, based on the findings of the Rapid Watershed Assessment Project.

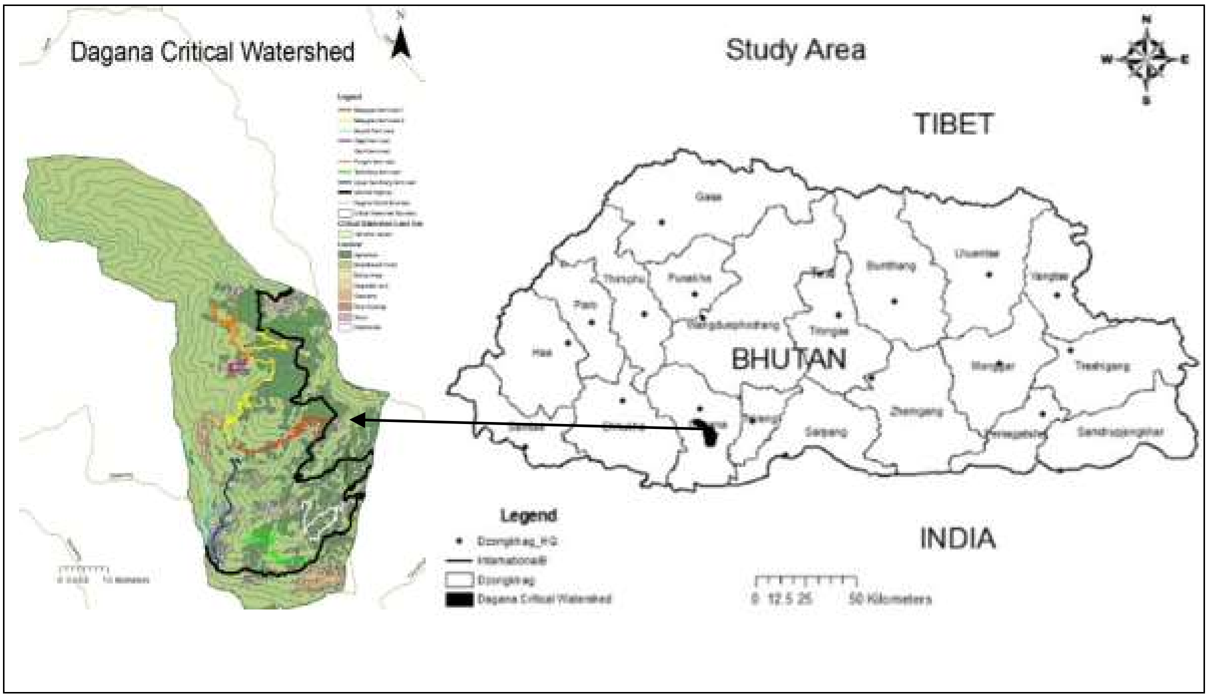


Figure 2: Map of the study Area

3.1.2 Climate, Hydrology and Vegetation.

Located along the mid elevation mountain ranges of the Bhutanese Himalayas, its altitudinal ranges fall within the warm to cool temperate zones. With relatively higher total annual precipitation than in temperate zone, the area is dominated with humid evergreen broad-leaved forests, the principal water source of the watershed which is mainly recharged by the annual monsoon rain. The total annual precipitation ranges from 1765.5 mm to 2019.1mm. The maximum values for the monthly precipitation was recorded for June- September coinciding with the monsoon periods (Hydrological stations, Dagana and Drujegang).

3.1.3 Population and Livelihood

The area has a total population of 8341 comprising of 952 households (Bhutan RNR Statistics 2012). Farmers in the area mainly practice mixed agriculture farming with terraced wetland cultivation of rice (752ha) as the main agricultural production. Maize, Paddy, Mandarin and Cardamom are the major crops grown over large areas in the villages of the watershed.

3.1.4 Spatial Distribution of Settlements, Farm roads and Land use.

Most of the settlements are confined within the vicinity of the road alignments (both farm roads and the national highway), consistently decreasing with the increasing distance from the road with almost no settlements towards the valley bottom and the ridge of the watershed (Figure 3). A total of eight farm roads take off from the national highway at various points and enter the villages with varied alignments. Major proportions of the households in the watershed are concentrated within the vicinity of the national highway. Of the total 6422 hectares of land, 76 % is forest, the dominant land use type, followed by agriculture, shrub and pasture. Agriculture accounts for only 18% of the total watershed area (Table 1)

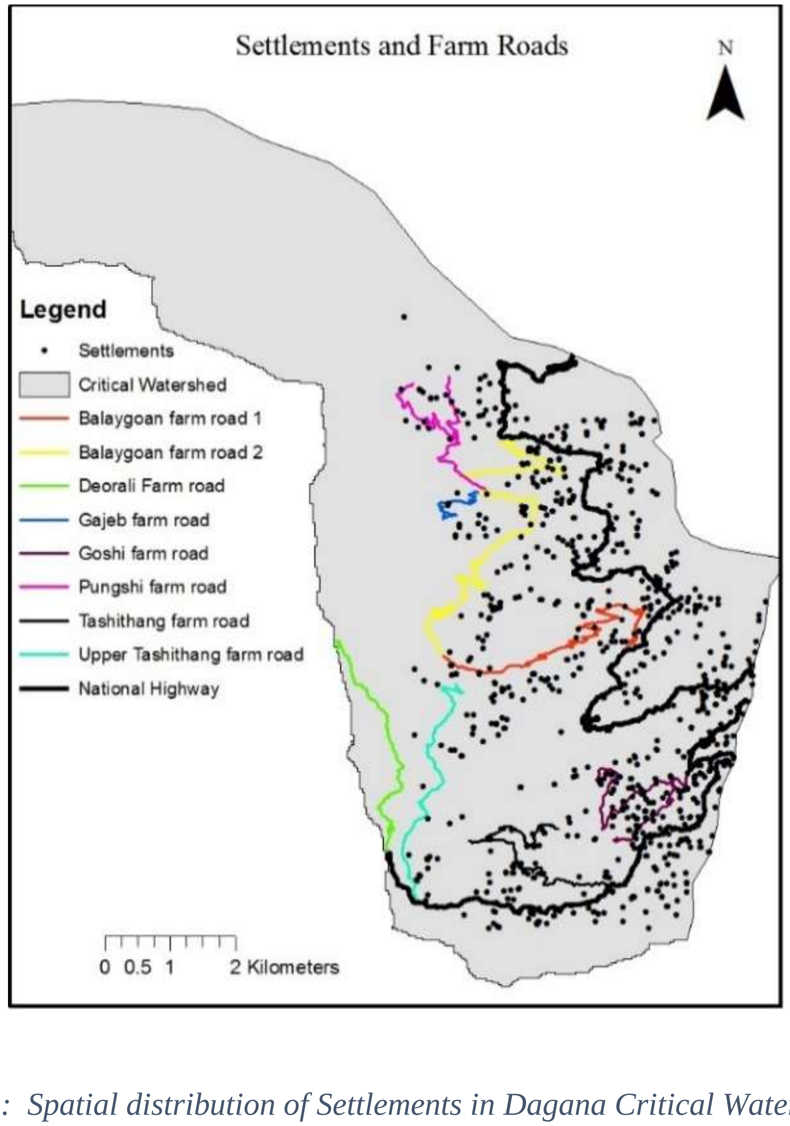


Figure 3: Spatial distribution of Settlements in Dagana Critical Watershed

Land use type	Area	% of the area
Forest.	4879.40	75.98
Agriculture	1161.97	18.09
Shrub	185.08	2.88
Pasture	132.00	2.06
Settlement areas	29.39	0.46
Degraded	19.01	0.30
Stream and Water spread	13.12	0.20
Rocky outcrop	2.12	0.03
Total	**6422.09**	**100.00**

Table 1: Land use and land cover type in the watershed (Source:(Land Cover Mapping Project 2012)

3.2 Sampling Design

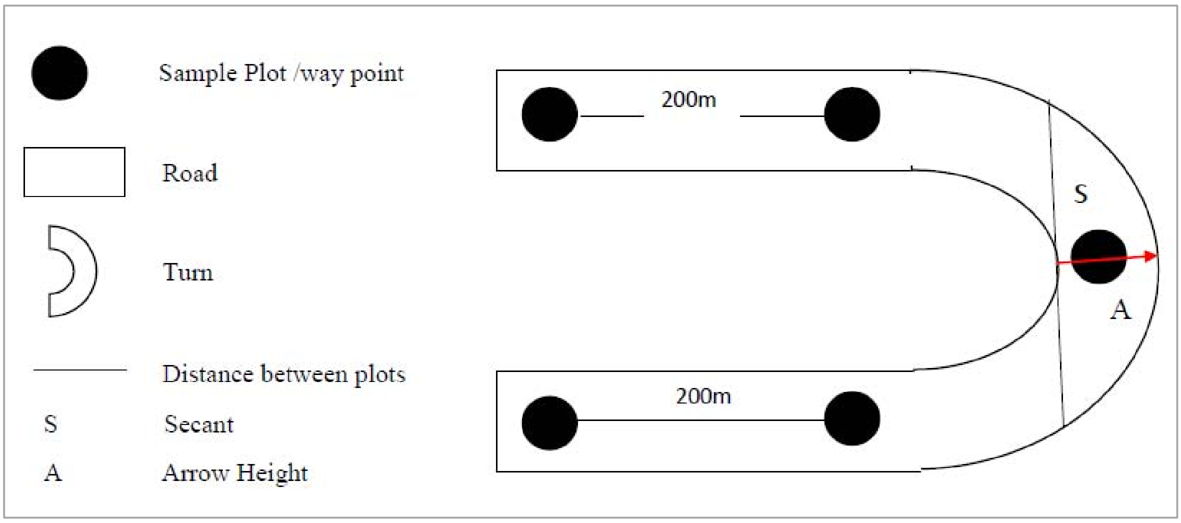


Figure 4: Sampling Design for the road section

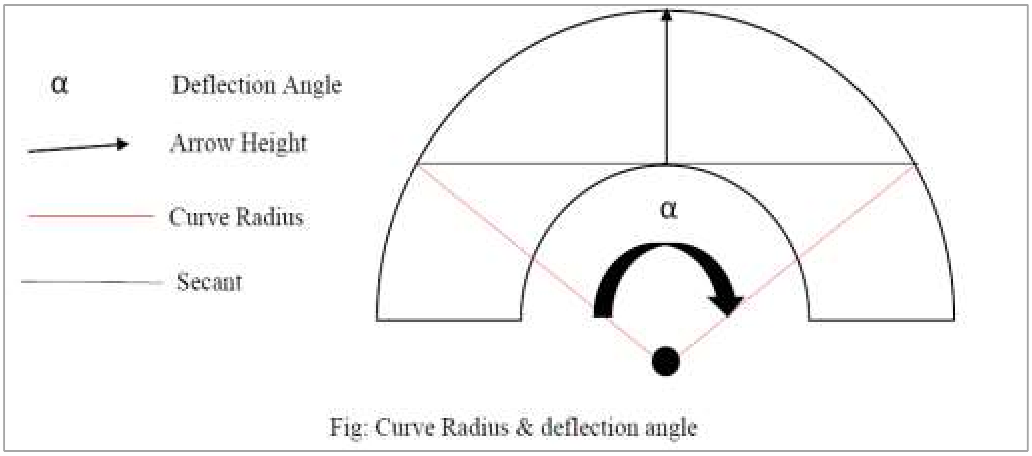


Figure 5: Sampling Design for the turn

A systematic sampling plots were laid along the road transect of each farm roads at every 200m distance. The sample plots were laid at the middle of the road surface (Figure 4). A total of 213 sample plots were laid for 42 600 meters of farm roads in the watershed. The starting point was always the starting point of the farm road and end point the end of the farm roads, excluding the lengths falling outside the watershed boundary. The entire tract of the road and the waypoints at each sampling point were recorded in the GPS simultaneously. Additionally, the turns were also assessed by laying sample points at each turns. In case of turns, each turns along the road transect was recorded in the GPS as waypoint, and values for Arrow height and Secant (Figure 5) (Sessions 2007) were measured and recorded in the data collection form. The arrow height is the distance between the inner edge and outer edge of the turn, perpendicular to the secant. The secant is the length of the tangent on the inner edge of the turn, touching at both ends of the road at a turn.

3.3 General Plot Description and Data Collection

At every sample plot along the road section, besides recording the waypoints in the GPS, data on various road parameters were collected and recorded in the data collection form (Figure 6). Both quantitative and qualitative data were collected for each sample points. Qualitative data included road quality, cut slope and fill slope qualities, utilization of terrains above and below the roads, which were assessed visually. A Sunto and Magnetic Compass were used for reading slopes, and measuring tape for the measurement of linear distance (Figure 7). For cut slope measurement, run and rise lengths were recorded at every sample plot, and subsequently the slope was calculated (Sessions 2007). To avoid biasness in determining the depths of erosion channels, mean value of multiple measurements made at a single sample point was taken as the final erosion cannel depth value for a particular sample point

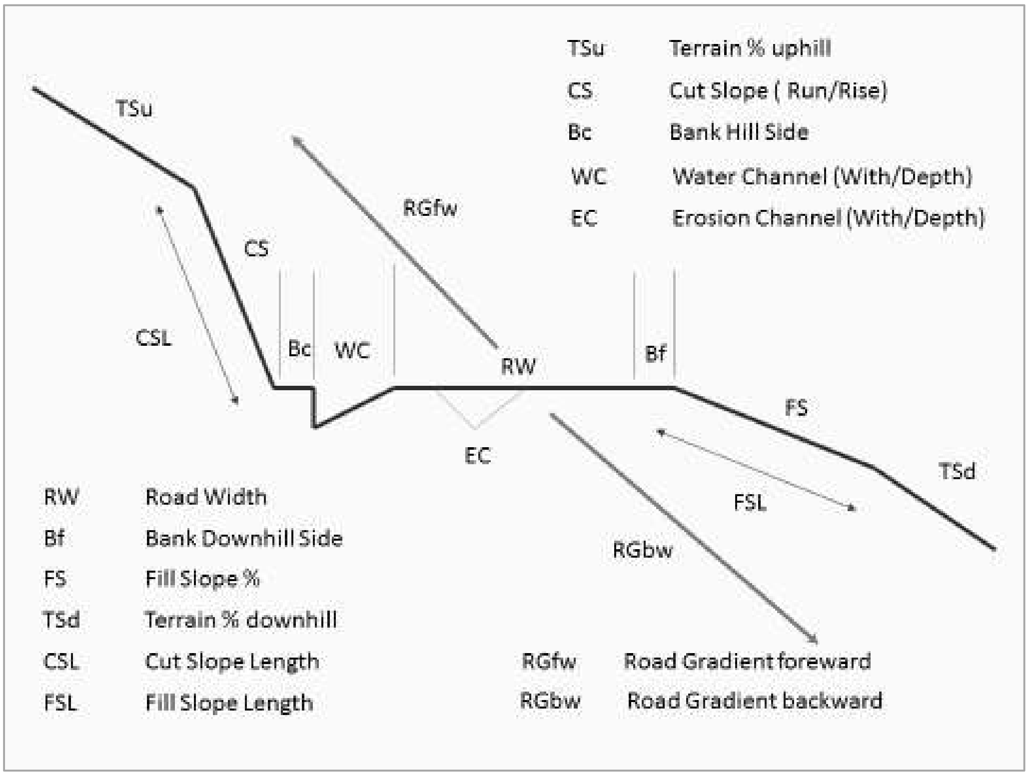


Figure 6: Road Cross Section for each sampling point[2]

Figure 7: Equipment used during the field works (A) Clinometer, (B) GPS, (C)Measuring Tape, (D) Measuring Scale.

4 Data Analysis

4.1 Statistical Analysis

SPSS version 19 software (Landau 2004) was used to analyze the data for descriptive statistical analysis. However, before performing the statistical analysis, the mean value for road gradients forward and backward, terrain slope above and below the road, were calculated. Only the mean value for the above parameters were taken for the analysis. Also the cut slope, the curve radius and turn angles of the turns were calculated from filed data using mathematical formula. The turn angles and curve radius of the individual turns were calculated using arrow height and secant measurements using standard formula. The datasets were also subjected to parametric statistical tests (Pearson's correlation and linear regression using scatter plots) to determine correlations between different road parameters. Data was also analyzed in the excel sheet for simple statistical analysis and graphs.

4.2 Spatial Analysis

ArcGIS 9.2 version was used to analyze the spatial aspects of the data. The tracks and waypoints recorded in the GPS were downloaded in to ArcGIS 9.2. Subsequently all of the road parameters thus collected from the field were fed into the attribute tables of respective waypoints and tracks of individual farm roads by joining tables from the excel sheet. The same was done for all the turns as well. Spatial maps showing spatial distribution of both qualitative and quantitative parameters were generated for all farm roads in the watershed.

4.3 Social Utility Analysis

The social utility analysis for farm roads was carried in ArcGIS by analyzing the number of households within concentric buffer strips of 200m widths laid at varying distance from the roads (Table 2). It was done by assessing the change in number of households within the buffer strips brought about by the buffering effects of the farm roads (Figure 8 & 9). The number of households in the buffer strips is affected by the buffering effects of the adjacent farm roads which has an effect on the utility of the farm road concerned.

Each farm road was assessed based on two scenarios as follows:

1. Each farm road with buffering effects of the adjacent farm roads in the watershed (Figure 8 left)
2. Each farm road without buffering effects of the adjacent farm roads (Figure 9).

#	*Buffer widths(m)*	*Mean aerial distance from the road(m)*
1	200	100
2	200-400	300
3	400 – 600	500
4	600 – 800	700
5	**800 – 1000**	**900**

Table 2: Buffer widths and its mean aerial distance from the roads

The change in number of households in each buffer strips due to buffering effects was observed. Subsequently, the road lengths per unit household was calculated for each farm roads. The calculated values for road length per unit household was used for assessing the intensity of farm road utility and its subsequent impacts on the surrounding environments. The assessment was also expected to indicate whether the road alignments are aligned in coherence to the maximum benefit to the communities.

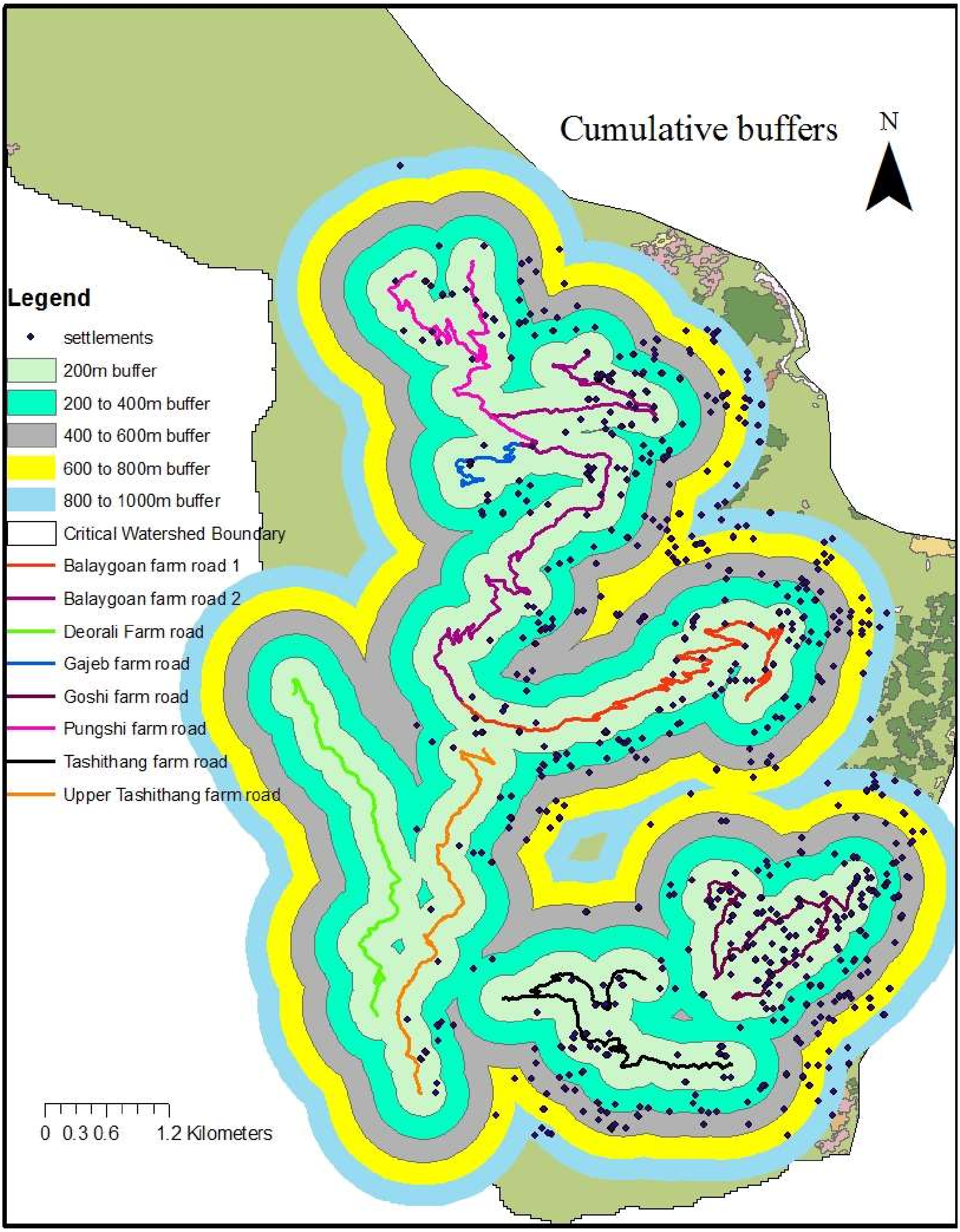


Figure 8: Cumulative buffers for all the farm roads considering buffering effects

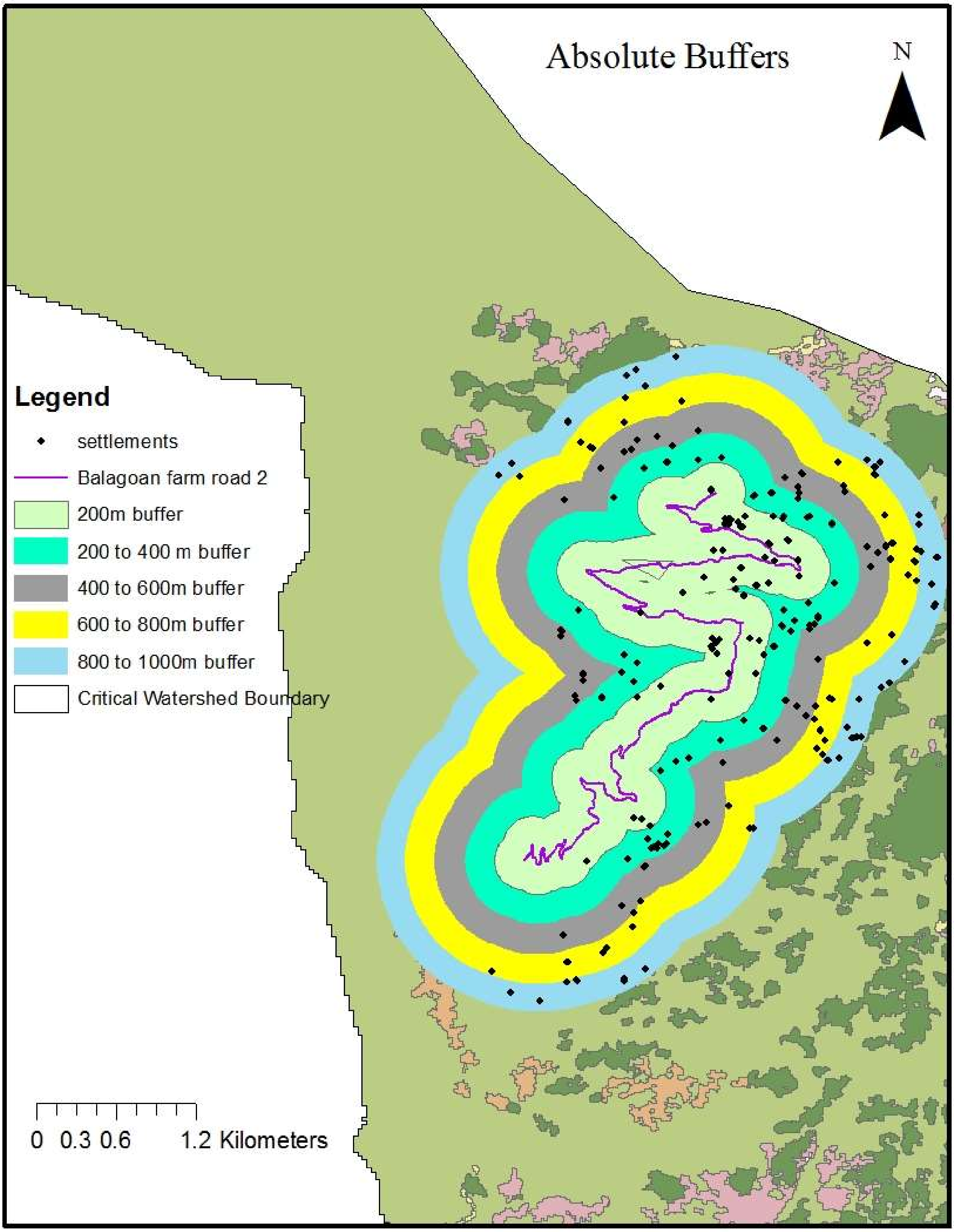


Figure 9: Absolute buffers for individual farm road without considering buffering effects

4.4 Qualitative Assessment of the Road Quality

The qualitative assessment of road quality was done as a function of different qualitative road parameters. The parameters considered in assessing the qualities of farm roads are:

1. The quality of road surface (surface course, base course and subgrade soil).
2. Provision of side drains.
3. Farm road infrastructures like culverts, cross drains, retaining walls, bank cuts.
4. Stability of cut slopes and fill slopes (biotechnical stabilization measures).
5. General stability of terrain above road.
6. General Stability of terrain below the road.
7. Presence/absence of erosion channels and rut developments.
8. Vehicle pliability.

Based on the above parameters, following categories of roads were assigned to each sampling points along the entire section of the road (Table 3).

#	***Categories***	***Qualifying tallies***
1	Very Good	7 and above
2	Good	5 to 6
3	Bad	3 to 4
4	Very Bad	1 to 2

Table 3: Road categories for road quality assessment

The qualitative assessment of the cut slope and fill slope was made visually based on the status of vegetative growth on the slope as fully vegetated, partially vegetated and not vegetated at all.

4.5 Quantitative Assessment of the Road Quality (Multi-Criteria Analysis)

Road Gradient	Points	Erosion Channel	Points
0	0	0	0
0 to 4	1	0.1 to 5	1
4.1 to 7	2	5.1 to 10	2
7.1 to 11	3	10.1 to 20	3
		20.1 to 40	4
Fill slope	Points	**Cut slope**	Points
0	0	0	0
0.1 to 20	1	45 to 50	1
20.1 to 25	2	50.1 to 55	2
25.1 to 30	3	55.1 to 60	3
30.1 to 40	4	60.1 to 65	4
40.1 to 50	5	65.1 to 75	5
50.1 to 60	6		

Table 4: Table showing criterions (parameters) used for the multi criteria analysis.

The quantitative assessment of road quality was analyzed by way of multi criteria analysis in which quantitative road parameters were used as the evaluation criteria to assess four categories of road (Table 5). Only four quantitative road parameters were used for the assessment (Table 4). Each of this parameters were assessed for every sampling points. The quality of the road worsens with the increasing points for every farm roads with 8 being the transition between good and bad roads (Table 5).

Road Categories	Qualifying points
Verg Good	0 to 4
Good	4.1 to 8
Bad	8.1 to 12
Very Bad	12.1 to 18

Table 5: Road Categories

5 Results

5.1 Average Road Gradient (Degree)

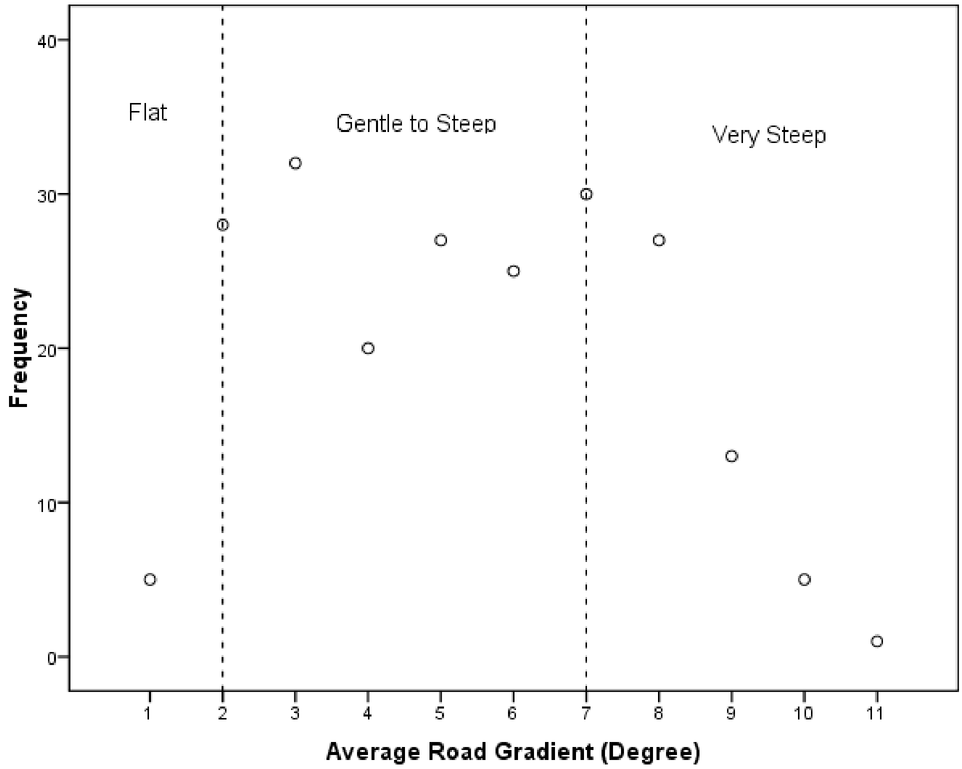


Figure 10: Graph showing the frequency distribution of average road gradients for farm roads in the watershed

Slopes in Degrees	*Frequency*	*Length (m)*	*Percent*	*cumulative percent*
0 to 2 (0 to 3%)	33	6600	15	15
2.1 to 7 (3.1 to 12%)	134	26800	63	78
7.1 to 11 (12.1 to 19%)	46	9200	22	100
Total	213	42600	100	

Table 6: Average road gradient classes and the corresponding road lengths for farm roads in the watershed.

The road gradients for the farm road networks in the Dagana Critical Watershed area ranges from as low as 1 to as high as 11 degree, with mean value of 5.23 (±0.16) degree. Only about 26 800m (63%) of the total road length has road gradient within the range of 2 to 7 degree (3 to 12%). Approximately 6600m (15%) and 9 200m (22%) of farm roads have road gradients less than 2 degree and more than 7 degree respectively (Table 6). Balaygoan I and II have maximum lengths of roads with gradient more than 7 degree (12%). Goshi, Tashithang and Upper Tashithang farm roads have more proportion of road length with gradients less than 2 degree relative to other roads in the watershed (Figure 11). Generally road sections with gradient more than 7 degree (12%) are located on steeper slopes with difficult terrains (Figure

12), which are subjected to higher intensity of road surface erosions during monsoon seasons (Photo 2). Due to steep road gradients, road surfaces were severely eroded leading to the formation of deep erosion cannels at several spots along the roads (Photo 7 and 8). Road sections with gradients less than 2 degree (3%) were mostly water stagnated due to lack of water drainage facilities. The stagnant water seeped into the road subgrade soils making the road surface clayey, leading to developments of ruts after vehicle movements (Photo 3). Also these sections of the road were deposited with debris and sediments carried by the runoff water. Road blocks caused either by accumulated debris/sediments or unstable road surface due to water stagnation were common along the roads.

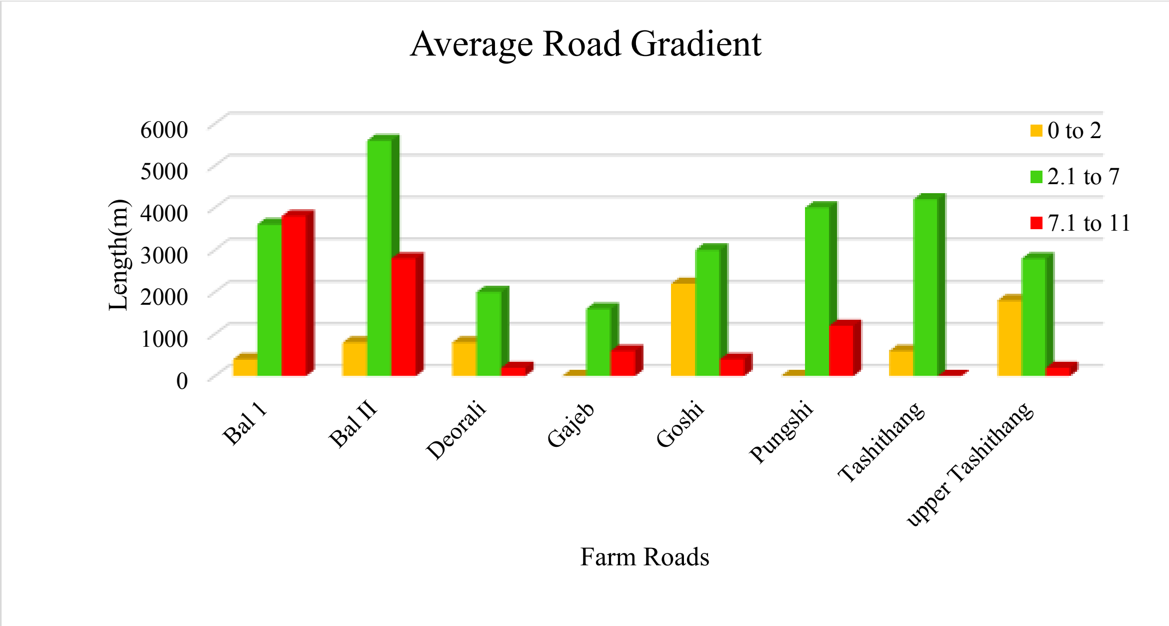


Figure 11: Bar Graph showing average road gradient classes and corresponding road lengths for individual farm roads in the watershed

Photo 2: Road surface highly eroded due to steep road gradient (more than 7 degree or 12%)

Photo 3: Water stagnation due to poor drainage and very low road gradient (less than 2 degree or 3%). Development of ruts on the road surface due to vehicle movements

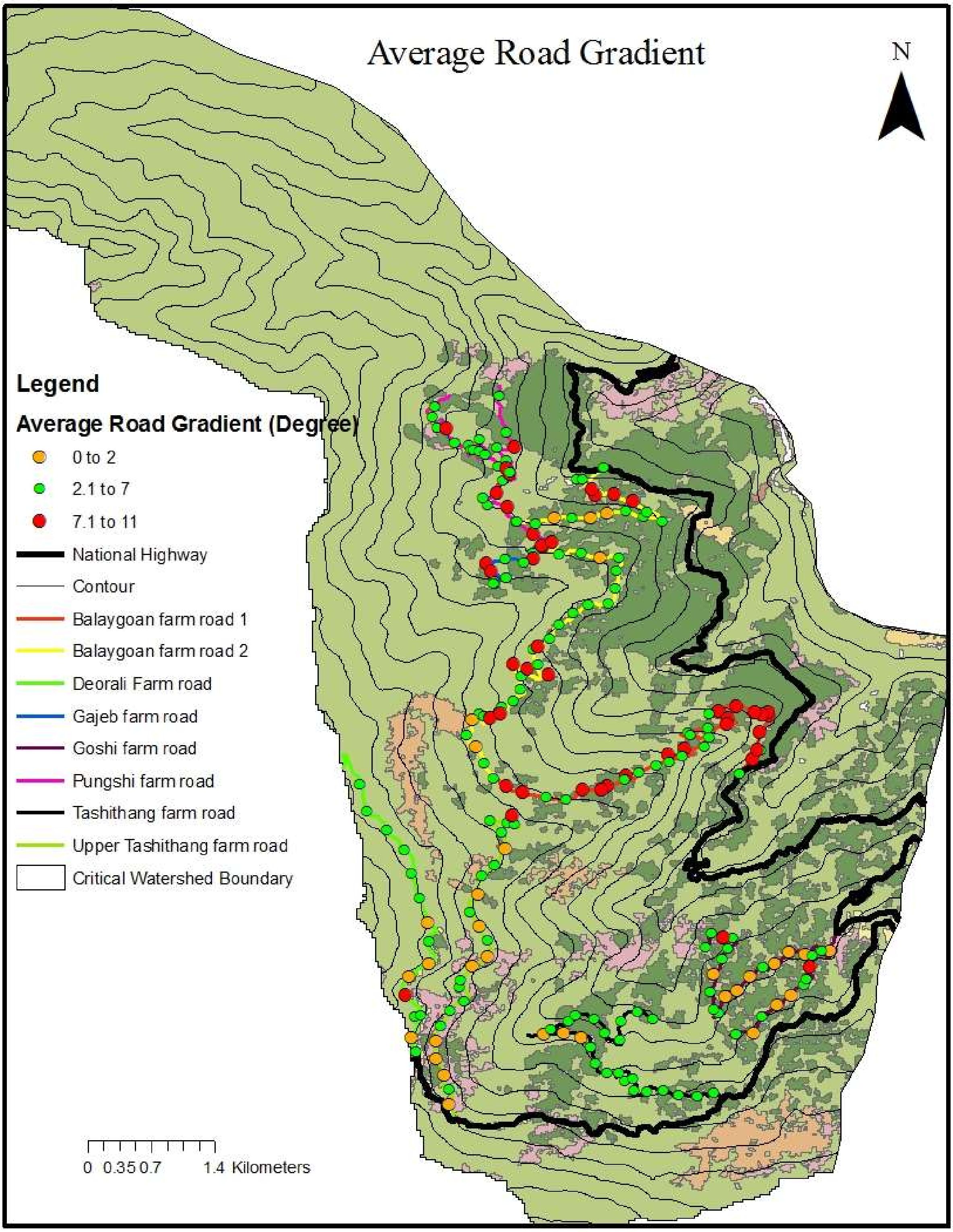


Figure 12: Map showing the spatial distribution of Average Road Gradients for farm roads in the watershed.

5.2 Road Quality (Qualitative Assessment)

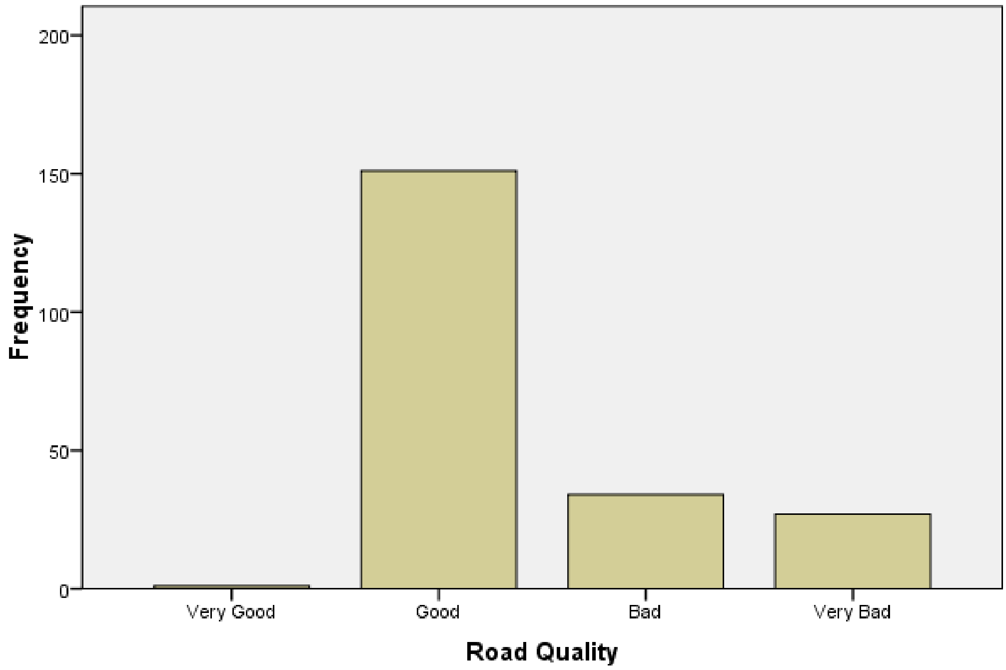


Figure 13: Bar Graph showing the frequency of road quality distribution for farm roads in the watershed as per qualitative assessment

As per the qualitative assessment of the road quality, approximately 16% (6 800m) of the total farm road length is in bad and 13% (5 400m) in very bad conditions (Table 7). Approximately, 70% (30 200m) of the total farm road length was found relatively in good condition, but would still require periodical maintenance and additional road structures like culverts, drainage channels and fords for long term sustainability of the farm roads. Further, slope stabilization measures, adequate road pavements and side drains for better drainage were lacking substantially for all categories of farm roads.

Categories	***Frequency***	***Length (m)***	***Percent***
Very Good	1	200	0.5
Good	151	30200	70.9
Bad	34	6800	16
Very Bad	27	5400	12.7
Total	**213**	**42600**	**100**

Table 7: Road quality and its corresponding lengths/percentage of farm roads

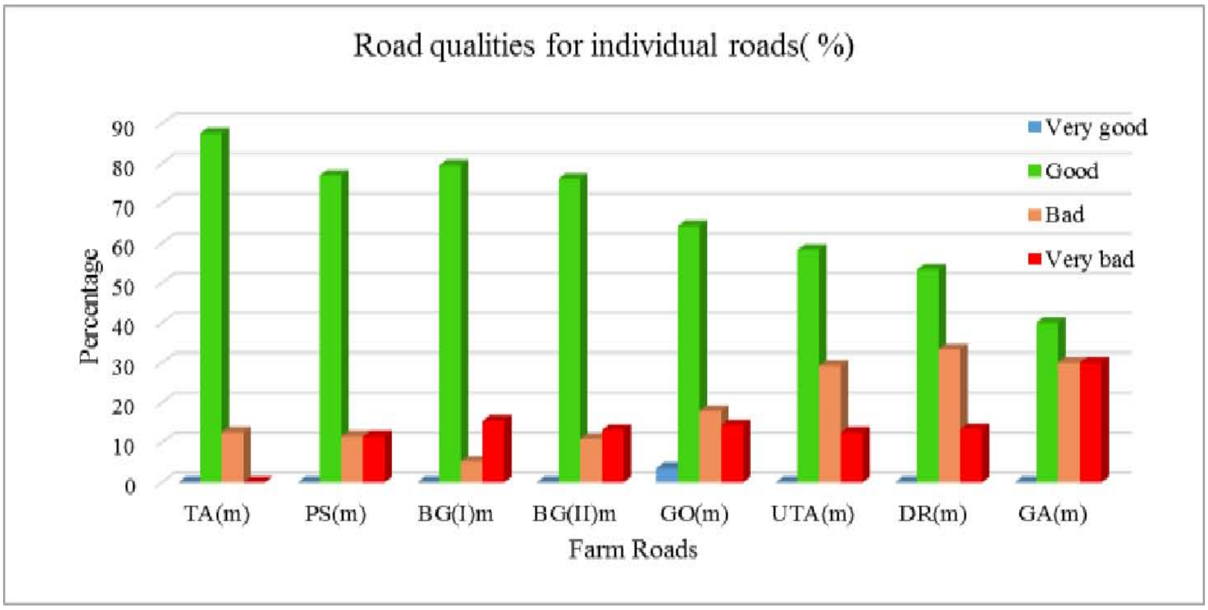


Figure 14: Bar graph showing road qualities proportions for individual farm roads in percentage (Qualitative Assessment) TA:Tashithang , PS:Pungshi, BG(I):Balaygoan I, BG(II):Balaygoan II, GO:Goshi, UTA:Uppertashithang, DR: Deorali, GA:Gajeb

Categories	*TA(m)*	*PS(m)*	*BG(I)m*	*BG(II)m*	*GO(m)*	*UTA(m)*	*DR(m)*	*GA(m)*
Very good	0	0	0	0	200	0	0	0
Good	4200	4000	6200	7000	3600	2800	1600	800
Bad	600	600	400	1000	1000	1400	1000	600
Very bad	0	600	1200	1200	800	600	400	600

Table 8:Road quality and corresponding road length for individual farm roads TA:Tashithang , PS:Pungshi, BG(I):Balaygoan I, BG(II):Balaygoan II, GO:Goshi, UTA:Uppertashithang, DR: Deorali, GA:Gajeb

Photo 4: (Left) Road surface severely eroded due to runoff water on Gajeb farm road.(Right) Irrigation channels coming in conflict with the road alignment damaging the road surface

Gajeb farm road is in the worst condition with about 60% of total farm road in bad and very bad conditions (Photo 4 Left), followed by the Deorali and Upper Tashithang roads, both of which have approximately 40 % of the total road length in relatively bad to very bad conditions. Balaygang I and II, as well as the Goshi farm roads are intermediate with about 20-25% of the road length in bad to very bad conditions. Tashitang farm road is relatively good with only about 13% of the road length in bad condition (Table 8 and Figure 14). The road condition is also deteriorated on several spots due to irrigation cannels coming in conflict with the road alignments (Photo 4 Right). The spatial distribution of the road quality is shown in the map below (Figure 15).

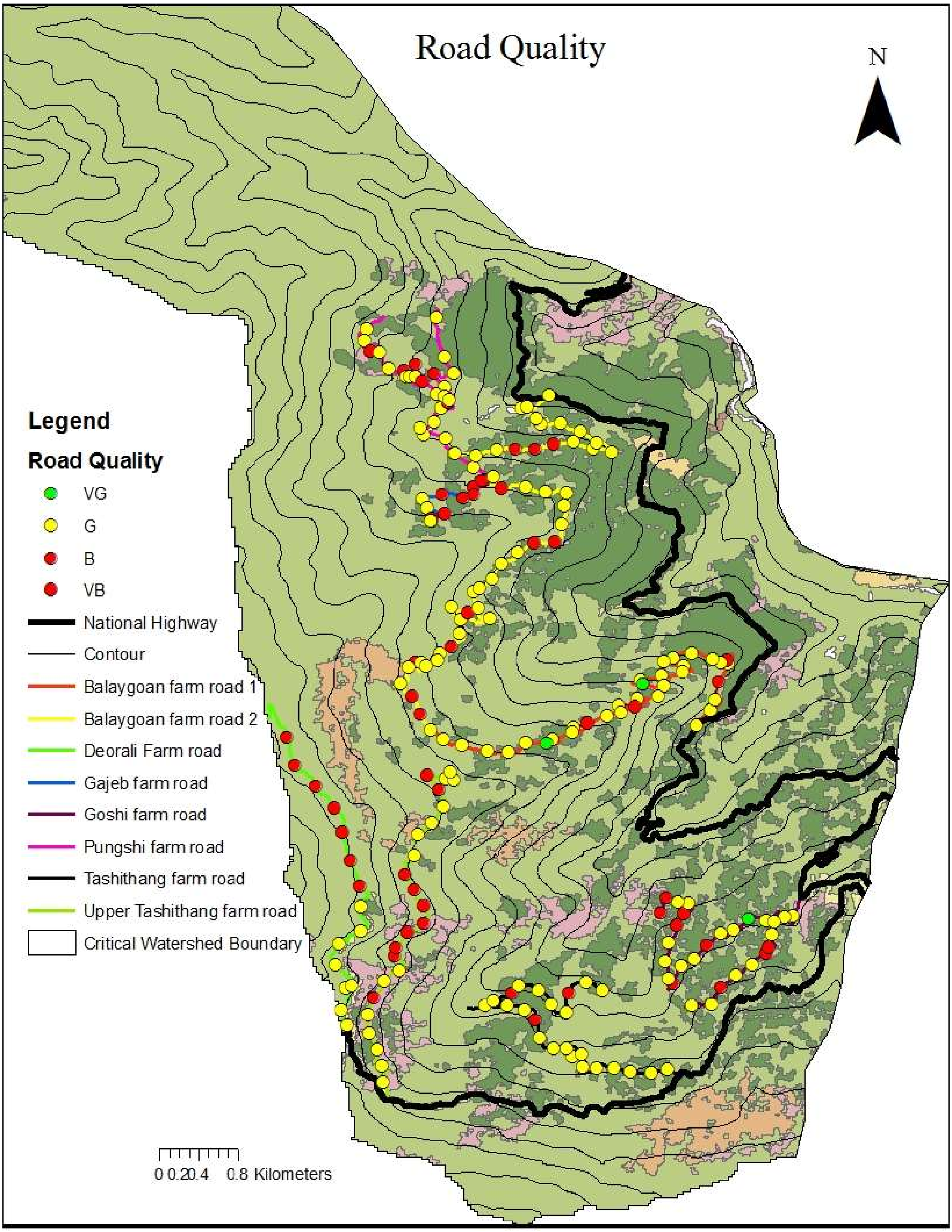


Figure 15: Map showing the spatial distribution of road qualities as per qualitative assessment of farm roads in the watershed

5.3 Road Quality (Quantitative Assessment)

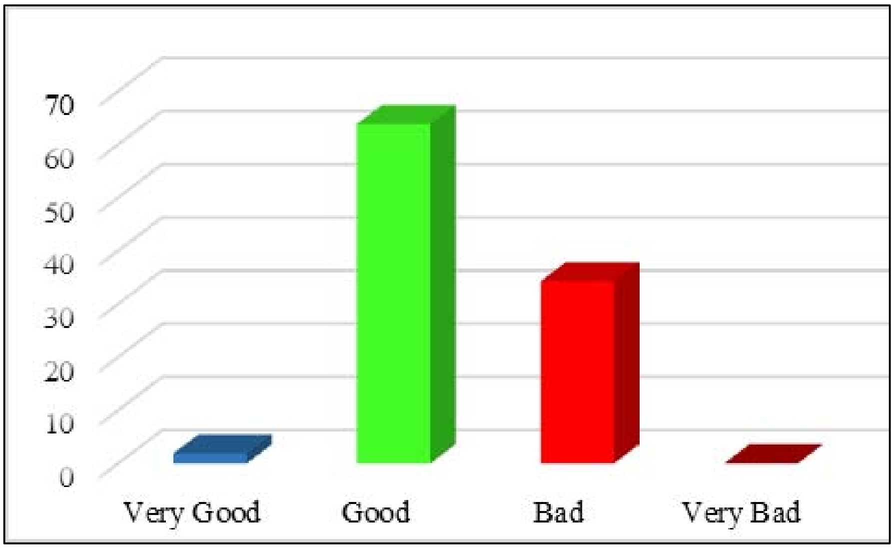


Figure 16: Bar graph showing the proportion of road quality in percentages (Quantitative assessment)

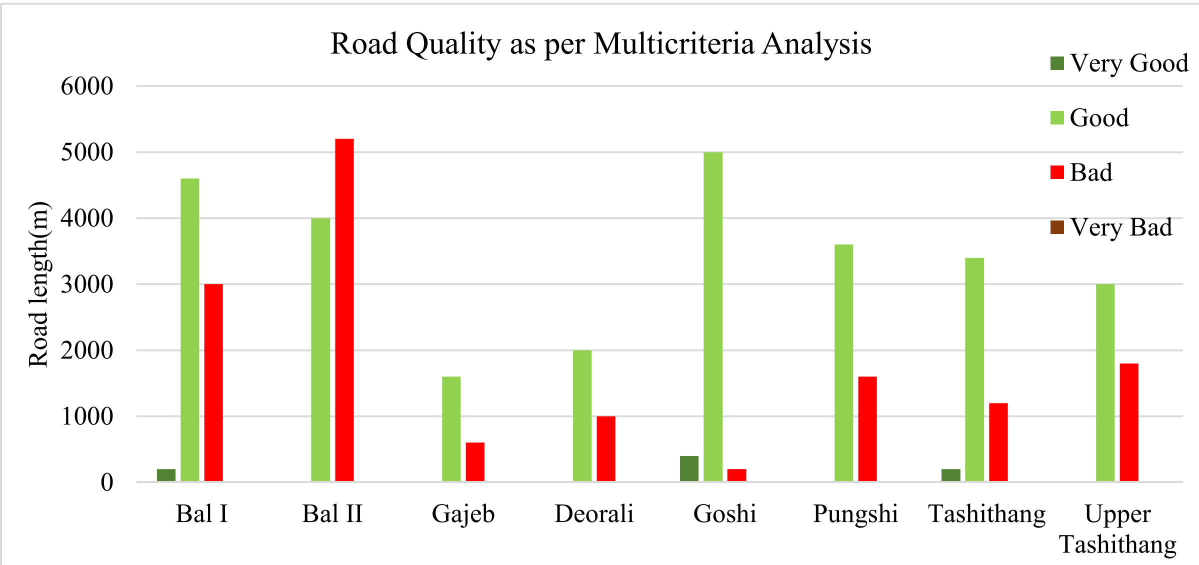


Figure 17: Bar graph showing the road quality as per Multicriteria analysis for individual farm roads in the watershed

As per the quantitative assessment of the road quality, approximately 66 % (including 2 % very good) of the farm roads in the watershed is in good condition. While about 34% is in bad condition (Figure 16). Most of the road sections in bad conditions are confined to steep terrains (Figure 18). However, in general most of the farm roads in the watershed is in good condition with Goshi farm road relatively better compared to other farm roads in the watershed. Balaygoan II has relatively larger proportion of road lengths in bad conditions (Figure 17).

With a difference of just 4%, the results of both quantitative and qualitative assessments did not vary much. To sum up the results of both the assessments by taking the mean values, approximately 68 % (28 968m) of the total road lengths in the watershed is in good condition while the remaining 32% (13 632m) is in bad condition.

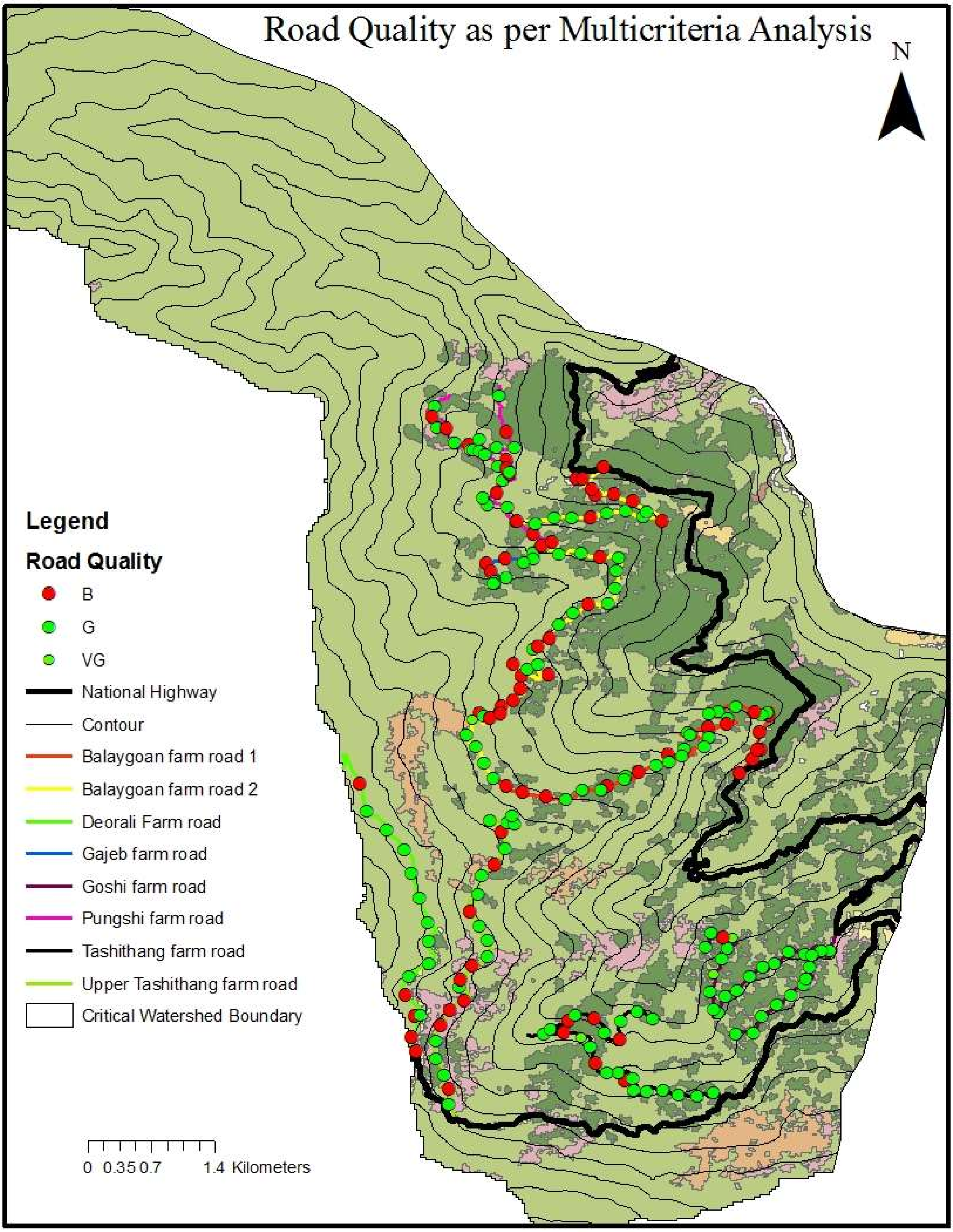


Figure 18: Map showing the spatial distribution of road qualities as per quantitative assessment of farm roads in the watershed

5.4 Water Cannels/ Drainage

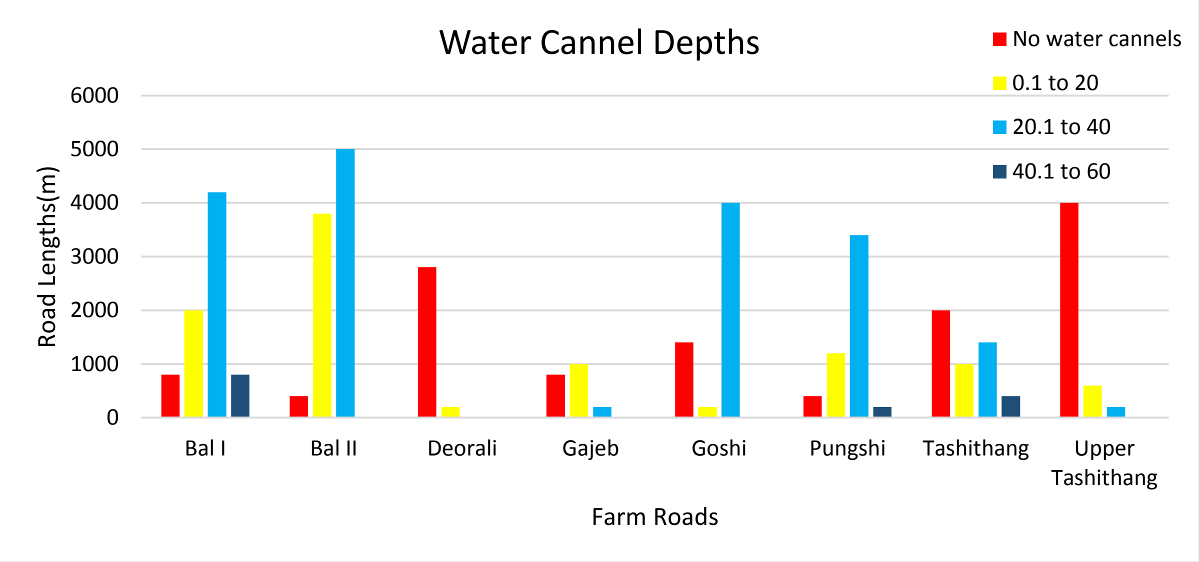


Figure 19: Bar Graph showing water cannel depth classes and corresponding road lengths for individual farm roads in the watershed

The mean depth of the water cannels in the watershed is 18.35 cm (± 0.995), with a maximum of 60 cm depth. 30% of the farm road length (or 12780m) in the watershed have no water cannels at all, while the remaining 70% have water cannels with a maximum depth of 60cm (Table 9). Upper Tashithang farm road has about 4000m (84%) of its length without water cannels, the highest, followed by Deorali and Tashithang farm roads (Figure 19).

Photo 5: Erosion cannels formed due to surface runoff in the absence of side drains

The water channels are absent mostly in newly constructed farm roads which are even more prone to soil erosions due to bare subgrade soils exposed to precipitations. Absence of water channels in combination with loose bare subgrade soils, has led to excessive erosions due to runoff water leading to the formation of deep erosion cannels at several spots. The road is rendered completely un-useable during the rainy seasons (Photo 5). The road is not useable even during the dry periods of the year unless with major maintenance works. In many instances, the erosion cannels have also destroyed the irrigation cannels of the villages, mostly due to siltation and deposition of debris in the irrigation channels, diverting the course of the irrigation cannels completely.

Depths (cm)	*Frequency*	*Length(m)*	*Percent*	*Cumulative Percent*
0	63	12600	30	30
0.1 to 20	50	10000	23	53
20.1 to 40	92	18400	43	96
40 .1 to 60	8	1600	4	100

Table 9: Water cannel depth classes and corresponding road lengths for farm roads in the watershed

Photo 6: Side Drains for Goshi farm road in the watershed

Even with the existing water cannels, most of the channels are defunct/blocked with debris of past monsoon. Such blocks were mostly noticed on road sections with minimal gradient causing water stagnation. The stagnant water either flowed over the road pavement deteriorating the road surface, or seeped into the road surface destroying the road subgrade soils. The spatial distribution of water cannel depths is illustrated in Figure 20.

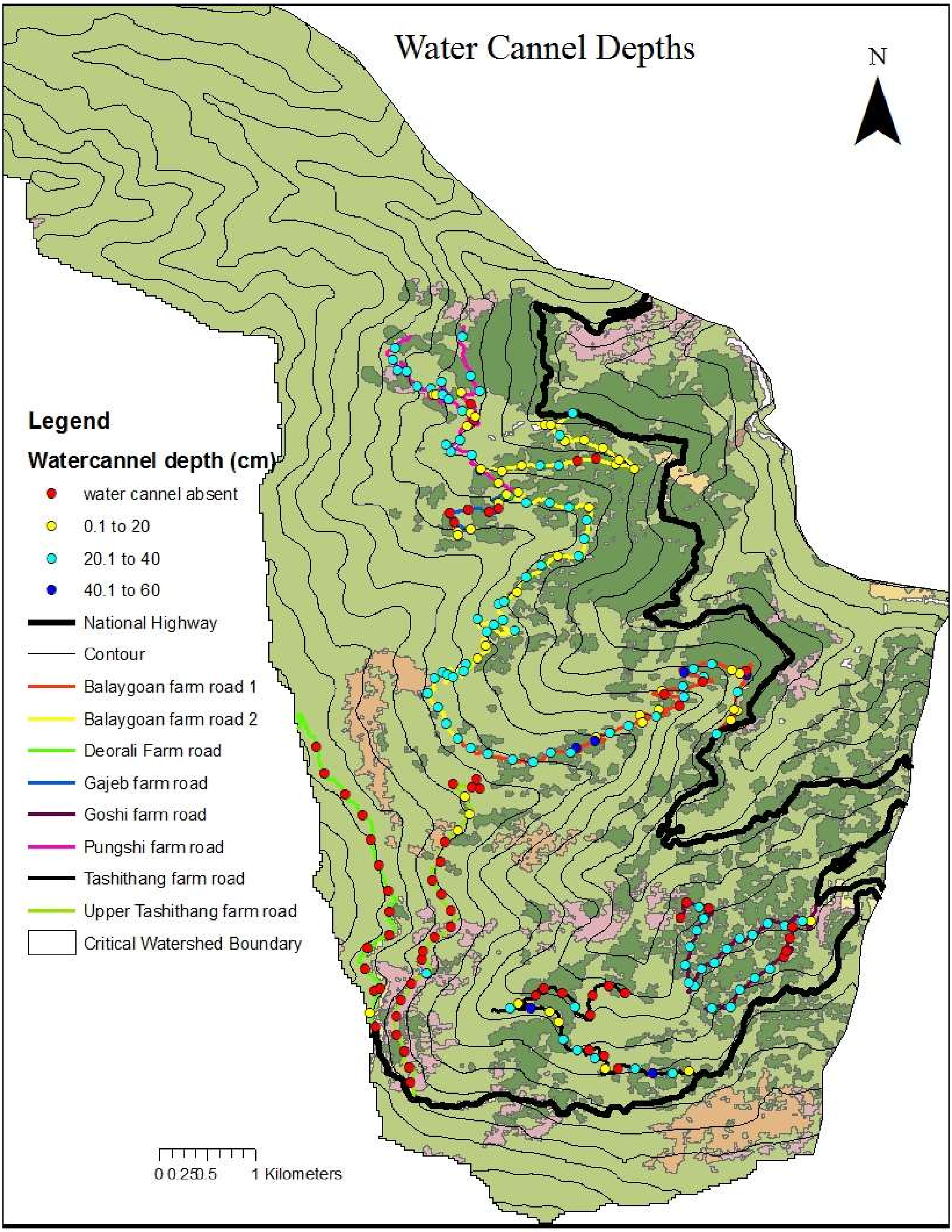


Figure 20: Map showing the spatial Distribution of Water Cannel Depths for farm roads in the Watershed.

5.5 Erosion Cannels

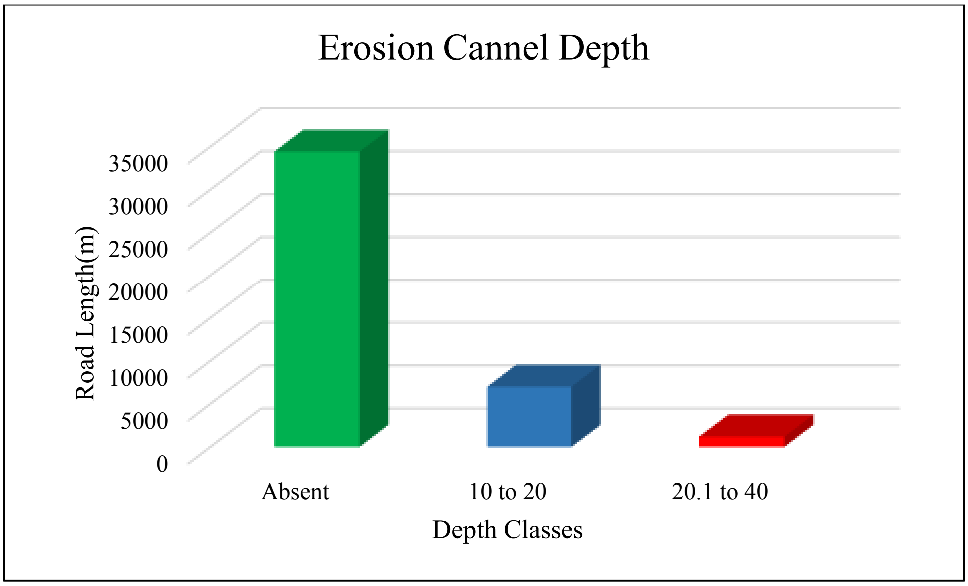


Figure 21: Bar Graph showing farm road lengths for corresponding erosion cannel depth classes.

The mean depth of erosion channels in the watershed is 15cm (± 3), with a maximum depth of 40 cm. 34 400 m (81%) of farm road length in the watershed has no major erosion cannel depths. While almost 8 200m (19%) of the farm roads have erosion cannels depths above 10cm, with a maximum of 40 cm (Figure 21). The erosional cannels with deeper depths were mostly seen on the roads on steep terrains (Figure 23). In general, the 19% of the total farm road lengths with deeper erosional cannel depths are and will be more detrimental to the surrounding environments. Road drainage is imperative in this section of farm roads.

Depth Classes	***Length(m)***	***Percentage***
Absent	34400	81
10.1 to 20	7000	16
20.1 to 40	1200	3
Total	42600	100

Table 10: Erosion Cannel Depth classes and corresponding Road Lengths for farm roads in the watershed.

Photo 7: Deep erosion cannels formed on the road surface

Photo 8: Road surface severely eroded due to excessive runoff

The lack of drainage facilities in combination with steep road gradient and bare subgrade soils has led to massive road surface erosions. These road surfaces are a major source of sedimentation for streams and irrigation cannels (Photo 8). The length of erosion channels ranges from few centimeters to as long as 50 meters at some sections of the road. Though the occurrence of erosion cannels is relatively low in old farm roads, they do have deep erosion cannels at several spots. The excessive runoffs initiated by these erosion channels have exacerbated fill slope instability at many spots along the road segments. The loss of soil due to surface erosions was relatively more in the newly constructed farm roads.

Depth Classes(cm)	***Bal I***	***BaL II***	***Deorali***	***Gajeb***	***Goshi***	***Pungshi***	***Tashithang***	***Upper Tashithang***
0	7000	4800	2600	1600	4000	4800	4000	4000
0.1 to 20	600	4000	400	200	1000	200	800	800
20.1 to 40	200	400	0	400	600	200	0	0

Table 11: Erosion cannel depth classes and its corresponding road lengths for individual farm roads in the watershed

Photo 9: Erosion cannel on the Pungshi Farm Roads

Balaygoan I and II have the maximum lengths of road section (7000m and 4800m respectively) with no erosion cannels, probably due to seasoned road surface and better drainage facilities (Table 11). The road sections on newly constructed farm roads are more severely eroded with higher frequencies of erosion cannels (Photo 7 &9).

5.5.1 Correlation between the Erosion Cannel Depth (ECD) and the Average Road Gradient (ARG)

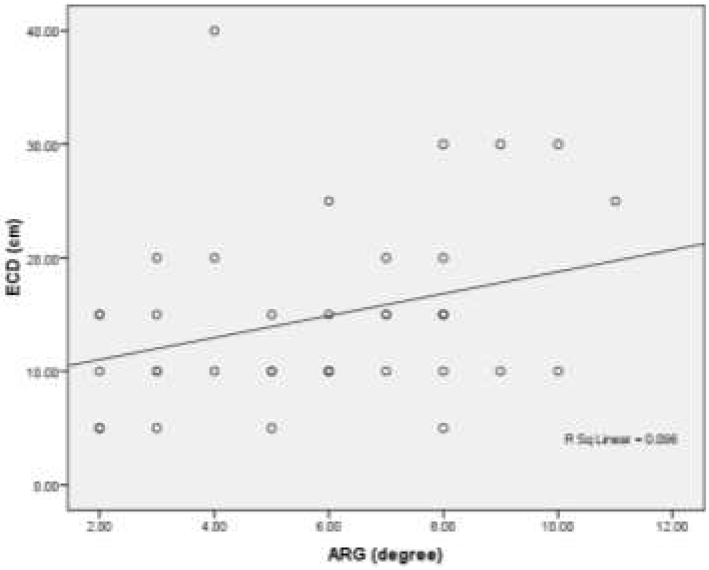


Figure 22: correlation between the Average Road Gradient and the Erosion Cannel Depths

Though weak, the erosion channel depth has a positive correlation with the average road gradient with r value of 0.31 at 0.05 significance level, indicating an increasing erosion channel depths with the increasing road gradient. The erosion channels above 30 cm depths are generally confined to road gradients above 8 degree but with lower frequencies. The frequencies of erosion channels are more at lower road gradients but with shallower depths (Figure 22).

The spatial distribution of the erosion cannel depths are illustrated in Figure 23.

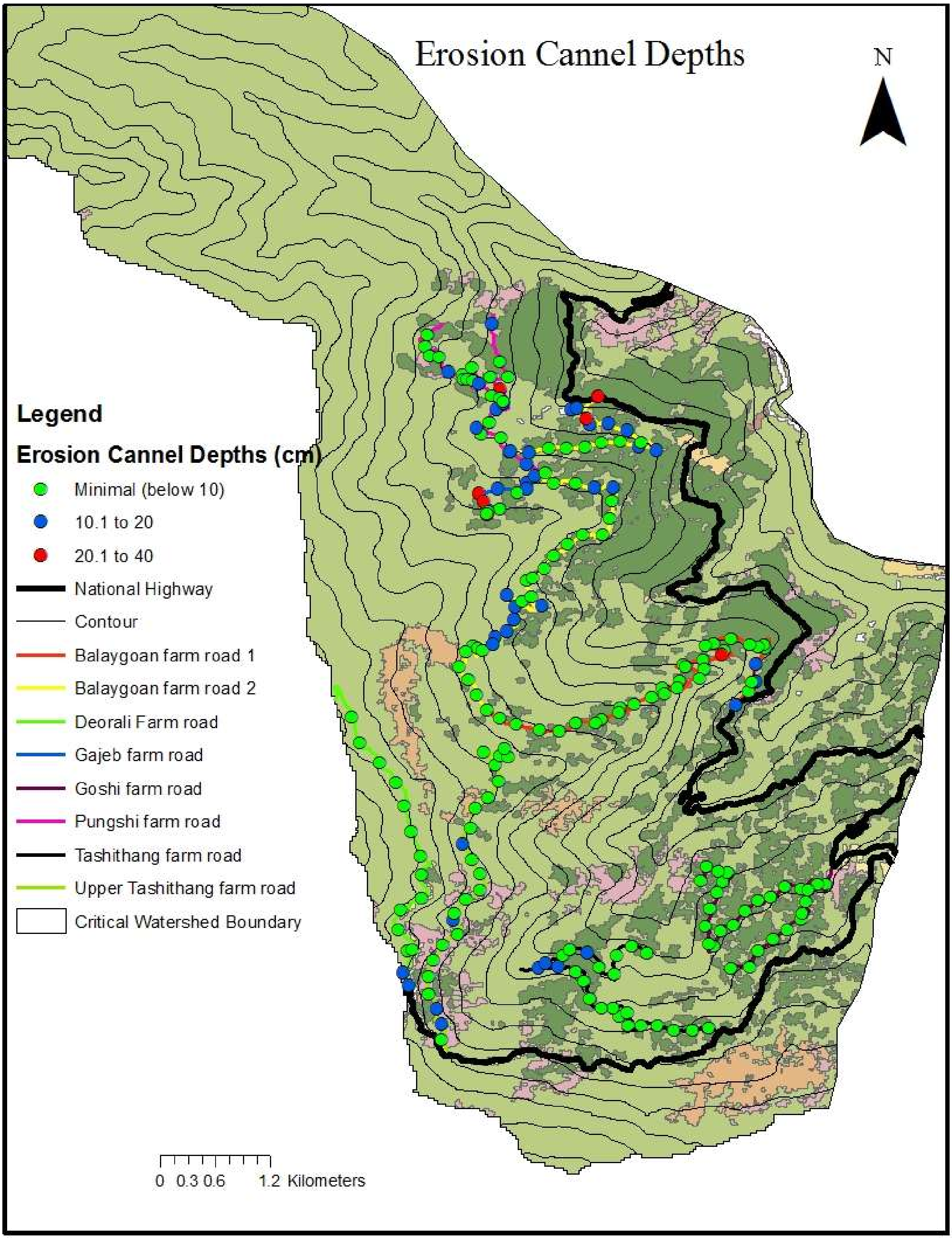


Figure 23: Map showing the spatial distribution of Erosion Cannel Depths for farm roads in the watershed

5.6 Fill Slope

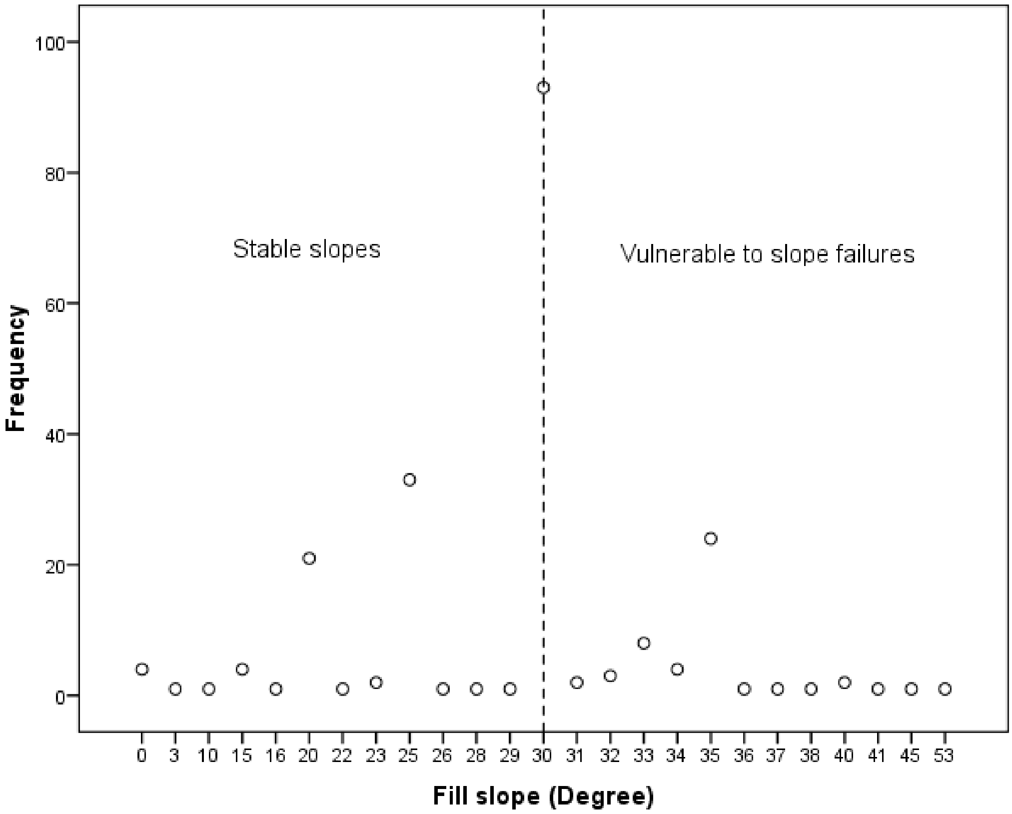


Figure 24: Graph showing frequency distribution of fill slopes of farm roads in the watershed

The mean value for the fill slope is 28.18 (±0.475) degree, with a maximum of 53 and minimum of 0 degree. Almost 77% (32 800m) of the total 42 600m of farm roads has fill slopes below 30 degree. Majority of the road lengths have fills slopes within the range of 21 to 30 degrees (Table 12). The steeper fill slopes are noticed especially on terrains which are steep (Figure 27). Also generally the higher fill slope has corresponding higher fill slope length which in turn increased with the increasing terrain slope. The downhill environmental impacts were observed to be more severe with the increasing fill slope and fill slope length. Since most of these fill slopes comprised of excavated materials that had been randomly deposited on the steep slopes by excavators without any retaining structures or biotechnical stabilization measures, occurrence of downward landslides and multiple cracks on the road edge were observed frequently along these road section (Photo 10). The technical knowledge of the excavator operators and the presence of engineers at the site during the excavation works will have a crucial impact on the competency of the work done in such steep terrains (Photo 12)

Fill slope classes	*Percentages*	*Length (m)*	*Cumulative %*
0 to 10	3	1200	3
10.1 to 20	12	5200	15
20.1 to 30	62	26400	77
30.1 to 40	22	9200	99
40.1 t0 50	1	400	100
50.1 to 60	0	200	

Table 12: Fill Slope classes and corresponding road lengths

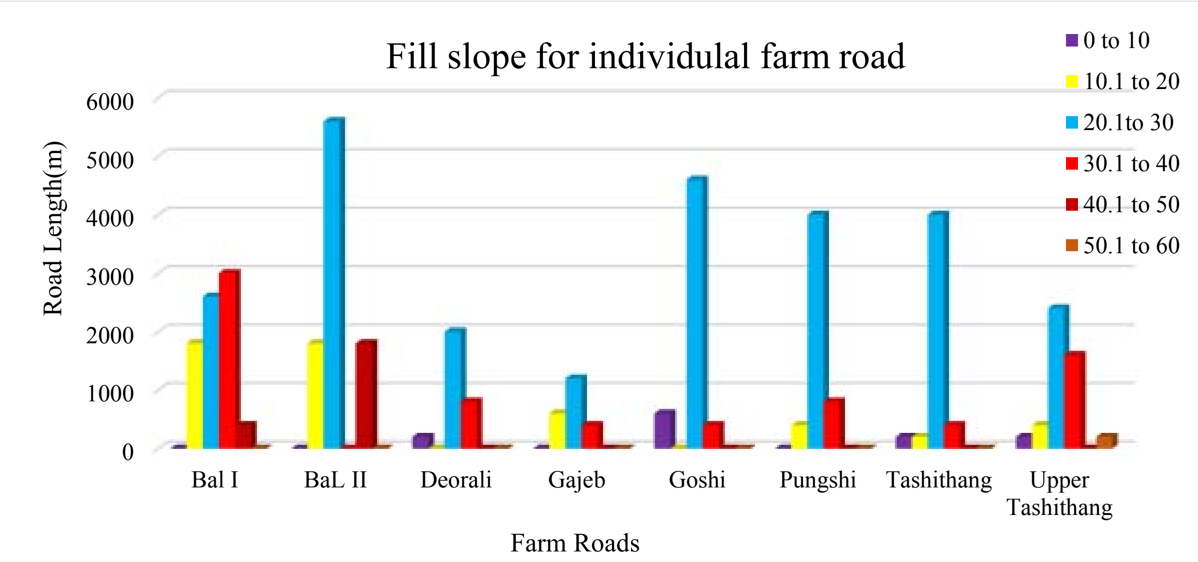


Figure 25: Bar Graph showing fill slope classes and corresponding road lengths for individual farm roads in the watershed

Slope Classes	Bal I	Bal II	Deorali	Gajeb	Goshi	Pungshi	Tashithang	Upper Tashithang
0 to 10	0	0	200	0	600	0	200	200
10.1 to 20	1800	1800	0	600	0	400	200	400
20.1to 30	2600	5600	2000	1200	4600	4000	4000	2400
30.1 to 40	3000	0	800	400	400	800	400	1600
40.1 to 50	400	1800	0	0	0	0	0	0
50.1 to 60	0	0	0	0	0	0	0	200

Table 13: Slope classes and the corresponding road length (m)

All of the farm roads have maximum proportion of road lengths with fill slopes ranging from 20 to 30 degree except for Balangaon I where the proportion of road length with 30 to 40 degree fill slope is relatively higher (Figure 25). However, it was observed that Upper Tashithang farm road has relatively more unstable fill slopes than other farm roads in the watershed, probably due to the terrain being too steep along major portions of the farm road (Figure 27). Also more vegetation destruction due to excess deposition of excavated materials on the downhill side of the road was observed in Upper Tashithang farm road.

5.6.1 Correlation between Average Terrain Slope (ATS) and the Fill Slope / Fill Slope Length

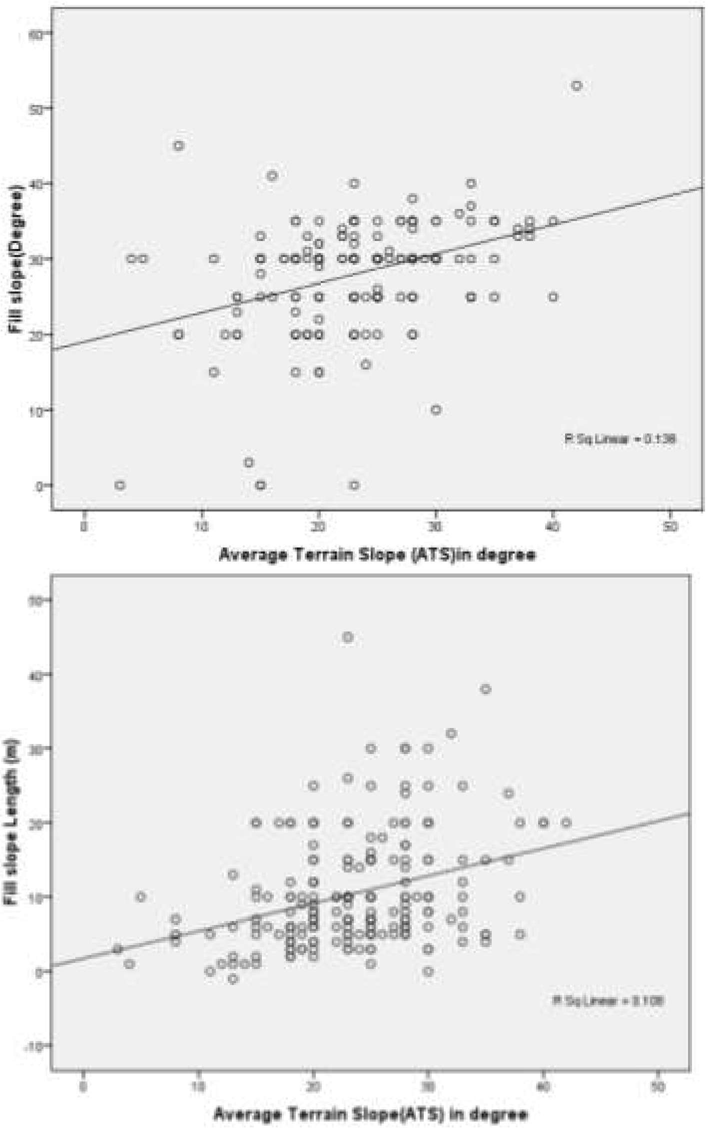


Figure 26:(above) Correlation between the Fill Slope and the Average Terrain Slope, (below) Correlation between Fill slope length and the Average Terrain Slope

A positive correlation (r =0.371) was found between the fill slope and the average terrain slope (Figure 26 above), with fill slope consistently increasing with the average terrain slope. Similarly a positive correlation (r=0.329) was also established between the fill slope length and the average terrain slope (Figure 26 below) with the fill slope length increasing consistently with the increasing average terrain slope.

However, the correlations in both the above cases was found to be weak. The increased fill slope length was mainly due to excessive deposition of excavated materials on the downhill side of the road. No excavated materials were transported even in full-bench cut system in steep terrain, probably due to high transportation cost that would incur if transported to dumping sites.

5.6.2 Fill Slope Stability and Quality

Photo 10: Arc shaped cracks indicating slope failures

Fill slope for older farm roads (Balagoan I & II) are relatively stable than the newly constructed ones. The fill slope of older farm roads are fairly well vegetated and compacted over time. However, the instances of fill slope failure was observed on both old as well as new farm roads. The major factors leading to fill slope failure were due to poor drainage of the runoff, which either seeped into or flowed over the fill slope eroding it considerably, bad road alignments ,ignorance of terrains conditions during road construction (swampy, moist, steep) and absence of stabilization measures. The arc shaped cracks on the road edge were observed frequently both in old as well as new farm roads of 3 to 10 meters length. The cracks on the road edge are good indications of soil erosions and fill slope failure in near future (Photo 10).

Fill slope			
Quality	**Frequency**	**Percent**	**Cumulative Percent**
Fully Vegetated	143	67.1	67.1
Partially vegetated	44	20.7	87.8
Not Vegetated	26	12.2	100
Total	213	100	

Table 14: Fill slope quality and its corresponding percentages

The quality of these fill slopes was assessed based on whether they were partially vegetated, fully vegetated or not vegetated at all. Approximately, 67% (28 500m) of road length has cut slopes fully vegetated. While 12.2% (5200m) of the road length has cut slopes not vegetated at all mostly so in the newly constructed farm roads (Table 14). Except for few locally made retaining walls (Photo 11), no other stabilization measures (vegetative or bio-technical stabilization) were taken along the entire sections of farm roads. In older farm roads, the stability of the fill slopes is entirely a work of nature where fill slopes have been adequately vegetated naturally (Photo 14).

Photo 11: Locally made retaining walls

Photo 12: Excavator at work

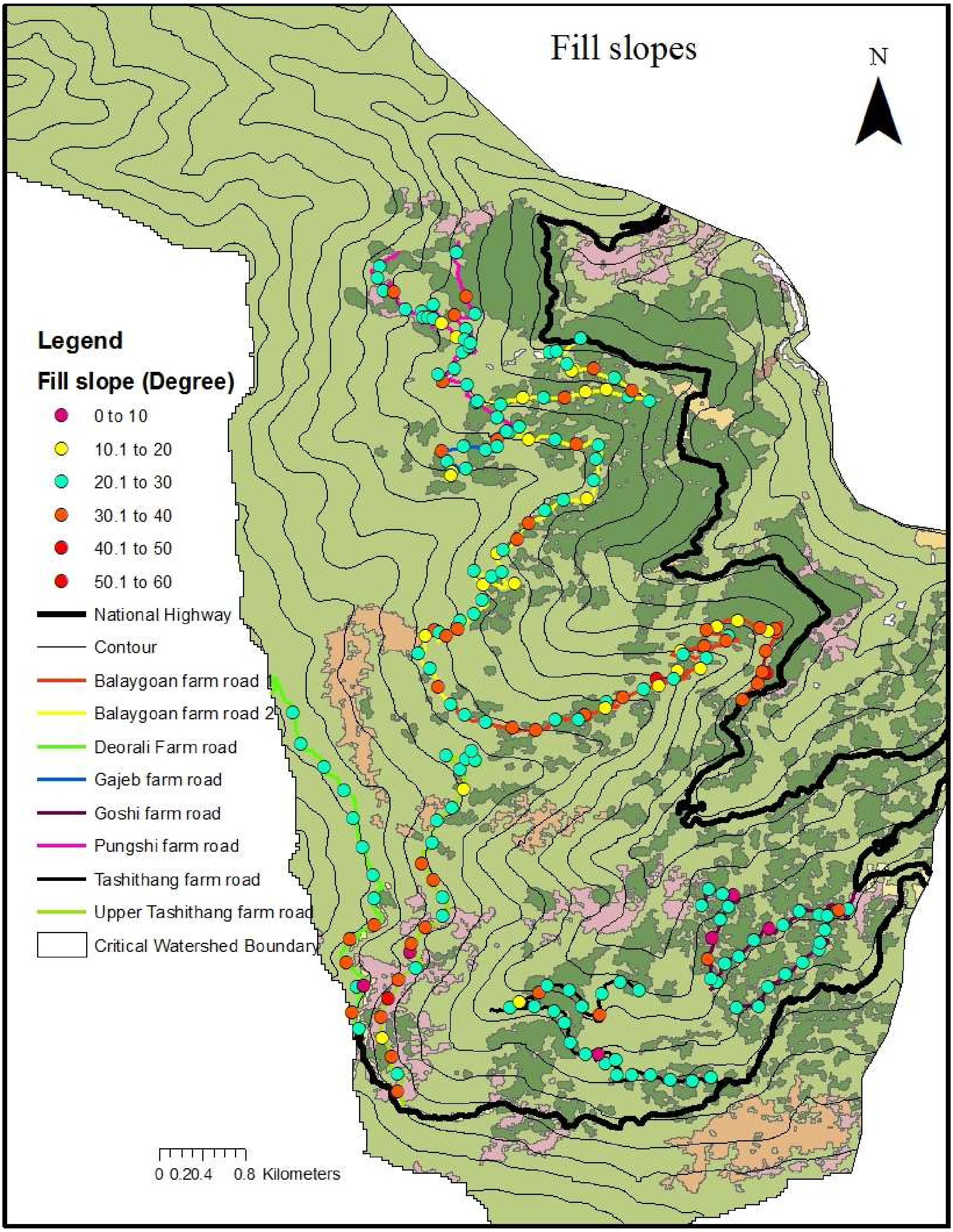


Figure 27: Map showing the spatial distribution of Fill slopes for farm roads in the watershed

5.7 Cut Slope

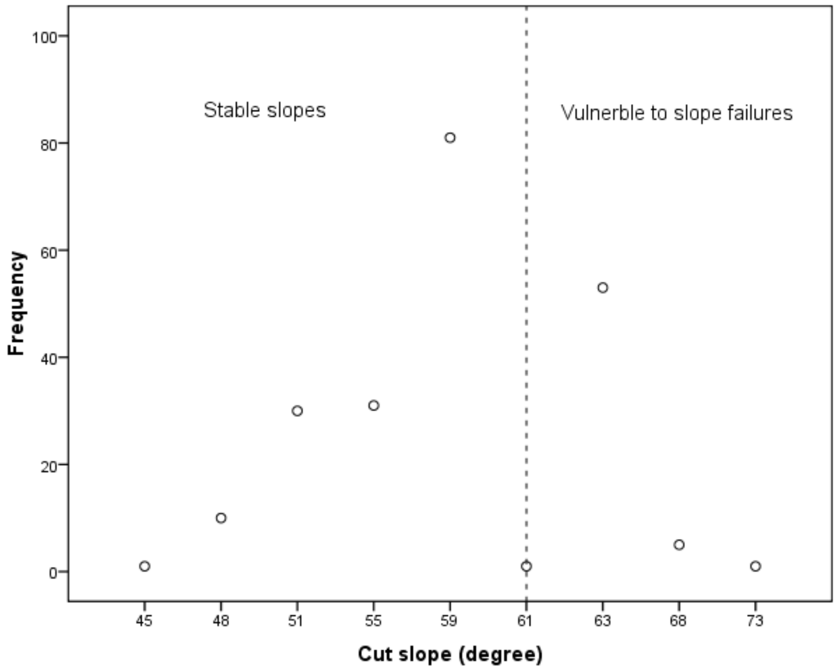


Figure 28: Graph showing the frequency distribution of cut slopes of farm roads in the watershed

The mean value for the cut slope is 57.99 (+/-0.339) degree, with a maximum of 73 and minimum of 45 degrees. Almost 70% (29 820m) of the total farm road length has cut slopes within the range of 45 to 60 degrees, which are relatively more stable. And 30% (12000m) of road length has cut slopes above 60 degree, which are more prone to slope failures (Table 15 & Figure 28). No potential correlation between the cut slope and the average terrain slope was established.

Figure 29: Bar Graph showing cut slope classes and the corresponding road length proportions for farm roads in the watershed

Slope classes	*Frequency*	*Length(m)*	*Percentage*	*cumulative percentage*
45 to 50	11	2200	5	5
50.1 to 55	61	12200	29	34
55.1 to 60	81	16200	38	72
60.1 to 65	54	10800	25	97
65.1 to 75	6	1200	3	100

Table 15: Cut slope classes and corresponding Road lengths for farm roads in the watershed

5.7.1 Cut Slope Stability and Quality

Photo 13: Erosion and road blocks due to cut slope failure

Cut slopes for old farm roads are fairly well vegetated compared to newly built farm roads. Thus, generally it was observed that cut slope for old farm roads are more stable than those of new farm roads. However, instances of cut slope failure was observed both in old as well as new farm roads (Photo 13). The most probable factors leading to cut slope failure are generally due to acute cut slope angles, deep and loose unstable soils on the cut slope, higher cut slope lengths especially on steep terrains and excessive runoff on the slope during rainy seasons in the absence of natural vegetation growth.

Cut slope			
Quality	**Frequency**	**Percent**	**Cumulative Percent**
Fully vegetated	143	67.1	67.1
Partially vegetated	47	22.1	89.2
Not vegetated	23	10.8	100
Total	213	100	

Table 16: Cut slope Quality and its corresponding percentages

As assessed for the fill slope, the quality of cut slope was also assessed based on whether they are partially vegetated, fully vegetated or not vegetated at all. Approximately, 67% (28 500m) of the farm road length has fully vegetated cut slopes while 11% of the road length has cut slopes not vegetated at all (Table 16). The proportion of road lengths with not vegetated cut slopes is higher in new farm roads than the old ones. Despite numerous instances of cut slope failures along the road sections, on both old and new farm roads, the roads lacked adequate cut slope stabilization measures. Except for few locally made retaining walls, the stabilization of the cut slope are left entirely to the natural processes, either by re-vegetation or the slope getting seasoned overtime on its own (Photo 14).

Photo 14: Naturally vegetated cut and fill slope

The slopes are taken over by grasses and shrubs naturally grown over the years, stabilizing the soil materials on the slopes. The natural vegetation on the slopes have well stabilized the soils and subsequently have reduced the instances of slope erosions along the older farm roads. The spatial distribution of cut slopes are illustrated in Figure 30.

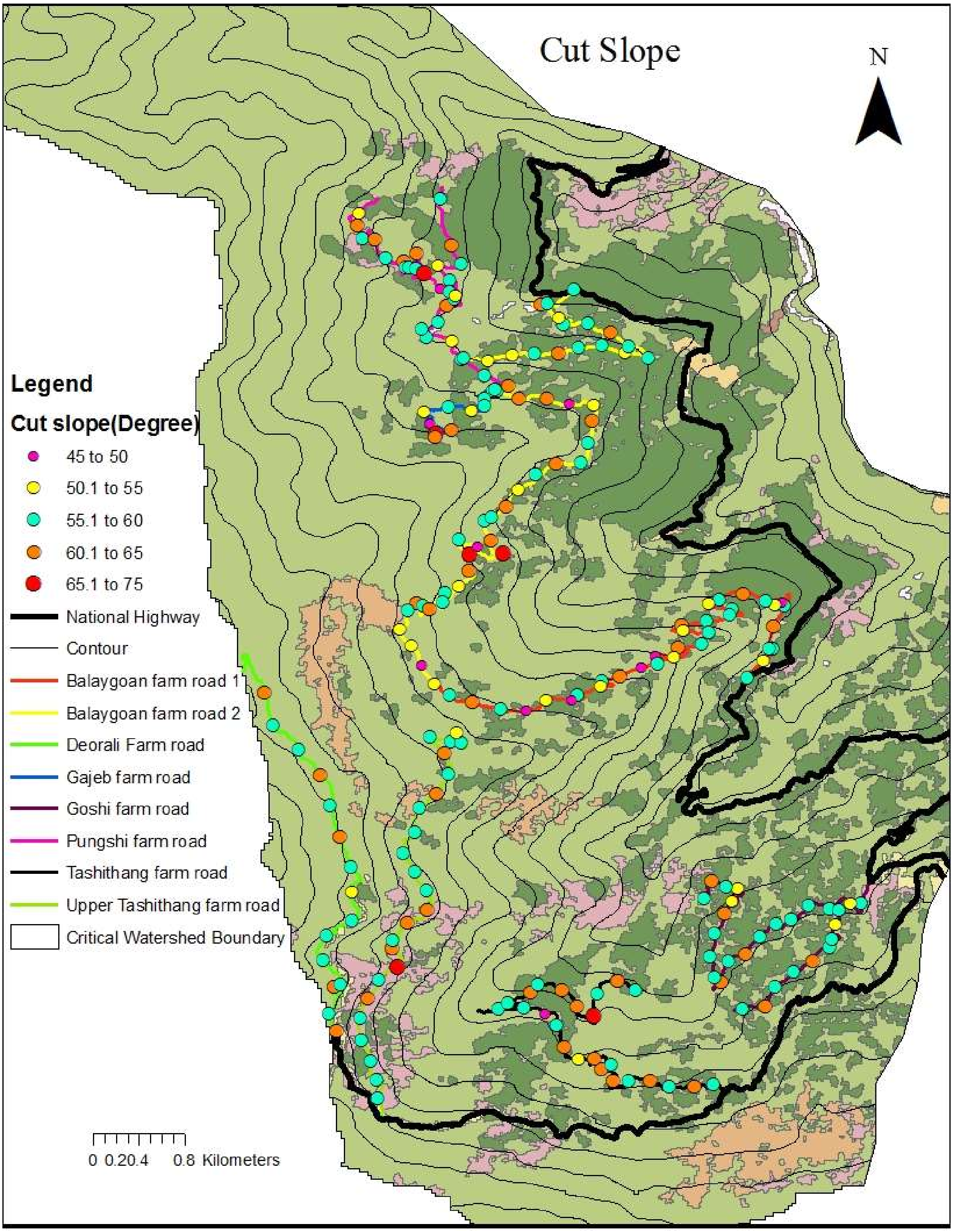


Figure 30: Map showing the spatial distribution of Cut Slope for farm roads in the watershed

5.8 Road Width.

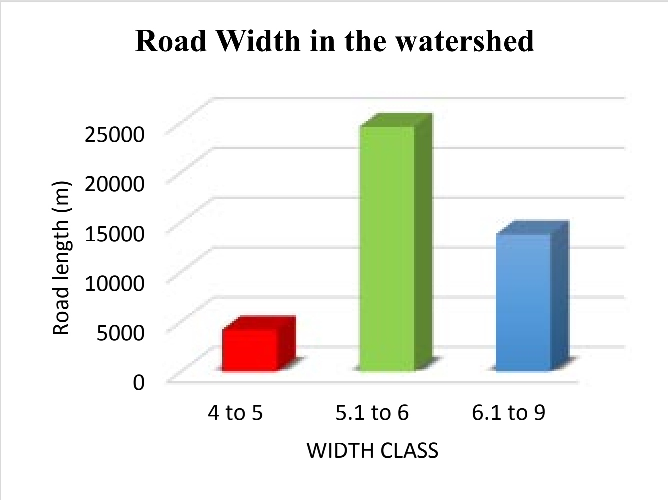


Figure 31: Bar Graph showing the Road Width classes and the corresponding road length

The farm roads in the watershed do not have uniform road widths but it varies randomly, depending on the terrain and the landscape. The mean road width of the farm roads in the watershed is 6 meters, with a maximum of 9 meters and a minimum of 4 meters. Approximately, 58% or 24 600 meters of farm roads have widths within the range of 5 to 6 meters, while less than 10% have road widths less than 5 meters (Table 17). It was also observed that wider road width were found in roads along steep terrains (Figure 33).

Width classes	*Frequency*	*Length (m)*	*Percent*	*Cumulative Percent*
4 to 5	21	4200	10	10
5.1 to 6	123	24600	58	68
6.1 to 9	69	13800	32	100
Total	213	42600	100	
			Maximum	9
			Minimum	4
			Mean	6.23

Table 17: Road width classes and the corresponding road length

Balaygoan 1 farm road has relatively narrower road widths, with maximum proportions of road lengths having 4 to 5 meters road width. Balaygoan 2 is relatively better than other farm roads in the watershed with almost 90% of the road lengths having 5.5 m road widths. Tashithang and upper Tashithang have relatively wider roads despite the steep terrains (Figure 32 & 33).

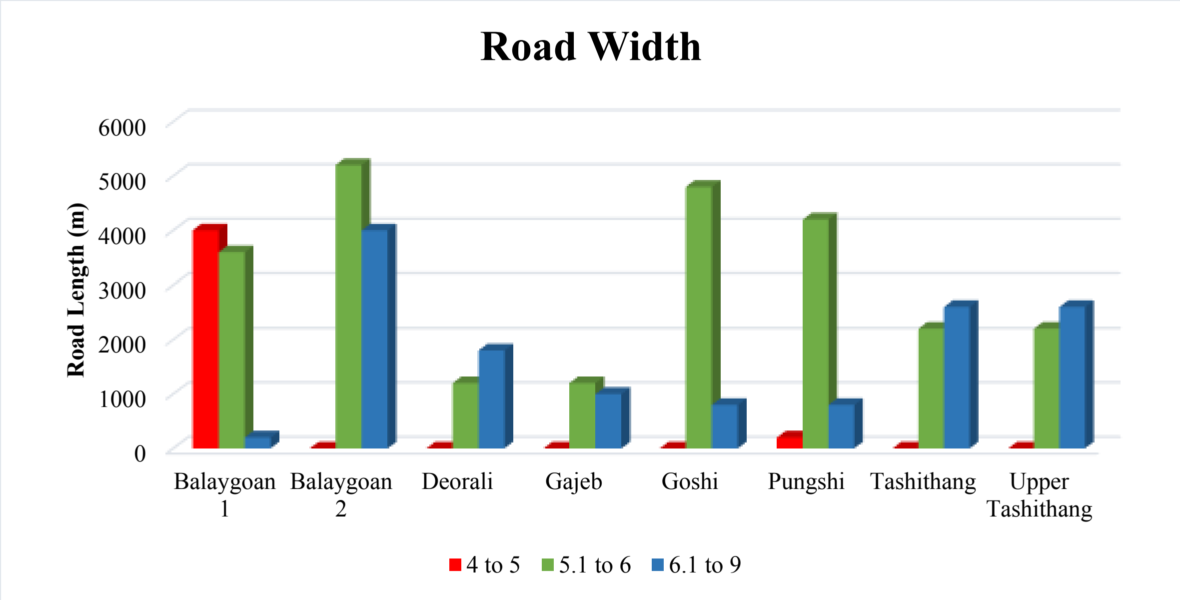


Figure 32: Bar graph showing the road width classes and its corresponding road lengths for individual farm roads in the watershed

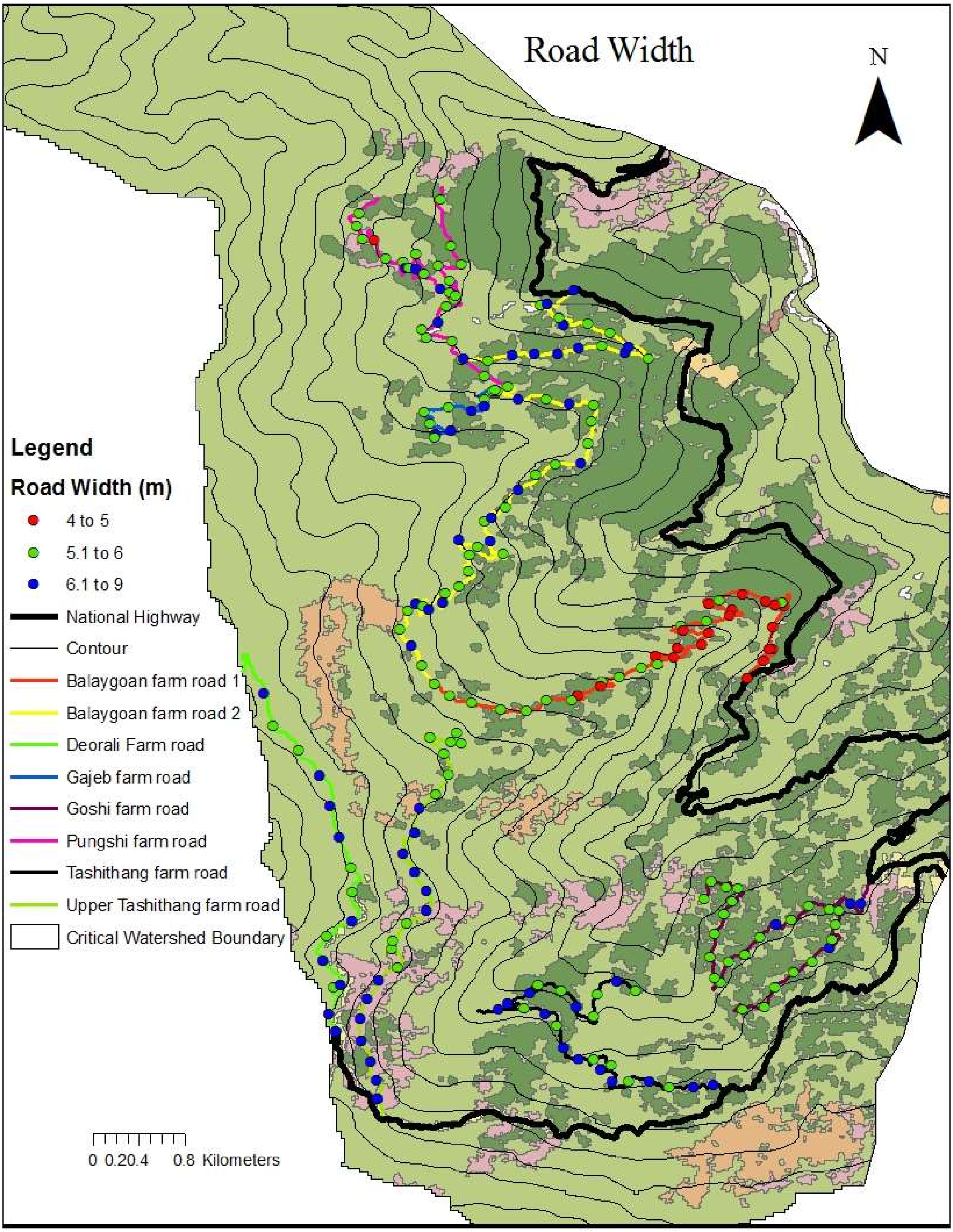


Figure 33: Map showing the spatial distribution of road widths in the watershed.

5.9 Terrain Utilization Above and Below the Farm Roads.

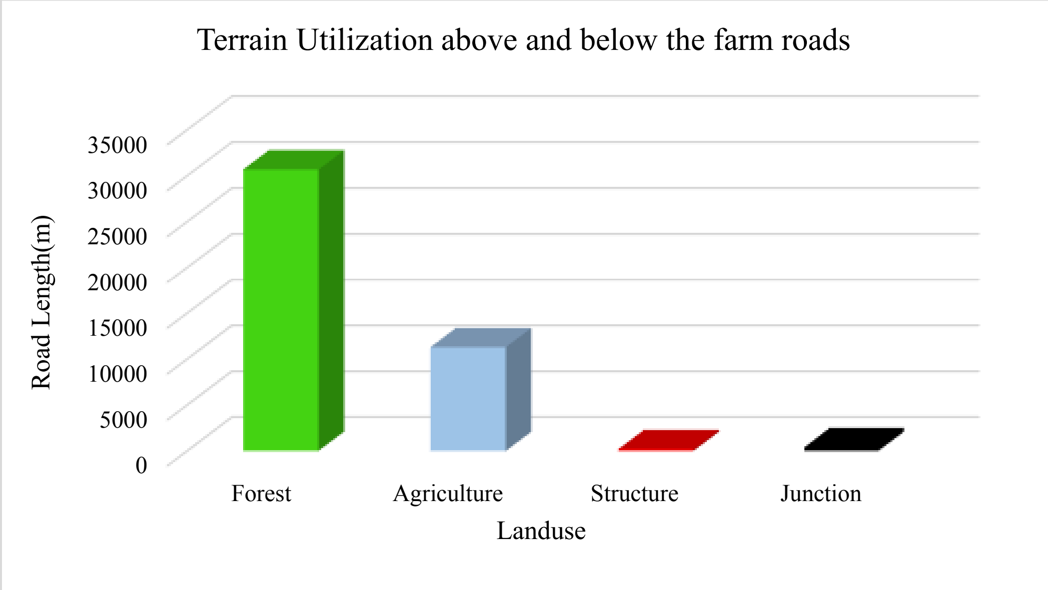


Figure 34: Bar Graph showing the road lengths and the corresponding terrain utilization above and below the farm roads

Land Use	Frequency	Length(m)	Percent
Forest	153	30700	72
Agriculture	57	11300	26
Structure	1	200	0
Road	2	400	1
Total	213	42600	100

Table 18: Road lengths and the corresponding terrain utilization above and below the farm roads in percentage

Almost 72% (30 700m) of the total farm road length in the watershed runs entirely through the government reserved forests, with only about 26% (11 300m) running within the agricultural land and village settlements (Figure 34). In case of Pungshi, Upper Tashithang and Deorali farm roads, almost 90% of the farm road length runs through the forests. While Goshi and Tashithang farm roads have relatively larger portion of their length passing through human settlements and agricultural lands (Figure 35). With 72% of the road lengths running through the forest, it seemed that the road alignments of most of the farm roads in the watershed were aligned by avoiding roads running through the private properties of the village settlements, probably to avoid the loss of private lands. Almost all of the forests in the watershed is broad leaved forests.

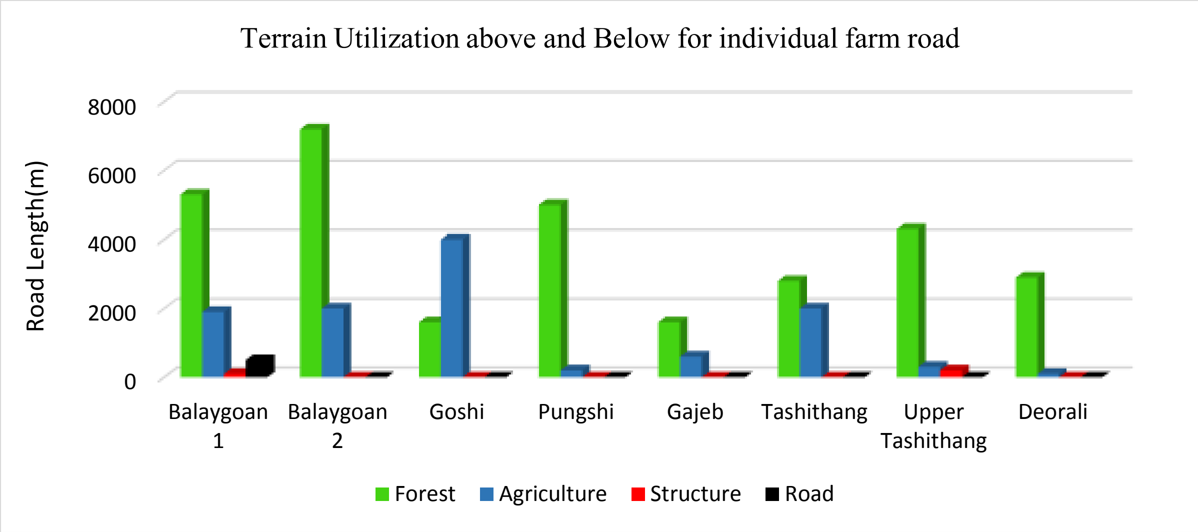


Figure 35: Bar Graph showing the road lengths and the corresponding terrain utilization above and below the individual farm roads in the watershed

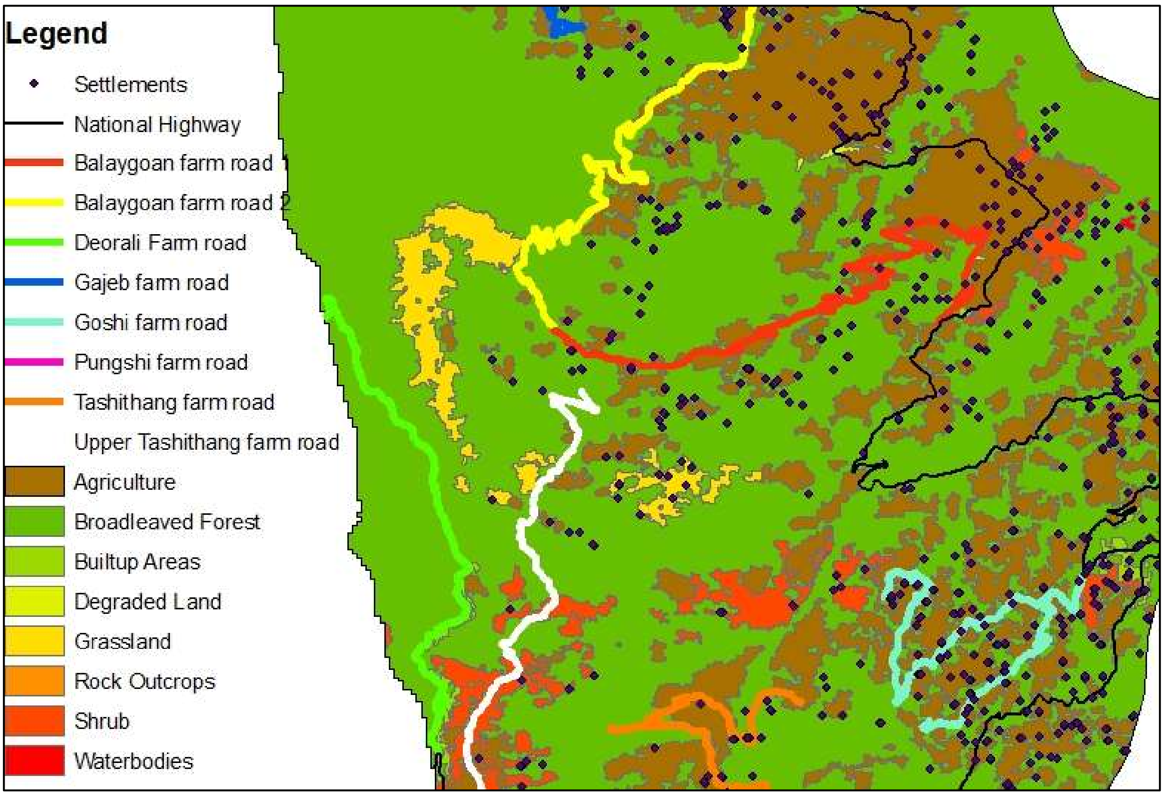


Figure 36: Spatial Distribution of Farm Roads and the Land use of Dagana Critical Watershed

5.10 Average Terrain Slope.

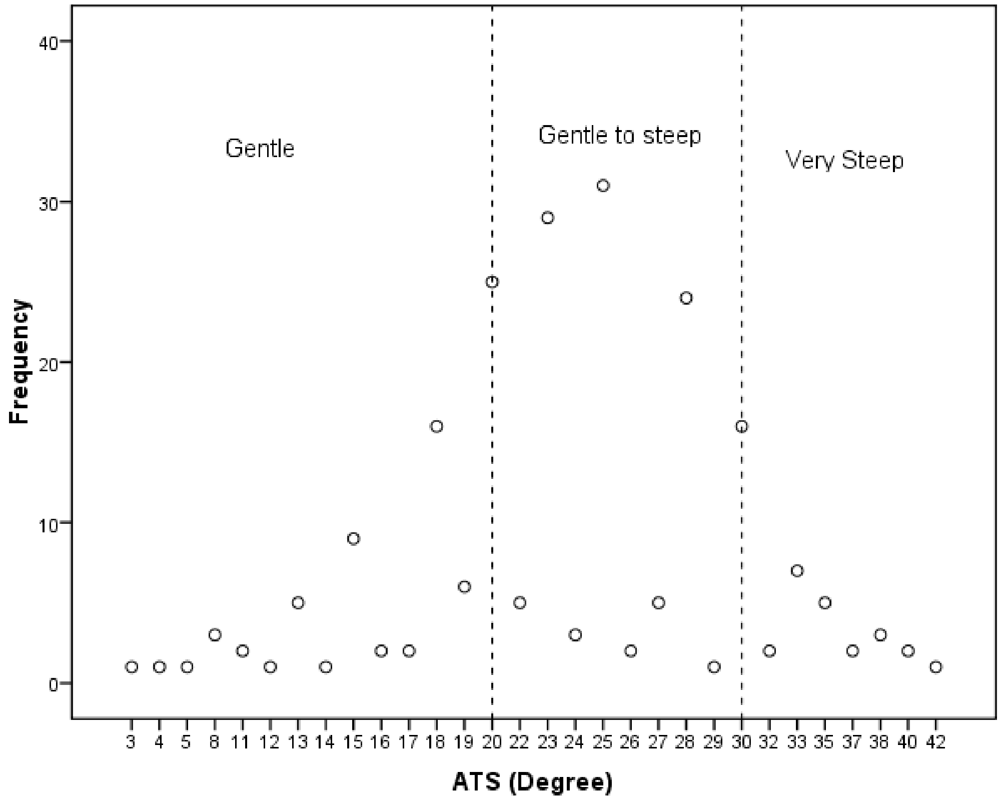


Figure 37: Graph showing the frequency distribution of average terrain slopes above and below the farm roads

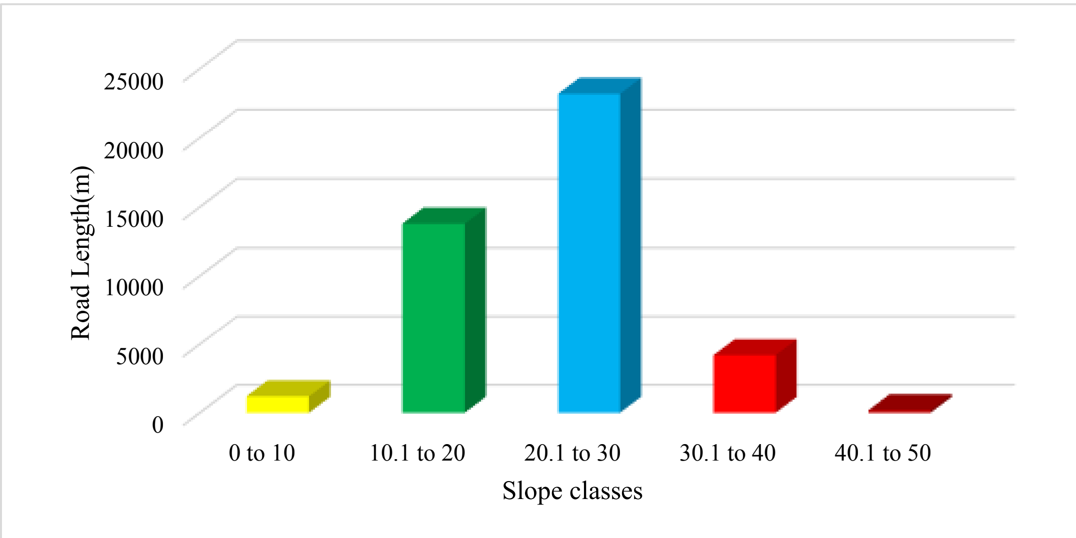


Figure 38:Bar Graph showing average terrain slope classes and its corresponding road length in the watershed

slope categories	Frequencies	Length(m)	Pecentage
0 to 10	6	1200	3
10.1 to 20	69	13800	32
20.1 to 30	116	23200	54
30.1 to 40	21	4200	10
40.1 to 50	1	200	0
Total	213	42600	100
		Maximum	42
		Minimum	3
		Mean	23.59

Table 19: Average terrain slope classes and its corresponding farm road lengths in percentage

Average terrain slope was calculated as the mean of terrain slope above and below the farm roads. The mean average terrain slope is 23.59 degree, with a maximum of 42 and a minimum of 3 degree. Almost 90% (38 200m) of the total road length runs through the terrain with slopes ranging from 0 to 30 degree, which can be classified as gentle to steep slopes. While the remaining 10% (4400m) of the farm road runs through the terrains with slopes more than 30 degree, which can be classified as very steep slopes in the context of Dagana Critical Waterhsed (Table 19 & Figure 37). The 10% or 4400m of road lengths which runs through terrains with very steep slopes is more vulnerable to erosions due to surface runoff.

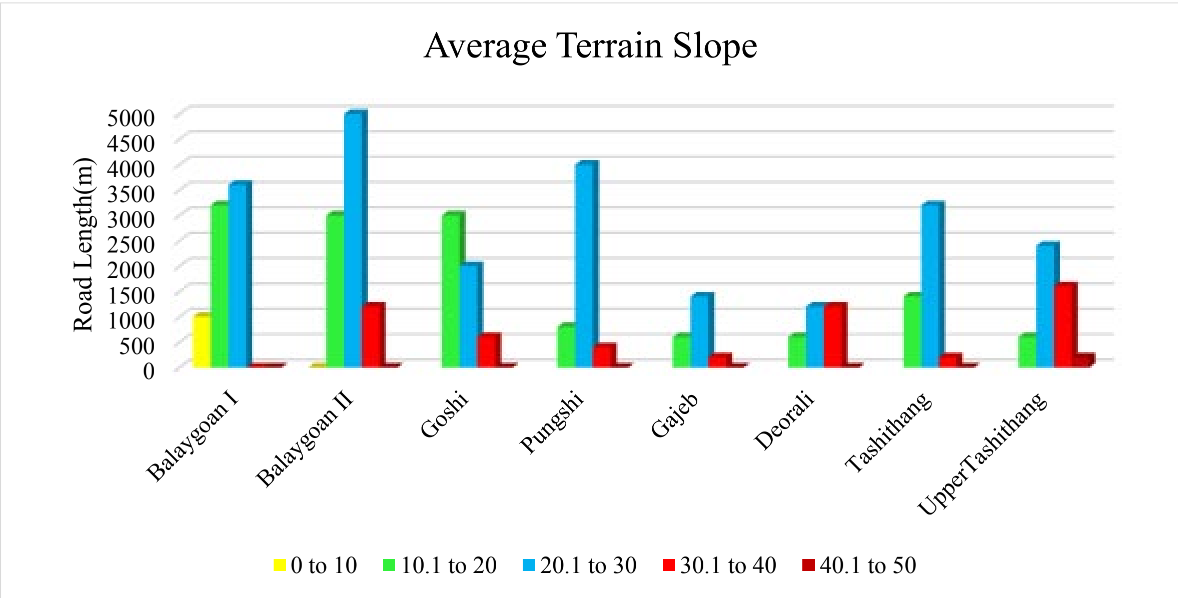


Figure 39: Bar Graph showing average terrain slope classes and its corresponding road length for individual farm roads in the watershed

The spatial distribution of the average terrain slope above and below the farm roads is illustrated in Figure: 40

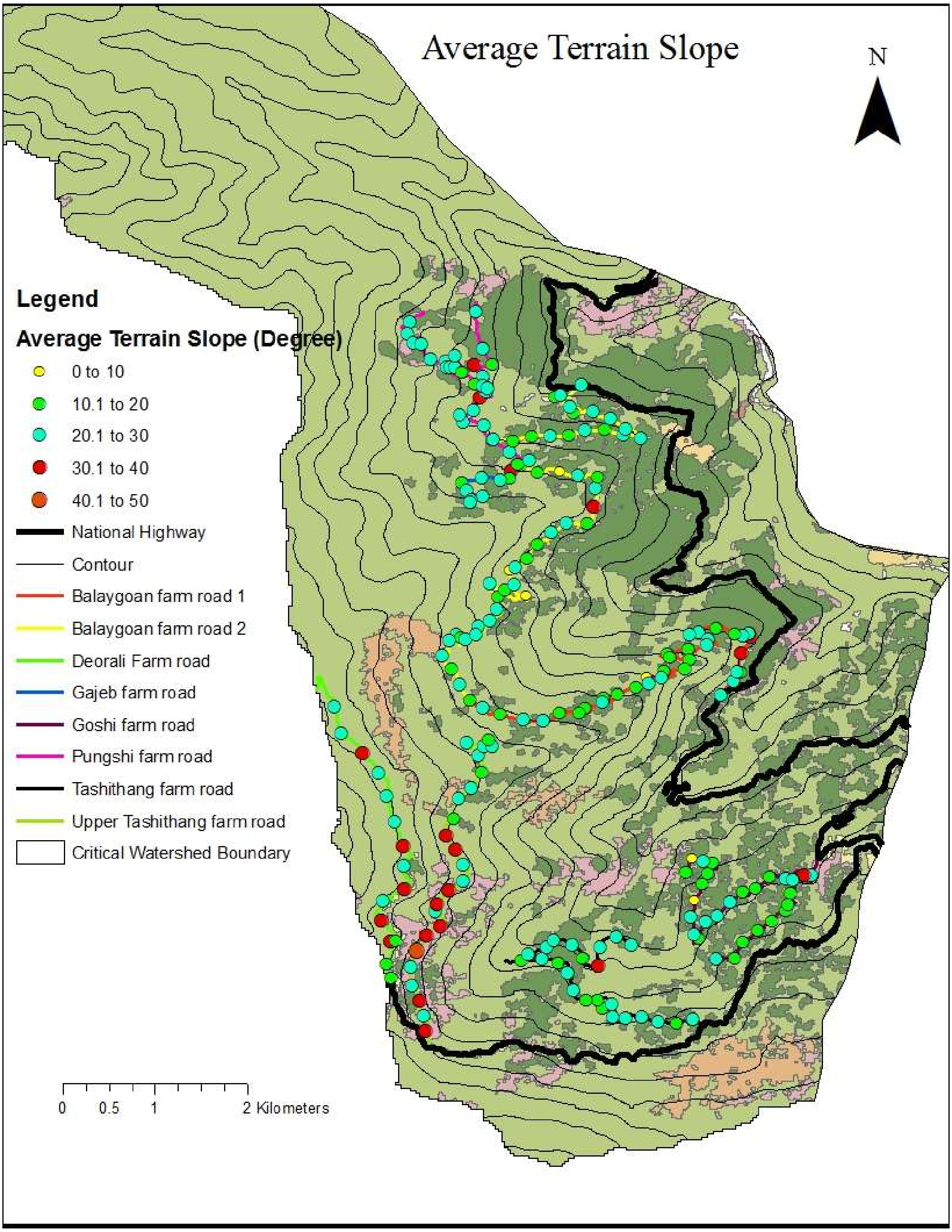


Figure 40: Map showing the spatial distribution of average terrain slope in the watershed

5.11 Curve Radius/Turns

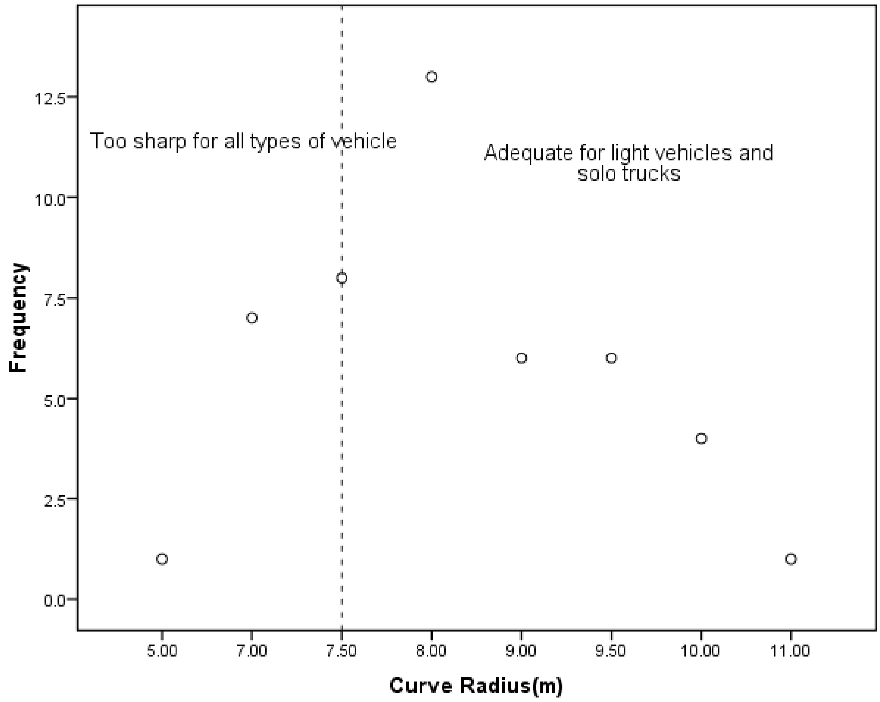


Figure 41: Graph showing the frequency distribution of curve radius for turns along the farm roads in the watershed

The turns (curves) in general should be long enough to allow a vehicle to negotiate the turn without bottoming out. Considering the average length of a solo truck, a turn with minimum curve radius of 8m is considered adequate for an easy turn. While for light vehicles, curve radius within the range 7.5 to 8m is considered adequate for an easy turn. Curve radius less than 7.5m radius is too sharp for all types of vehicles (CSFS 2011). For the 46 turns evaluated, the mean curve radius of the turns is 8.3m, with a maximum of 10.9m and minimum of 5.1 m. Almost 26% of the turns have curve radius ranging from 5 to 7.5m. Only about 74% of the turns have curve radius more than 7.5m (Table 20). Balaygoan I, Gajeb and Pungshi farm roads have relatively more number of acute turns with curve radius less than 7.5m. Almost all the farm roads have one or more turns with curve radius less than 7.5m radius, which are bottle necks for vehicle mobility unless modified and extended (Figure 44). The frequency distribution of turns with varying curve radius and its suitability for different vehicles is illustrated in figure 41.

Curve Radius Classes (m)	Frequency	Percentage	Cumulative%
5 to 7.5	12	26	26
7.51 to 8	8	17	43
8.1 to 11	26	57	100

Table 20: Table showing the curve radius classes and the corresponding percentages

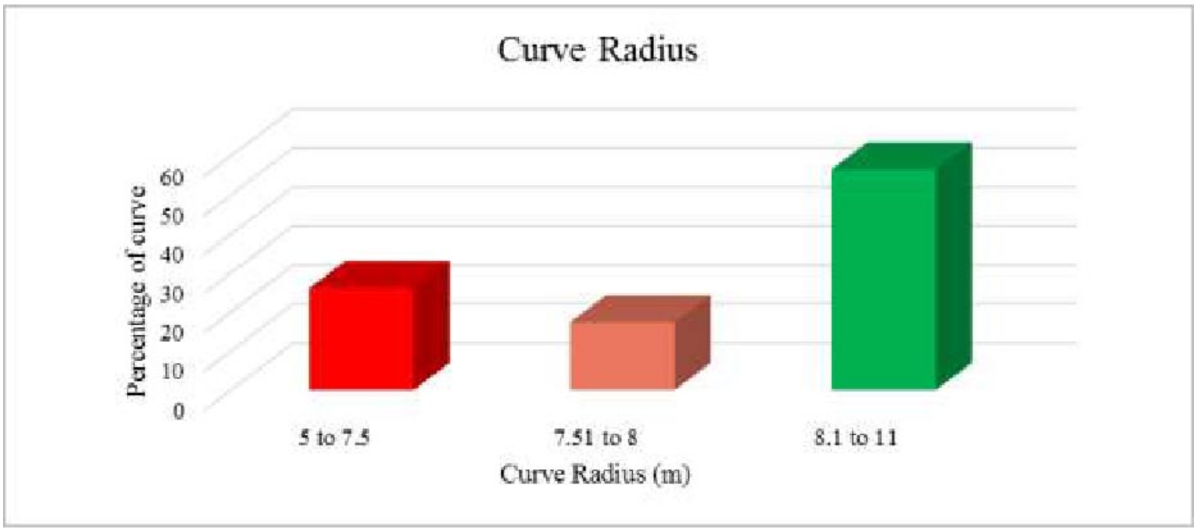


Figure 42: Bar Graph showing curve radius classes and the corresponding percentages

5.12 Turn Angle/ Deflection

Turning Angle classes	Frequency	Percentage	Cumulative%
130 to 145	10	22	22
145.1 to 160	12	26	48
160.1 to 180	24	52	100

Table 21: Turn angles classes and the corresponding percentages

Though the turn angles of the curves are strongly determined by the terrain of the landscape and the road alignment, it can be decided to a large extend during the initial road planning and ground reconnaissance survey. As far as the turn angles of the turns in Dagana critical watershed are concerned, the mean turn angle for the curves is 158.28 degree with a maximum of 180 degree and minimum of 133 degree. Of the 46 number of turns evaluated, almost 22% of the turns have turn angle less than 145 degree. While 78% of the turns have turn angles more than 145 degrees (Table 21). Balaygoan I and Pungshi farm roads have more number of turns with turn angles above 145 degree (Figure 45). It would be technically recommended for turns with turn angles more than 145 degree to have vehicle off-tracking site of minimum 2m wide for safer turns and sight distance (CSFS 2011).

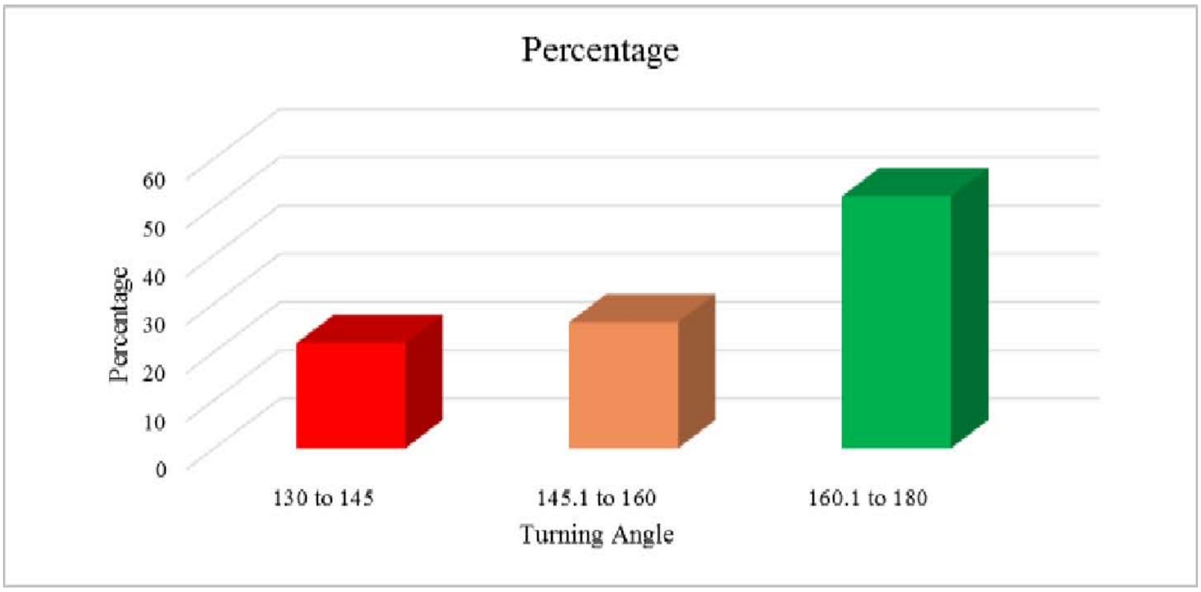


Figure 43: Bar Graph showing the turn angle classes and the corresponding percentages

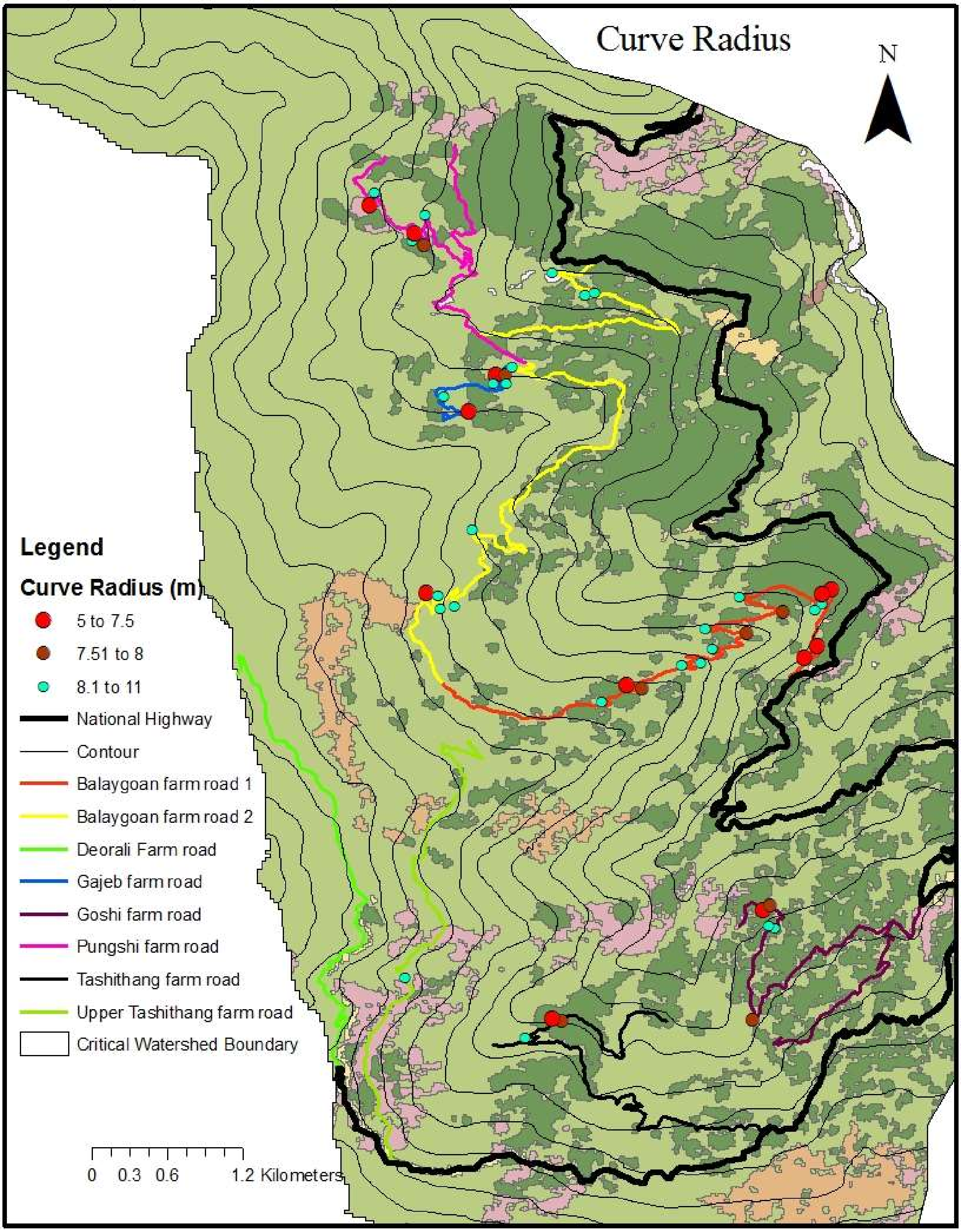


Figure 44: Map showing the spatial distribution of curve radius for the turns in the watershed

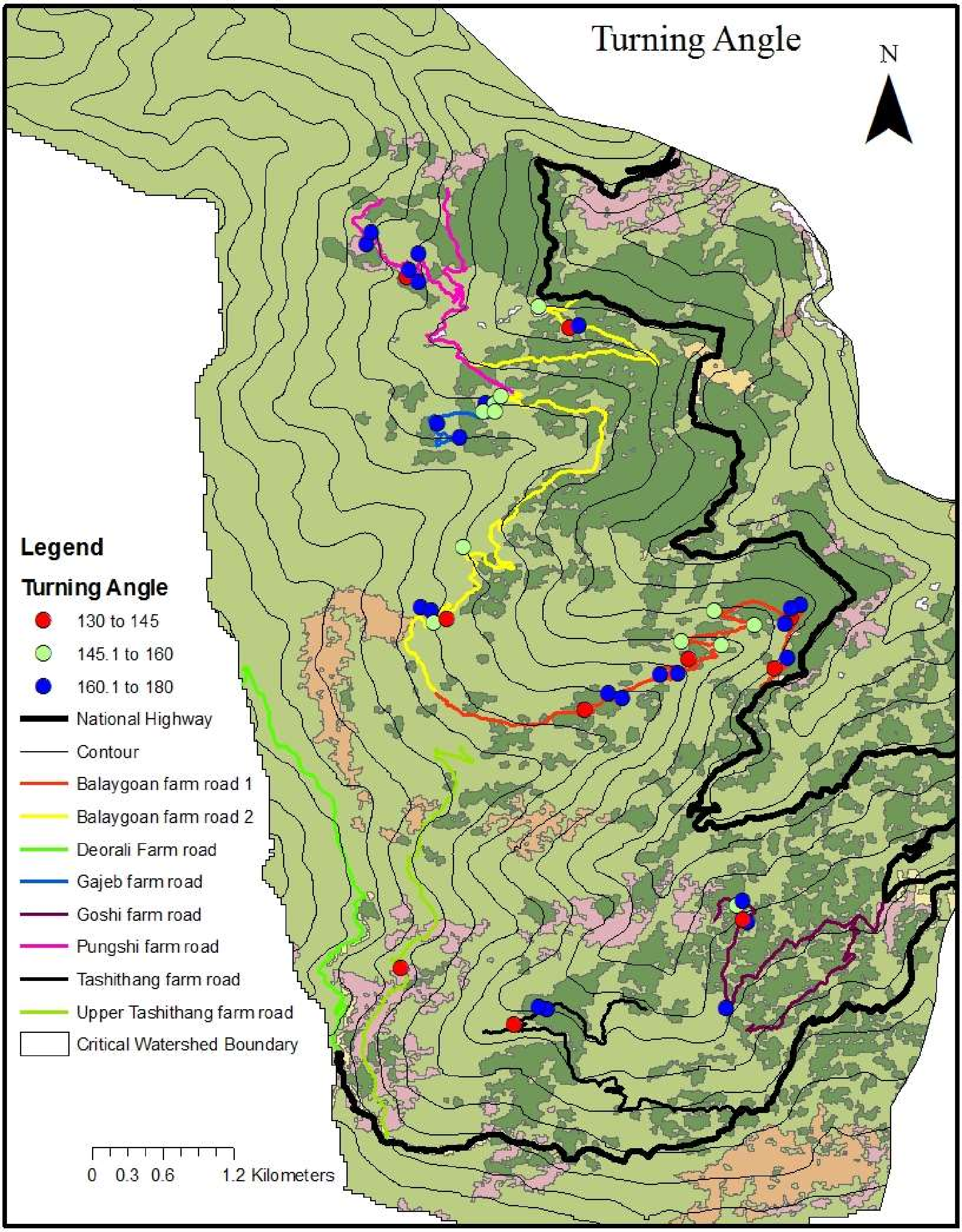


Figure 45: Map showing the spatial distribution of turn angle of the turns in the watershed

5.13 Road Connectivity

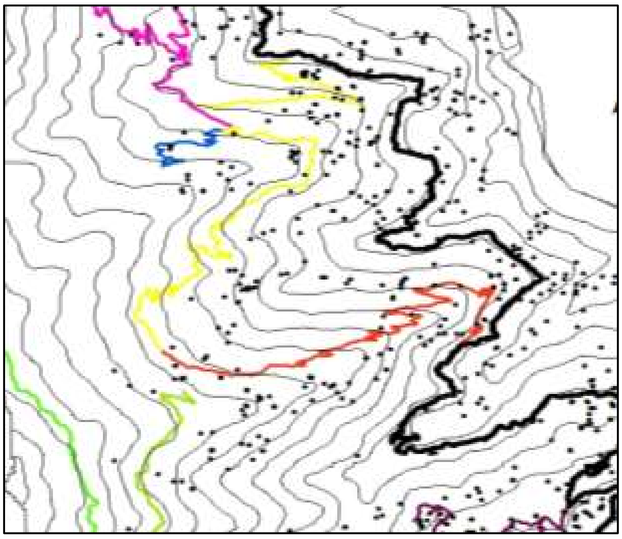


Figure 46: Spatial Distribution of Settlements in the watershed

A relatively dense network of farm roads with a total length of 42 600m has been constructed in the Dagana Critical Watershed in recent years. These roads have an average width of 6m and generally runs along the contours of the terrain, connecting and providing road access to almost all of the villages and households in the watershed. Also a total of approximately 25 500m of national highway runs through the watershed. Almost all of the farm roads takes off from the national highway at various locations within the watershed. Most of the settlements/ households in the watershed are confined within the vicinity of the national high way. The number of households decreases with the increasing distance from the highway with almost no settlements towards the ridge and bottom of the valley (Figure 46). The only Chiwog without farm roads in the watershed is Lower Gozhi. Taking into account both the national highways and the farm road networks in the watershed, the mean aerial distance from the nearest road heads to households in the watershed is 190m with a maximum of 960m and a minimum of 0.015 m. The road density in the watershed is about 10.6m/ha (Table: 22).

Total Number of households	**905**
Minimum distance to nearest road head	roadside
Maximum distance to nearest road head	960m
Mean distance to nearest road head	190m
Road Density	10.6 m/ha

Table 22: Road connectivity statistics

However the assessment of road density was done excluding the power lines roads that are constructed in the watershed in recent times by the Bhutan Power Corporation to transport materials of transmission lines to various spots in the watershed. The power lines road are temporary roads usually away from the settlements and abandoned after the construction of the transmission lines. The power line roads will have some impact on the road density in the watershed but not considerably.

5.14 Social Utility of the Farm Roads

Farm roads	Road length (m)/household
Bal I	39
Bal II	45
Deorali	3000
Gajeb	138
Tashithang	40
Upper Tashithang	109
Goshi	23
Pungshi	133

Table 23: Road length per unit households

The change in number of households in the buffer strips for individual farm roads due to buffering effects of the adjacent farm roads is presented in the Figure 47 & 48. Abrupt decrease in the number of households within the buffer strips due to buffer effects of adjacent farm roads was observed in almost all the farm roads. Maximum decrease in the household numbers was observed in case of Gajeb, Pungshi and Deorali farm roads. Subsequently, road length per unit households for individual farm roads was calculated after considering buffering effects (Table 23). Higher the road length per unit households, lower is its social utility and vice verssa. Deorali farm road has the highest road lengths per unit households with 3000m/household and Goshi has the lowest with 23m/household. Thus, Deorali farm road has the least and Goshi farm road has the highest social utility. Also Punghi, Upper Tashithang and Gajeb farm roads have relatively higher road length per unit households compared to Balaygoan I, II and Tashithang farm roads (Table 23). All of these farm roads have a decreasing number of households in subsequent buffers with increasing distance from the road head (Figure 49).

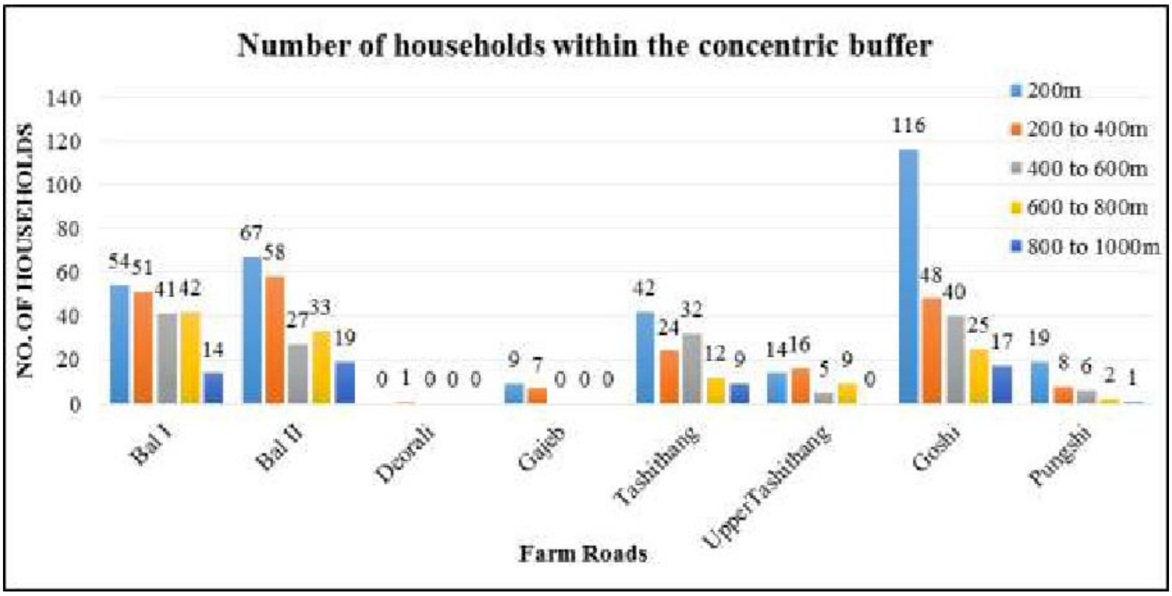


Figure 47:Bar Graph showing number of households within different buffer of individual farm road considering the buffering effects of the adjacent farm roads.

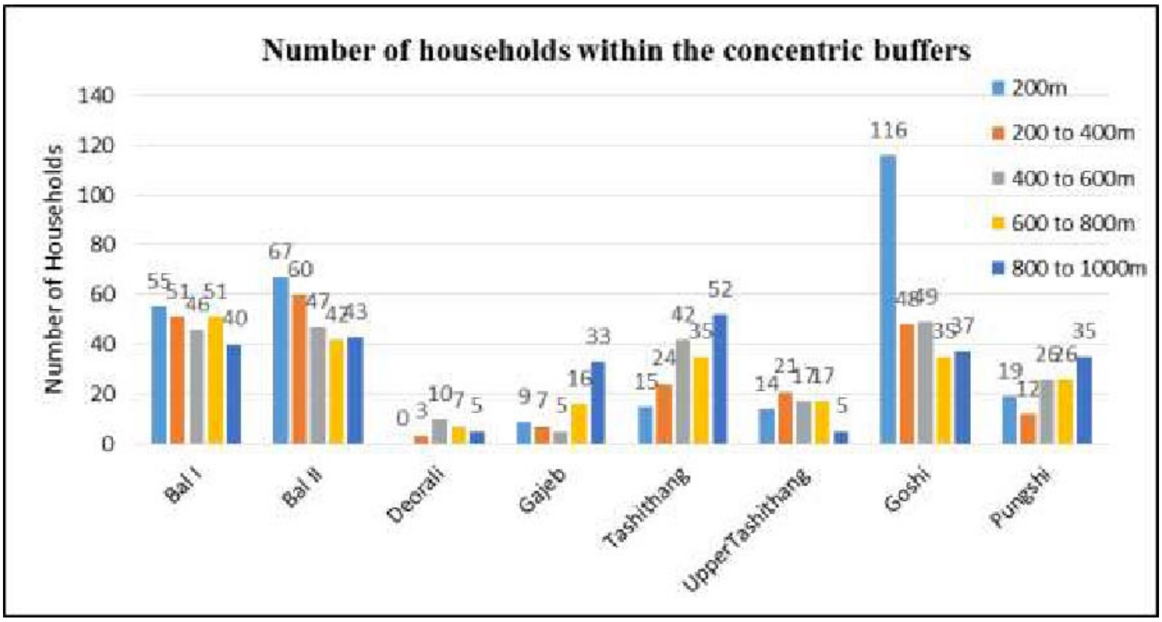


Figure 48:Bar Graph showing number of households within different buffer of individual farm road without considering the buffering effects of the adjacent farm roads.

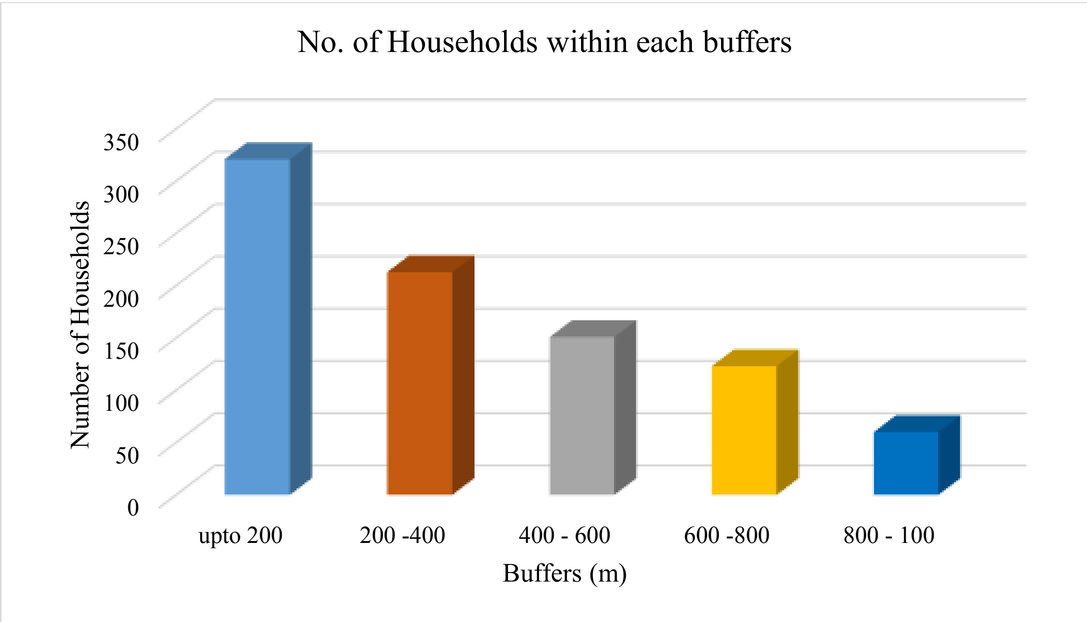
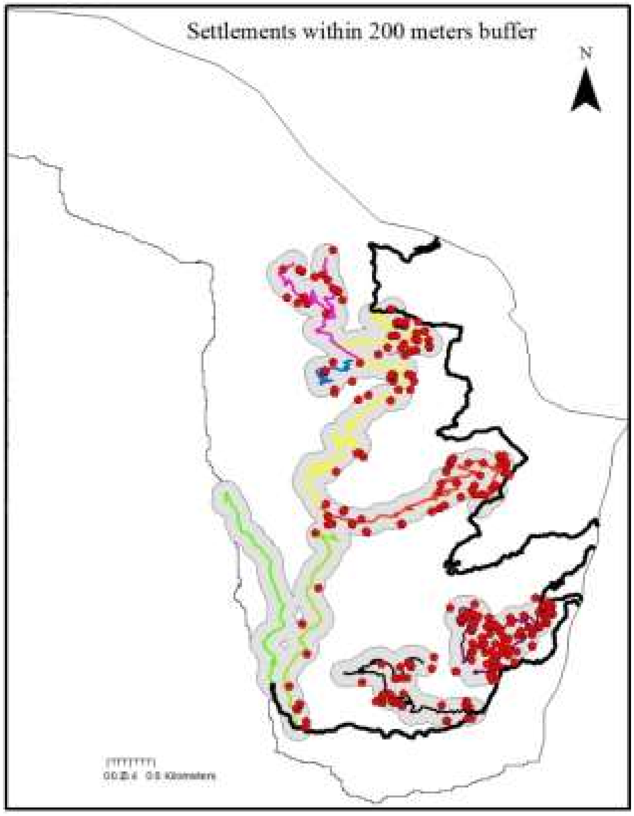
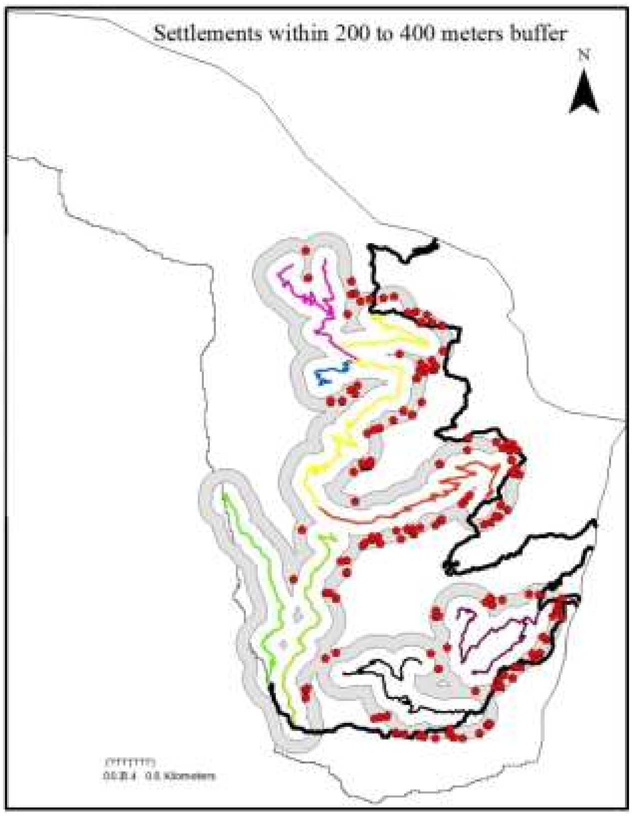


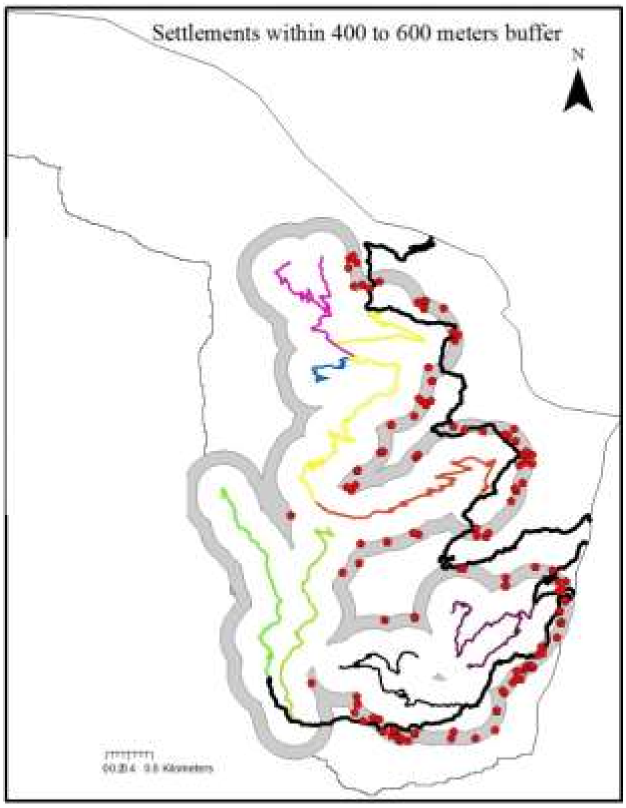
Figure 49: Bar graph showing number of households within each buffer widths



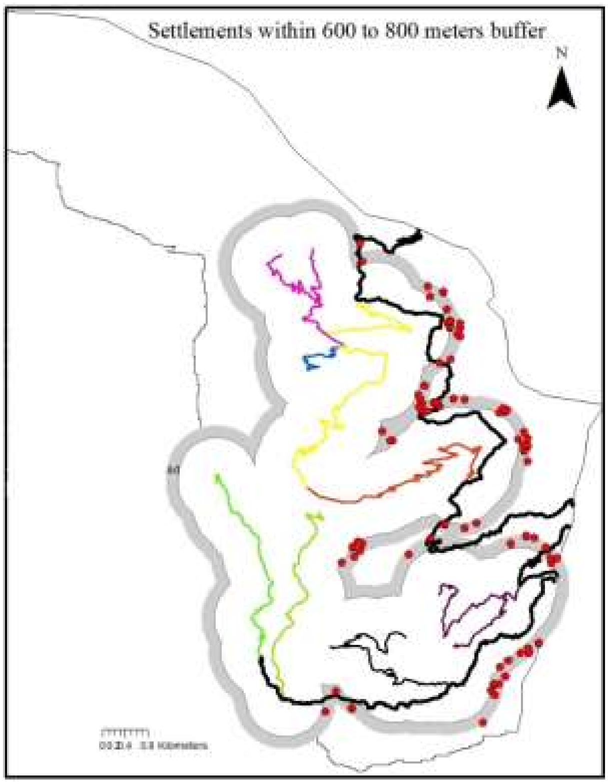
Settlements within 200m buffer



Settlement within 200-400m buffer



Settlement within 400-600m buffer



Settlements within 600-800m buffer

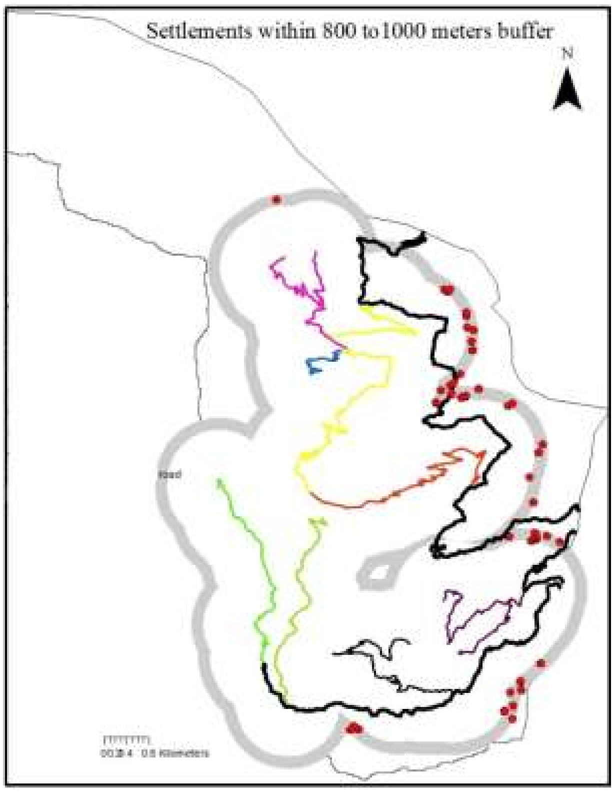


Fig: Settlements within 800-1000m buffer

Fig: Settlements outside 1000m buffer

Figure 50: Spatial distribution of settlements within different buffers

6 Discussion

6.1 Road Gradient, Road Pavement and the Erosion Cannels.

Road grade is generally classified as a flat grade for 0 to 1 %, a gentle to moderate grade for 2 to 8 %, steep grade for 9-12% and very steep grade for 12% and above (CSFS 2011). Maintenance of roads with gentle gradients are the easiest, provided the slope is adequate to drain out the water from the road surface. Generally, a minimum of 3% gradient is necessarily required for any road surface to avoid water stagnation and saturation of the subgrade soils.(Sessions 2007). Unstable surface course, formation of ruts and pot holes on the road surface are basically the results of saturated subgrade in combination with heavy traffics. Although steeper road gradients assist in easy and fast removal of water from the road surface, it too facilitates the water to generate more erosive power and greater surface erosions which necessitates for stabilization measures to prevent the erosions. A gradient more than 12% is not recommended for farm roads. Also road pavement is a structural system that contributes towards good road surface for the vehicles. It basically consists of a layer of surface course, a layer of base course laid on top of the prepared subgrade soil (CSFS 2011).

Farm roads in Dagana critical watershed have road gradients ranging from 0 to 19%, with an average of 9%. Only about 26 800m of the total road length in the watershed have road gradients within the range of 3- 12%, which can be classified as gentle to steep gradients. About 9200 m of the road lengths have gradient more than 12% and 6600m of the road length have gradients less than 3% slope, which can be classified as very steep and flat gradients respectively (Table 6). Specifically, Balaygoan I, Balaygoan II, Pungshi and Gajeb farm roads have relatively more portions of road sections with road gradients more than 12%. While Goshi and Upper Tashithang have relatively more portions of road sections with gradients less than 3% (Figure 11). With regards to the road pavements, except for parts of few old farm roads, almost all of the farm roads lack adequate road pavements. Most of the road, specially the newly built, are left to be used with bare subgrade soils after initial excavation works.

The road lengths with flat and very steep gradients are detrimental to environmental impacts on the surrounding environments in the watershed besides hampering the overall road quality. Some of the major problems associated with very steep sections of roads were frequent cut slope and fill slope failures (Photo 13), excessive road surface erosions (Photo 8) and deep erosion cannels (photo 7). Bare subgrade soil without surface and base course layers in combination with steep grades, considerably accelerated the erosion rates and are the major source of sediments (Photo 9).On flat grades, the major problems were water stagnation, deteriorating the subgrade and leading to development of ruts which severely deterred the road surface quality (Photo 3). The ruts thus formed are also a major source of sediments for downstream sedimentation (Brink, Slate et al.) Subsequently, these sections of road are bottle necks which are detrimental to road functionality and environmental impacts.

To elaborate more on the erosion cannels in the watershed, the mean depth of erosion cannels along the farm roads is 15 cm (+/-3cm) with a maximum of 40cm. About 81% of the farm road length has no or minimal erosion cannel depth, while about 19% of the total length have erosion cannels with maximum depth of 40 cm (Table 10).Statistically, a positive correlation was established between the erosion cannel depths and the average road gradients with r value of 0.31 at 0.05 significance level, indicating an increasing erosion channel depth with the increasing road gradient, however without any strong positive correlation. Thus, the sections of road which have gradient above 12% classified as very steep road, approximately 9200m in length, will be and has been subjected to more road surface erosions due to runoff in monsoon seasons .Similar findings were reported by Ziegler, Giambelluca et al. (2004). The increased surface erosion in turn will cause more downstream sedimentation in the watershed, adversely hampering the aquatic ecosystem due to increased turbidity of the stream water (Forman and Alexander 1998).

6.2 Water Cannels

Drainage basically refers to the removal of intercepted and collected water from the road pavement either on the upslope or downslope side of the road. A good drainage involves methods that controls and prevents damage to the road by any surface or intercepted water (Nunamaker 2007). The main objective of a good road drainage is to maintain the slope stability and cause as minimal change in the natural pattern of a terrain as far as possible by intercepting water on the upslope side and discharging it on the downslope side (Brink, Slate et al.). This objective of the drainage is achieved through frequent interception of the rain water and effective discharge of the intercepted water. A good drainage infrastructure for a road networks basically consists of proper road surface grading, ditches, culverts and fords at appropriate sites. These are considered as typical drainage provisions in road constructions. The basic principles while developing road drainage facilities is to ensure that the natural hydrological pattern of the landscape is disturbed as minimal as possible. (Fannin and Lorbach 2007). Side drain or ditches runs parallel to the road length on the cut slope side which drain water from the road surface and adjoining slopes (Brink, Slate et al.), thus avoiding the formation of gullies and erosion cannels on the road surface which if not checked would render the road unpliable on a long run. They are used for suitable discharge of the accumulated water. The shape, size and the longitudinal gradient of the cannel will depend upon the runoff volume and the locally generated velocity of the water (Fannin and Lorbach 2007). Road drainage is one of the most important infrastructural elements in road construction that helps sustain the road in long run (Kocher 2007). Usually grading the pavement either as in-sloped, out sloped or crowned helps improve the surface runoff (Fannin and Lorbach 2007).

Dagana critical watershed is located in the East Himalayan tropical zone with annual precipitation ranging from 1765.5 mm to 2019.1mm (Meteorological stations, Dagana). Given the high annual precipitation, proper drainage facilities for any kind of roads in the watershed is a necessity, both for long term sustainability of the roads and minimal environmental impacts on the surrounding environments. However, the farm roads in the watershed substantially lacks drainage facilities, with about 30% (12 600m) of the farm road length having no side drains/water channels at all (Table 9). The existing water channels are seen only in portion of old farm roads, with majority of the newly constructed farm roads lacking it (Figure 20). Most of the existing water channels are defunct due to blockages caused by debris deposited from the previous monsoons. The result being runoff water running stray on the road surface, severely eroding and destroying it (Photo 6). The mean depth of water channels in the watershed is 18.35 cm (± 0.995) with a maximum of 60cm. Upper Tashithang, Deorali and Tashithang farm roads have relatively larger portion of their lengths without water channels, while Balaygoan I and II are relatively better with maximum portion of their length with water cannels (Figure 19).

Culverts and fords were seldom seen along the road, the result being frequent disruption of the road alignments with erosion channels and soil erosions. The absence of drainage facilities and proper road pavements have led to immense loss of soils form the road surface due to runoff. Besides excessive sedimentation of natural water channels, absence of proper drainage facilities to roads is also likely to disrupt the natural hydrological pattern of the landscape in the watershed in long run (Wood and Armitage 1997).

6.3 Average Terrain slopes, Terrain Utilization, Fill slope and Cut slope.

Average Terrain slope was calculated as the mean of the terrain slopes above and below the farm roads at every sample points. The average terrain slope has a mean value of 24 degree, with a maximum of 42 and minimum of 3 degree. Approximately, 90% (or 38 340m) of farm road length run through terrains with slopes less than 30 degree, classified as gentle to steep slope and the remaining 10% (or 4260 m) run through terrains with slopes greater than 30 degree (Table 19), classified as very steep slope in the context of Dagana Critical Watershed (Figure 37) . The road lengths running through the very steep terrains (approximately 4260m) will be subjected to greater erosional damages due to surface runoff during monsoon seasons, with greater probability of cut slope failures and deposition of erosional debris from the terrains above the roads.

With regards to the fill slop, the stability of the fill slope depends on the slope materials and the slope angle. Generally in steep terrains with most in place soils, a fill slope of 30 degree is considered stable beyond which probability of slope failures increases (CSFS 2011). The mean value of the fill slope in the watershed is 28.18 (±0.475) degree with a maximum of 53 and minimum of 0 degree. Almost 77% (32 800m) of the road length has fill slope less than 30 degree and the remaining 23% (9800m) has fill slope more than 30 degree (Table 12). The slopes above 30 degree are more likely to fail and trigger erosions in the absence of stabilization measures (Figure 24). Also it was observed that roads with higher fill slope have corresponding higher fill slope length which in turn increased with the increasing terrain slope. The downhill environmental impacts on forests were more severe with the increasing fill slope and the fill slope length. Most of the fill slopes comprised of excavated materials that were randomly deposited on the steep slopes, irrespective of the downhill terrain slopes .Occurrence of downhill landslides and multiple cracks on the road edge were observed frequently along the road section, mainly due to the absence of retaining structures or biotechnical stabilization measures. The arc shaped cracks on the road edge are good indication of slope failures which will eventually lead to downhill landslides in future (Photo 10).The fill materials were continuous source of sediments to the rivers and streams. The rate of such erosion was highly acerbated in rainy seasons due to high runoff from the road surfaces. It seemed the vegetation below the road alignments were totally ignored during the road excavation which has led to severe destructions of vegetation in many instances. Also the natural drainage channels of streams and rivers were destroyed and blocked due to debris and rocks from the road excavation, disrupting the natural water cannels.

The excavated materials mostly included boulders, tree trunks, roots and shrubs. In most of the instances, the trees (timber/ trunk) thus uprooted during the excavation were left to rot which otherwise could have been utilized efficiently. Further, boulders excavated during the road construction were randomly rolled off over the steep terrains which caused considerably destructions downhill, which otherwise could have been used efficiently for road surface pavement or construction of retaining structures along the roads. Except for occasional few locally made retaining walls (Photo 11), fill slope stabilization is mostly left to naturally grown vegetation which grows over time and stabilizes the slope.

With regards to the cut slope too, the stability is a function of the slope materials and the cut slope angle. For a soil composed mostly of rock , a cut slope of maximum 75 degree is recommendable while for slope materials composed mostly of soils, a cut slope of maximum 53 degree is recommended (CSFS 2011). Taking the average of these two values, for Dagana Critical watershed, a maximum of 60 degree cut slope is recommendable. The cut slope has a mean value of 57.99 (+/-0.339) degree with a maximum of 73 and minimum of 45 degree. Approximately, 70% (29 820m) of the total road length in the farm road have cut slope ranging from 45 to 60 degree. The remaining 30% (12 780m) has cut slope more than 60 degree (Table 15). Thus, 30% (12 780m) of the road length which have cut slopes more than 60 degree will be vulnerable to failures in absence of appropriate stabilization measures in place (Figure 28).

For cut slopes too, except for few retaining walls built locally by the local villagers, the stabilization is mostly left to naturally grown vegetation which stabilizes the slope over time (Photo 14). The cut slope failures were observed frequently in newly constructed farm roads than the old ones. Cut slopes for old farm roads were relatively more stable due to already established vegetation.

Further, almost 72% (30 700m) of the total farm road length in the watershed runs almost in entirety through the government reserved forests, with only about 26% (11 300m) running within the agricultural land and village settlement (Figure 34). In case of Pungshi, Upper Tashithang and Deorali fram roads, almost 90% of the farm road length runs through the government reserved forests (Figure 35). It seemed the road alignments for most of the farm roads in the watershed were aligned by avoiding roads running through the private land of the village settlements to avoid loss of private land. The fact that 72% of these roads running almost in entirety within the forest area will certainly have an adverse ecological and environmental impacts on the wild life through habitat fragmentations (Chomitz and Gray 1996), interrupting ecological flows in natural environment (Forman and Alexander 1998), disruption of landscape processes and loss of biodiversity (Forman and Alexander 1998), disruption of natural hydrological processes (Brink, Slate et al.), the micro climatic edge effects and its impacts on the forest dynamics in the area (Young and Mitchell 1994; Murcia 1995; Spellerberg 1998), which can alter the community composition and abundance of many different faunal groups (Laurance, Goosem et al. 2009). Besides the above ecological impacts, considerably loss of vegetation through improved anthropogenic accessibility also cannot be denied as was the case in Baso valley of Pakisthan (Ali, Benjaminsen et al. 2005)

Upon random interviews of some of the households in the villages, it was observed that all they have to say were of immense benefits that these farm roads have rendered to them but none on the impacts that these farm roads have on their surrounding environments. Given an opportunity and the monetary assistance, they would like to further extend these farm roads to the nooks and corners of the villages. The precedence have been already set in some of the Chiwogs.

6.4 Road Quality

Road qualities for farm roads in the watershed was assessed based on multi parameters using two different methods viz. quantitative and qualitative. Both of these assessment were based on completely different road parameters. Quantitative assessment was based on multi-criteria analysis for which multiple quantitative road parameters like cut slope, fill slope, erosion channel depth and average road gradient were used for the assessment. For qualitative assessment of the road quality, qualitative road parameters like fill and cut slope quality, road pavement conditions, vehicle pliability, provisions of side drains, general stability of terrain above and below the roads and presence or absence of ruts on the road surface were used for the assessment.

As per the qualitative assessment, approximately 70% (30 200m) of road length is found to be in good condition, while the remaining 30% is in bad condition (Table 7). Of all the roads, Tashithang farm road is relatively better than all other farm roads in the watershed with over 80 % of its length in good condition. Gajeb farm road is the worst with over 60% of its total length in bad condition (Figure 14).

As per quantitative assessment (multi- criteria analysis), approximately 66% (28 116m) of the road length is in good condition while the remaining 34% is in bad condition (Figure 16).Of all the roads, Goshi farm road is seen to be relatively in good condition than other farm roads in the watershed. Balaygoan II has relatively larger portion of its length in bad conditions (Figure 17). With a difference of just 4%, the results of both the assessment did not vary much.

To sum up the results of these two methods by taking the mean values, approximately 68 % (28 900m) of the total road lengths in the watershed is in good condition. The remaining 32% (13 600m) is in bad condition. The spatial distribution of good and bad condition roads is not uniform but confined to mostly difficult terrain of the landscapes in both the assessments (Figure 15 & 18).

Most of the farm roads lacked basic road infrastructures like road pavement and drainage facilities which are crucial in managing the excessive runoff and the subsequent erosions on the road surface. In case of farm roads like Upper Tashithang, and Pungshi, no road pavement has been carried out except for bare subgrade soils left after the initial excavation works. Some of the major problems observed in the bad to very bad sections of the roads are:

- Excessive surface erosions with deep erosion cannels on steep road gradients (Photo 4).
- Absence of drainage facilities like side drains, culverts and fords which lead to excessive runoff over the road surface rendering it un-useable for vehicles during rainy seasons (Photo 3).
- Unstable cut slopes and fill slopes due to acute steepness of the slopes and absence of stabilization measures which led to fill slope/cut slope failures (Photo 13).
- Frequent road blockage due to cut slopes and fill slopes failures.
- Absence of road pavement, retaining walls and proper irrigation water management infrastructures which often comes in conflict with the road alignments along the terrain (Photo 4).

6.5 Road Width, Turns and Turn Angle

Farm roads in the watershed have a mean width of 6m with a maximum of 9m and a minimum of 4m varying randomly depending on the terrain and the landscape. Generally, wider road width was observed on roads with difficult terrain and in newly constructed roads (Fig 33). Approximately, 24 600m of the road length has road width within the range of 5 to 6 meters and 4200m of the road length has road width less than 4m (Figure 31).

The average radius of the 46 curves (turns) evaluated is 8.34m with a maximum of 10.9m and minimum of 5.1 m. Approximately, 26% of the curves have radius ranging from 5 to 7.5m . Only about 74% of the turns have curve radius more than 7.5m (Table 20). Generally, horizontal curves are planned with a design vehicle in mind. Taking 7.5m as the desirable minimum horizontal curve radius for heavy (solo trucks) and light vehicles, only 74% of the turns are suitable while the remaining 26% are too sharp and narrow for any types of vehicle (Figure 41 & Table 20). Almost all the farm roads have one or more turns with curve radius less than 7.5m radius which are bottle necks for vehicle mobility unless modified and extended (Figure 44). Further, it is desirable to have minimal road gradient at turns generally below 5%. However, it was observed that except for few turns, most of the turns have gradients more than 5% which is too steep for vehicles to take easy turns.

As far as the turn angle of the turns are concerned, almost 22% of the turns have turn angle less than 145 degree. While 78% of the turns have turn angles more than 145 degrees (Table 21). Balaygoan I and Pungshi farm roads have more number of turns with turn angles above 145 degree (Figure 45). It would be technically recommended for turns with turn angles more than 145 degree to have vehicle off-tracking site of minimum 2m wide for safer turns and sight distance.

6.6 Road Connectivity and Social Utility of Farm Roads

Dagana critical watershed has a dense network of roads which comprises of 42 600 meters of farm roads and 25 500 meters of national highway running through the watershed. Taking into account both the farm roads and the national highway, it has a road density of 10.6m/ ha (Table 22). However, the watershed too comprises of power line roads constructed by the Bhutan Power Corporation for transportation of equipment which will add on to the density but has been excluded in the current analysis as these roads are negligible in number and are usually temporary roads which are abandoned after use.

Taking into account the farm roads and the national highway, the households are concentrated mostly within the vicinity of the national highway and diminishes with increasing distance from the highway with almost no settlements towards the ridge and bottom of the valley (Figure 46). The average mean aerial distance to households from the nearest road head is 190m with the maximum of 960m and minimum of 0.02 m (Table 22). Thus, taking into account the maximum travel distance of 960 m (aerial distance), it would take less than half an hour to walk to any of these households from the nearest road head depending on the terrains and topography.

The social utility aspects of the farm road was assessed by counting the number of households within absolute and cumulative buffer strips (Figure 8 & 9), laid at varying distance from the farm roads (Table 2). For any particular farm road in the watershed, the buffering effects of adjacent farm roads has an impact on the number of households actually using it for their daily needs. This in turn will have an impact on its utility, maintenance priorities of the communities and its subsequent environmental impacts on the surrounding environment.

For instance, in case of Balaygoan I farm road, for the buffer strip 600m to 800m and 800m to 1000m with mean aerial distance of 700m and 900m from the road respectively, the number of households within these buffer strips without considering the buffering effects of the adjacent farm roads are 51 and 40 respectively. However, considering the buffering effects of the adjacent roads, the number of households decreases to 42 and 14 respectively (Fig 47& 48).

Abrupt decrease in the number of households within the buffer strips of almost all of the farm roads was observed. Maximum abruptness was observed in case of Deorali, Gajeb and Pungshi farm roads (Figure 47& 48). Consequently, Deorali , Gajeb, and Pungshi farm roads has the higher road lengths per unit household compared to other roads in the watershed indicating lower social utility of the roads. Deorali has the highest road lengths per unit households at 3000m/households and Goshi has the lowest at 23m/households (Table 23). Thus, Goshi farm road has the highest and the Deorali farm road has the lowest social utility in the watershed. Higher road lengths per unit households would also mean higher burden for individual households for maintenance as road maintenance is the responsibility of the community using it as per the farm roads utilization bylaws. This in turn will have its subsequent negative impacts on the environment. In essence, taking into account both the higher environmental impacts and the lower social utility aspects of Deorali, Pungshi and Gajeb farm roads, construction of all of these roads should have been avoided in the watershed.

The efficacy of the road alignment in coherence with the maximum community benefits and farm road utility was also analyzed by using above method. It was found that the number of households in the subsequent cumulative buffers decreased with increasing distance from the road head for all the farm roads (Figure 49). Thus in general farm roads in the watershed have been aligned in order to have a good connectivity of households.

7 Conclusion

The study concluded that technically, considering both the qualitative and quantitative assessment of the road qualities, only about 70 percent of the total road length is found to be in good condition while the remaining 30% is in bad condition. The 32% of the road length which are in bad condition is detrimental to the surrounding environment from environmental impacts point of view. Spatially, the bad roads are mostly confined to steep and difficult terrains. Some of the major problems with the bad roads are lack of side drainage and very steep or flat road gradients. Almost 30% of the road length has no side drains at all, mostly so with the newly constructed farm roads. The existing side drains of the old roads are defunct due to debris deposition or cut slope failures. Approximately, 22% of the road length has road gradient above 12% (Very steep) and 15% have below 3% (flat). Further, except for parts of few old farm roads, none of the farm roads have adequate road pavements. New farm roads have been left to be used with the subgrade soils after the initial excavation works.

The lack of road drainage in combination with steep road gradient and loose subgrade soil has led to severe erosions of the road surfaces. Multiple erosion cannels of various depths along the roads has rendered the roads completely un-useable unless for a major maintenance works. Further, the road surface runoff in absence of proper drainage has exacerbated fill slope failures, landslides, erosions, distraction of natural hydrological patterns of the streams which cumulatively contributes to downstream sedimentation and increased stream turbidity. In flat road gradients, lack of proper drainage has led to water stagnation and debris deposition leading to development of ruts and severe destruction of the road subgrades. The road surface is completely un-useable for vehicles especially during rainy seasons. This sections of road are often bottle necks for vehicle mobility on the road. The poor drainage of the roads has also affected and distracted the irrigation facilities of the village community at several spots. Farm roads in the watershed also substantially lacks other vital road infrastructures like proper fords at stream crossings, culverts and adequate fill slope and cut slope stabilization measures.

Approximately, 23% of the road length have fill slopes more than 30degree and 30% have cut slopes more than 60 degree. These slopes are vulnerable to failures in absence of adequate bio-technical engineering stabilization measures. Except for few locally made retaining walls and naturally grown vegetation, the roads considerably lacks technical slope stabilization measures. The slope failure is more likely to occur in newly constructed roads due to poor status of vegetation establishment on these slopes, the only means of natural stabilization mechanism seen along the roads.

The farm roads in the watershed are wide enough with mean width of 6m. However, most of the turns along the roads need widening for safer traffics. Of the 46 turns evaluated, 26% of the turns have curve radius less than 7.5m which is not adequate for any types of vehicles for safe turns, not at all convenient for heavy vehicle like solo trucks. Also most of the turns have turn angle more than 145 degree without adequate vehicle off-tracking sites. Further, most of these turns have gradients more than 5% which is not technically sound. These inefficient turns will act as bottle necks and will be detrimental to road functionality.

Households in the watershed are adequately connected with farm roads with road density of 10.6m/ha and mean aerial distance of 960m to the nearest road head from any of the households. It would take less than an hour to reach to any of these households from nearest road head on foot. Thus, need for additional farm roads in the watershed in future is not at all recommendable. Farm roads like Deorali, Pungshi and Gajeb have more lengths per unit households than other roads. This will have an impact on its maintenance, road quality, utility and its subsequent impacts on the environment. Rationally, taking into account the environmental impacts and the social utility aspects of these farm roads, all of these roads should have been avoided in the watershed.

Further, although road alignments for farm roads in Dagana Critical Watershed has been designed to optimize the household connectivity and reduce the loss of private property of the village settlements, this objective has been achieved largely at the cost of substantial destruction of the natural forests and landscapes. About 72% of the farm road length runs entirely through government reserved forests. Though the assessment and quantification of economic and social benefits of these farm roads to the community in lieu of ecological impacts has not been carried out so far and is beyond the scope of this study, micro-climatic and edge effect influences due to road construction on the vegetation dynamics, biodiversity, wild life habitat, landscape hydrology, stream sedimentations and overall ecosystem of the watershed cannot be denied as there are ample scientific research evidences of such influences due to road constructions.

8 General Recommendations

It is technically recommendable to have roads with road gradients within the range of 3-12%. For farm roads in the watershed, road grades which are too steep (above 12%) or too flat (below 3%) are detrimental to environmental impacts, thus are recommendable for re-grading. Further, adequate drainage facilities along with other vital road infrastructures like fords and culverts at appropriate sites are felt imperative for long term sustainability and environment friendly farm roads in the watershed. Specifically, the road lengths lacking drainage facilities and those with road gradients beyond the range of 3 to 12% must be prioritized in providing with adequate drainage facilities, the size and shape to be determined depending upon the velocity and the water volume generated. The side drains which are defunct must be maintained and restored at the earliest. Since sub grade soils of road surface are the major source of sediments, road surface pavement with adequate surface and base course is also recommended for all farm roads in the watershed. As far as possible, cut slope and fill slope must be made stable during the slope cutting and filling process by not deviating from the recommended stable angles. However, post excavations, fill slopes and cut slopes which are vulnerable to failure must be stabilized with adequate vegetative or bio-technical stabilization measures for slope stabilization. Various kind of stabilization measures can be explored depending on the suitability of the sites. It could be purely vegetative to a combination of vegetation with artificial structures. Vegetative method may include planting fast growing plants/grasses with rigid and widespread root networks on the slopes. Artificial structures may include constructing retaining walls or stone gabions which can be built using stones that are available onsite during the excavation works. A minimum of 2m wide vehicle off-tracking site is recommended for all turns with turn angles above 145 degree for safer turns and sight distance. Also re-grading of turns with grades above 5% is recommended for vehicle friendly turns. Though the current farm road construction guidelines mandatorily requires for EIAs reports prior to construction of any farm roads , field implementation of the activities seems very irrational and incompetent. The EIAs of farm roads must mandatorily incorporate comprehensive assessment of ecological impacts due to road construction. The EIAs should be carried out only by competent professionals. Further, rational cost benefit analysis of the socio-economic benefits in lieu of the ecological and environmental impacts must be carried out prior to construction of any farm roads. Also constant monitoring of the excavation works by competent site engineer, and excavator operators with certain technical expertise in road construction is deemed necessarily required for all sorts of future road constructions.

9 Limitations of the Study

The current study was largely focused on the technical and social utility aspects of farm road constructions. The environmental impacts was grossly analyzed based on the physical observations and technical measurements of road parameters. More holistic understanding of the ecological and environmental impacts of farm road construction would have been possible had it been for temporal and spatial based scientific quantification of specific ecological impacts due to road constructions. It would have been interesting to include in the study the edge effects and micro-climatic influences on the aspects of forest dynamics like vegetation structure, species diversity, structural diversity, wild life habitat fragmentations and other vital environmental services that forest ecosystem renders. Subsequent cost benefit and tradeoff analysis of socio-economic benefits of the farm roads to the community in lieu of quantified ecological and environmental impacts would be a helpful tool to which operational decisions on any type of road constructions could be based upon.

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11 Acronyms

ADB	Asian Development Bank
ARG	Average Road Gradient
ATS	Average Terrain Slope
BC-CAP	Bhutan Climate Change Adaptation Potential of Forests in Bhutan
Chiwog	Sub-block
CSFS	Colorado State Forest Service
Dzongda	District Magistrate
Dzongkhag	District
EIA	Environmental Impact Assessments
FYP	Five Year Plan
GDP	Gross Domestic Product
Gewog	Administration Block
GIS	Geographic Information System
GPS	Global Positioning System
Gup	Administrative Block Head
MCA	Multi Criteria Analysis
MDG	Millennium Development Goals
NGO	Non-Governmental Organization
PHCB	Population and Housing Census of Bhutan
RAA	Royal Audit Authority
RNR	Renewable Natural Resources

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