# DETERMINATION OF TOTAL SEDIMENT IN CHHUKHA DAM AND ITS MEASURES

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## *Abstract*

*Bhutan has realized its potential in hydropower production but is yet to capitalize on the abundance of natural water. Bhutan, both at the individual and a country as a whole relies heavily on hydropower as the highest revenue generator which increases with the increase in population and the development occurring in and around the country. Therefore, the study on hydropower plant is inevitable for the benefit of all which provides us with the opportunity to study the challenges faced due to various means, one of which being the deposition of sedimentation in the dam.*

*The problems associated with hydropower are sedimentation reduction of live storage, the power generation and the detrimental effect on the various components of hydropower plant. Thus, the study was conducted to determine the total sediments in Chhukha dam with Revised Universal Soil Loss (RUSLE) model integrated with Geographic Information System(GIS). The annual soil loss in the catchment area is obtained by first obtaining the various parameters such as R-factor, K-factor, LS factor and C & P factor and further calculation was done with SDR (Sediment delivery Ratio) which gives the total sediments deposited in dam excluding the one deposited along the channel.*

*After finding the total sediment deposit and comparison with the actual sediment in Chhukha dam, the study came up with a map that proposes various mitigation measures.*

*Keywords: Revised Universal Soil Loss Equation (RUSLE) Model, SDR, Soil Erosion, GIS.*

## 1. INTRODUCTION

### 1.1 Background

Bhutan known as the last ‘Shangri-La’ to the outside world through its unique culture and life style holds its outmost value in the form of land covered by natural flora and fauna with at least 60% of the land area, enforced to remain under forest cover according to the constitution of the country. With 2674 lakes and icy steep rugged mountains, Bhutan has the potential to produce 30,000 MW of which 23,760 MW are found to be technically feasible and only around 6.8%(1488MW) are being achieved as of now (DHPS,2013). Furthermore, one of the highest revenue generators of the country is hydropower alongside tourism industry for which the study on hydropower plant is inevitable for the benefit of the country. Bhutan's annual revenue from the hydropower generation crossed Rs.14 billion in 2015 and after paying back the loans, the economy is left with net revenue of Rs.10 billion (BBS, December 15, 2015).

Chhukha Hydropower Plant was Bhutan's first mega power project, with installed capacity of 336 MW which is located on the Wangchhu and uses the discharges of Thimphu, Paro and Haa valley. The hydropower project was financed by the government of India through an agreement which was signed in 1974 between the two governments and the total cost of the project on completion was Nu. 2,460 million and generates over 1800 million units annually (Bhutan Electricity Authority, Feb 09, 2017). It has a catchment area of 3555.19 sq. km and a perimeter of 312.8 km. With the ever-changing climate there comes a challenge of maintaining constant energy generation which becomes difficult due to sedimentation in the dam.

Sedimentation over a period of time reduces the live storage capacity of the dam and power generation (NEC, 2012). It can also have a detrimental effect on their life of various components of the hydropower projects (Agrawal, 2005). Excessive sedimentation in the dam indicates soil loss from runoff and soil erosion in the upstream catchment area.

### 1.2 Problem Statement

Over the next 30 years, river flow may increase 26% in Wang Chhu which will carry more sediment down from the already heavily silt-laden rivers of Himalayas. This silt will affect the turbines of the hydro-power projects/plants and prevent them from producing power (Walker, 2016). Sediment can have a detrimental effect on the life of the various component of the hydro-power projects (Agrawal, 2005) and over a period of time reduces the live storage and power generation (NEC, 2012). So to determine the sediment in Chhukha Dam which generates the highest revenue of the country is not only essential but rather the opportunity to confront the prime problem which hampers the power production.

The study of sedimentation allows us to explore the different methods of determining the sediments and means to defy the nature in order to reduce the sediments. Therefore, determining the sedimentation helps in keeping the record for future reference and assist in increase the efficiency of the power generation as well as for future development of new power plant.

### 1.3 Objective of the Study

Primary Objective:

Determination of Total Sedimentation Yield and Proposing Mitigation Measures.

Specific Objectives:

- Comparison and Analysis of the calculated results with the actual Sedimentation Data recorded at the dam.
- Studying the present management measures and Identification of factors affecting the sedimentation in the Dam.
- Understanding the soil loss at the upstream catchment area.

## 2. DETERMINATION OF SEDIMENT BY RUSLE MODEL

Soil erosion is considered as one of the major problems and has widespread effects on soil degradation, agriculture, water quality and hydrological system. It is the major factor which helps in shaping the earth itself. However, the determination of loss due to soil erosion is a very complex process as it involves a lot of interconnected factors such as soil, topography, land cover, rainfall and human activities. Accurate and timely estimation of soil erosion loss or evaluation of soil erosion risk has become an urgent task. (Mbugua W. 2009)

Numerous methods and calculations developed further derange us from choosing them even though they determine the same Soil Erosion loss but each being applicable for certain topography and climatic conditions. The methods which are developed and available in order to determine the amount of sediment due to soil erosion are such as Pacific Southwest Inter Agency (PSIAC), Soil and Water Assessment Tool (SWAT), Water Erosion Prediction Project (WEPP) and Universal Soil Loss Equation (USLE).

Among these numerous mathematical models used to determine the soil erosion, the Revised Universal Soil Loss Equation (RUSLE) is used in this project as it is simple to use, can be incorporated in ArcGIS 10.2 and is the least data demanding among all the other models. The model uses rainfall data, soil map, digital elevation map, land cover and land use map. It has been extensively used to estimate soil erosion loss, to assess soil erosion risk, and to guide development and conservation plans in order to control erosion under different land-cover conditions, such as croplands, rangelands, and disturbed forest lands. (Arnold, Srinivasan, Muttiah & Williams, 1998) RUSLE model enables prediction of an average annual rate of soil erosion for a site of interest for any number of scenarios involving cropping systems, management techniques, and erosion control practices, and it has been found to produce realistic estimates of surface erosion over small areas(Alemaw, Majauale, & Simalenga, 2013).

The RUSLE is expressed as:

$$A = R \times K \times L \times S \times C \times P$$

Where,

A=Average annual soil loss in Mg/ha/yr

R=Rainfall/runoff erosivity (MJ.mm.ha-1.h=1.yr-1)

K=Soil erodibility (Mg h/MJ/mm)

LS=Slope Length and Steepness Factor

C=Cover-management

P=Support practice factor

Source: (Environmental GIS: Lab 10)

### 2.1 Rainfall Erosivity Factor(R)

The R Factor represents the relation between precipitation occurring over an area and its runoff potential. The rainfall erosivity factor (R) reflects the effect of rainfall intensity on soil erosion, and requires detailed, continuous precipitation data for its calculation (Wischmeier and Smith, 1978). In other terms, it is the product of the annual sum of the rainfall energy and the maximum 30-minute rainfall intensity in each rainfall event of greater or equal to 13 mm per hour (Kitahara et al., 2000). The original equation of (R) uses the kinetic energy of the rain and requires measurements of rainfall intensity (Wischmeier & Smith, 1978) equation:

$$R = EI30$$

Where;

E=total storm kinetic energy per unit area;

I30= Maximum 30-minute rainfall intensity.

This direct method of Wischmeier and Smith can only be applied in areas equipped with autographic recorders. However, datas of such nature were unavailable in the region, therefore other alternative formulas developed by Jain et al. (2001) and Babu et al. (2004) have been used for computing R-factor which is shown below.
The annual and monthly precipitation data of Thimphu, Paro, Haa and Chukha for 6 years (2009- 2014) collected from the Snow & Glacier Division, Department of Hydro-Met Services, Ministry of Economic Affairs were used for calculating the R Factor using the formulas mentioned below:

- **Jain et al. (2001):**

  $R = 79 + .363R_N$

  Where R = Rainfall Erosivity factor in MJ mm/ha/hr/yr,

  RN = Mean annual rainfall (mm)

- **Babu et al. (2004):**

  $R = 81.5 + .0375A$ ($340 \le A \le 3500$ mm);

  Where A = Mean annual rainfall in mm.

In our present study, we employed the 'Inverse Distance Weighted' method (IDW) of interpolation for spatial distribution of average annual precipitation. IDW determines cell values using a linear-weighted combination set of sample points (Childs. C, 2004). In the process of interpolation, 6 years of precipitation data for 9 rain-gauging stations in the study area were considered. It is observed that the highest rainfall occurred in Betikha region and the lowest rainfall occurred in Gidakom region. Figure 4 represents the rainfall erosivity map prepared using rainfall data of the study area.

Rainfall and Rainfall Erosivity Factor Map


*Figure 23: R-Factor Map*

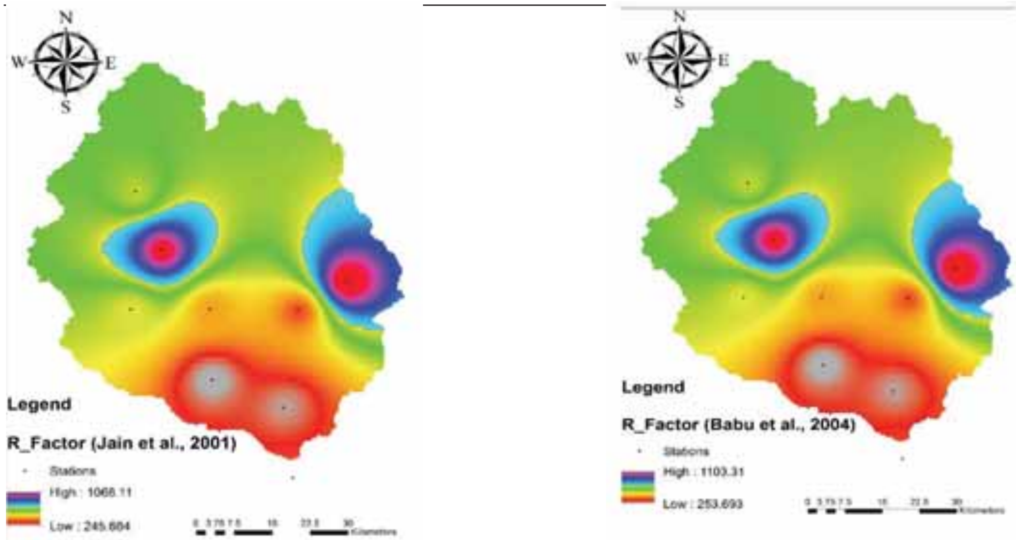



*Figure 22: Station in and around catchment area*

## 2.2 Soil Erodibility Factor (k)

The soil erodibility is different from soil erosion as the inherent properties of the soil are the causes of erodibility rather than the physical properties like land slope, rainstorm characteristics, cover and management factors (Wischmeier & Smith, 1978). The present of organic matter increases the infiltration and reduces the runoff thus reducing the erosion and even the permeability of the soil profile affects K factor as it affects the runoff. Therefore, K factor can be calculated using the soil erodibility nomograph solution proposed by Wischmeier and Smith (1978) where the detail soil parameters are required as shown below:

$$100k = 2.73 \times 10^{-6} \times M_{1.14}(12 - a) + 3.25 \times 10^{-2}(b - 2) + 2.5 \times 10^{-2}(c - 3)$$

Where,

M = Particle size diameter

a = % organic matter

b = the soil-structure code used in soil classification, and

c = the profile-permeability class

However, due to dense forest in the study area detail field survey was not possible and even there was no soil map available for the study area so that we could get the detail soil parameters required to use the soil erodibility nomograph solution. Therefore, in line to the limited data the classification of soil texture was done using soil map obtained from HWSDB (Harmonized World Soil Data Base V 1.2 (FAO/

IIASA/ISRIC/ISSCAS/JRC, 2012)) from which the composition of different soil at the catchment area is extracted (i.e., % of silt, % of sand and % of clay) and k factor map was produce by using formula proposed by Geleta (2011) as shown below:

$$\mathrm{ERFAC-K} = 0.32\left(\frac{\%\,Silt}{\%\,Sand + \%\,Clay}\right)^{0.27}$$

The soil map obtained from HWSDB was clipped to our catchment area to get the soil map and classification of the soil in our study area. Using the attributes table, the different types of soil available were extracted and the table below represents the % of different soil parameters and the K factor value calculated by using the formula proposed by Geleta (2011).

| | Sand | Silt | Clay | K-Factor |
|---|---|---|---|---|
| Orthic Acrisol (AO) | 49 | 27 | 24 | 0.2446 |
| Dystric Cambisols (Bd) | 41 | 39 | 20 | 0.2836 |
| Lithosols (I) | 43 | 34 | 23 | 0.2675 |
| CMi | 31 | 49 | 20 | 0.3165 |
| LPe | 46 | 34 | 20 | 0.2675 |
| LPi | 56 | 38 | 6 | 0.2803 |

*Figure 3: Soil Map*

*Figure 4: K-Factor Map*

## 2.3 Slope Length Steepness Factor (LS)

The Slope Length and Steepness Factors (LS) represents erodibility due to combinations of slope length and steepness relative to a standard unit plot. It expresses the effect of topography, specifically hill slope length and steepness, on soil erosion. An increase in hill slope length and steepness results in an increase in the LS factor (Karaburun, 2010). The slope length factor (L) is defined as the distance from the source of runoff to the point where either deposition begins or runoff enters a well-defined channel that may be part of a drainage network.

On the other hand, the steepness factor (S) reflects the influence of slope steepness on erosion (Wischmeier & Smith, 1978). As already pointed out, the longer the slope length, the greater the amount of cumulative runoff, and the steeper the slope of the land the higher the velocities of the runoff, which contribute to erosion.

The slope length and slope steepness factors are commonly combined in a single index as LS and referred to as the topographic factor. Soil erosion by water also increases as the slope length in- creases due to the greater accumulation of runoff. The modified equation for computing the topographic factor (LS factor) in GIS environment is employed by the formula recommended by (Pelton, Frazier and Pickling, 2014).

Power (“flowacc”*[cell resolution]/22.1,0.4)*Power(Sin(“sloperasterdeg”*0.01745))/0.09, 1.4)*1.4

Where, flow accumulation is the number of cells contributing to flow into a given cell and derived from the DEM after conducting fill, flow direction and flow accumulation processes in ArcGIS. Cell size is the size of the cells being used in the grid, based representation of the landscape. Finally, the LS factor map was derived using the above formula in ArcGIS spatial analysis raster calculator function.


*Figure 5: LS-Factor Map*

## 2.4 Cover & Management Factor(C)

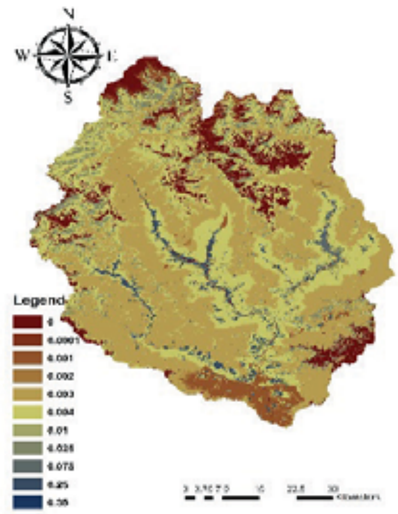
The Cover and Management Factor, C is used to reflect the effect of cropping and management practices on erosion rates and is used to compare the relative impacts of management options on conversation plans (K.G. Renard et al, 1997).

It is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from an identical area in tilled continuous fallow. This factor measures the combined effect of all the interrelated cover and management variables and ranges from 0 to 1 (Wischmeier & Smith, 1978). It indicates how the conservation plan will affect the average annual soil loss and how that soil-loss potential will be distributed in time during construciton activities, crop rotation, or other management schemes (K.G. Renard et al, 1997).

The C value for the study area has already been assigned corresponding to each land cover/use by National Soil Service Centre, Department of Agriculture under Ministry of Agriculture and Forest.

*Table 2: C factor for the corresponding land use/cover type for the study area*

| Sl. No. | Land cover/use | C factor |
|---|---|---|
| 1 | Chuzhing | 0.2500 |
| 2 | Kamshing | 0.2500 |
| 3 | Built-up Areas | 0.0750 |
| 4 | Landslides | 0.0350 |
| 5 | Broadleaf Forests | 0.0010 |
| 6 | Broadleaf + Conifer | 0.0020 |
| 7 | Fir | 0.0030 |
| 8 | Mixed Conifer | 0.0030 |
| 9 | Meadows | 0.0250 |
| 10 | Non-Built-up Areas | 0.0100 |
| 11 | Snow and Glaciers | 0.0000 |
| 12 | Rock Outcrops | 0.0001 |
| 13 | Shrubs | 0.0040 |
| 14 | Lakes | 0.0000 |
| 15 | Rivers | 0.0000 |
| 16 | Reservoirs | 0.0000 |
| 17 | Blue pine | 0.0040 |
| 18 | Apple Orchards | 0.0030 |
| 19 | Screes | 0.0010 |
| 20 | Moraines | 0.0010 |




*Support Practice Factor (P)*

## 2.5 Support Practice Factor (P)

The support practice factor, P is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage (K.G. Renard et al, 1997). For cultivated agroculture land, the support practices considered include contouring, stripcropping, terracing, and subsurface drainage.

P does not cosnider improved tillage practices such as no-till and other conservation tillage systems, sod-based crop rotations, fertility treatments, and crop-residue management. Such erosion-control practices are considered in C factor (K.G. Renard et al, 1997).

A low P factor (approaching 0) indicates that conservation practices are effective, while a high P factor (approaching 1.0) indicates that conservation practices are ineffective.

No specific support practice is put in the study area, hence the study area comprising of 3.13% of agriculture land (Chuzing & Kamshing) with the most common practice of farming in these steep terrain landscape being terraced farmland (Duba, 2016) is considered as one support practice.

The P factor value was assigned by classifying land into agricultural and other land use types. The agriculture land in the study area consists of an average slope percentage between 0 to 30 hence according to Wischmeier & Smith, the P of value

0.1375 is assigned to it. For water bodies it is assigned P value of 0 and other land use type P value is assigned 1.

The agricultural land of the study area is categorized into six slope classes and P-value to the respective slope classes were assigned as the management activities are highly dependent on the slope of the area (Duba, 2016 & Wischmeier, W.H., Smith, D.D., 1878). Lower slope range with C factor value close to 0 indicates that the conservation practice are effective as most of the agriculture land are located towards the lower land of the valley.

*Table 3: P-factor for the corresponding land use/cover type*

| Land use type | Slope Percentage | P-factor |
|---|---|---|
| Agriculture land | 0-5 | 0.1 |
| | 5-10 | 0.12 |
| | 10-20 | 0.14 |
| | 20-30 | 0.19 |
| | 30-40 | 0.25 |
| | 40-50 | 0.33 |
| Other land use type excluding water bodies | All | 1 |
| Water bodies | All | 0 |

(Wischmeier & Smith, 1978 (George et al, 2013)

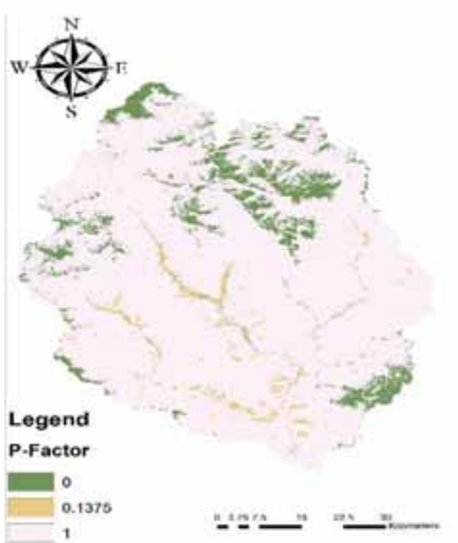



*Figure 7: P- Factor*

# 3. SEDIMENTATION DELIVERY RATIO

Sediment Delivery Ratio (SDR) is a fraction of gross erosion that is transported from a given area in a given time interval (Gelagay, 2016) also referred to as a transmission coefficient, which is fraction of gross soil erosion by water that is delivered to a particular point in the drainage system (Ouyang and Bartholic, 1997).

RUSLE only gives the gross soil erosion of the catchment which is not equivalent to sediment yield at the basin as not all materials eroded is transported by the river. Only portion of the material is transported by the river and rest gets deposited along the way.

The expression for calculating SDR can be written as follows:

**SDR=Y/E**

Where

SDR = Sediment Delivery Ratio

Y = Sediment Yield of the Basin

E = Gross Erosion of the Basin

There are two approach to calculating SRD

1. **Based on Drainage Area**

$SDR = 0.51 \times A^{-0.11}$ (Boyce, 1975) based on the data from the Blackland Prairie, Texas.

$\text{Log}(SDR) = 1.7935 - 0.14191 \text{ Log}(A)$ (Renfro, 1975) based on sediment yields observed in 14 watersheds in the Blackland Prairie Area in Texas.

$SDR = 0.42 \times A^{-0.125}$ (Vanoni, 1975) based on data from 300 watersheds throughout the world which is also a more generalized SDR formula.

Where: A = Drainage Area in $\text{Miles}^2$

2. **Based on Relief Length**

$\text{Log}(SDR) = 2.94259 + 0.82362 \text{ Log}(R/L)$ (Renfro, 1975)

Where: R = Relief of Watershed

L = Max. Length of Watershed

Among these formulas the use of drainage area method is widely used and accepted considering its applicability and data availability.

All the above formulas are developed for different study area outside of our country and no specific formula is developed for mountainous Himalayan region.

SDR involves complex process and numerous factors considered including sediment source, texture, nearness to the main stream, channel density, basin area, slope, length, land use/land cover, and rainfall-runoff factors (Kim & Julien, 2006). Hence all the formulas are used to compare their results to get approximate values.

## Conclusion

Sedimentation is an inherent part of the dam. This project was carried out in effort to reduce the sedimentation, which hampers the life and functionality of hydropower plants. The current method adopted in reducing the sedimentation in Chhukha dam is dredging which limits the maximum power production capacity of the dam.

In order to clear out the sediment without affecting its maximum power potential several upstream mitigation models have been developed such as PSIAC (Pacific Southwest Inter Agency), SWAT (Soil and Water Assessment Tool) and RUSLE approach. Therefore, RUSLE approach integrated with GIS was used in order to carry out the project pertaining to its ease of use and less data requirement.

RUSLE Model required the development of factor maps whereby different aspects of the catchment area were used in order to determine the total sediments. The maps developed provided the effective study of the influencing factors. The factors were Rainfall erosivity (R), Slope length and steepness factor (LS), Soil erodibility factor (K), Cover management factor (C) and Support Practice factor (P).

The study required comprehensive rainfall data for six years, high resolution DEM and a wholesome land cover map in order to accurately determine the soil erosion at our catchment area. The calculation of these factors also required lots of research for determining which formulas and techniques are most suitable for Bhutanese conditions. Furthermore, SDR (Sediment Delivery Ratio) was also to be selected which would yield the result as close to actual sedimentation yield.

As no study on the SDR have been done for Bhutan, all the formulas having catchment area was used in order to find out which SDR formula gave the closest sediment yield. RUSLE model provides a comprehensive study on sedimentation which is based on remote sensing and GIS. This theoretic approach is a very effective and efficient way to spatially locate where the maximum sedimentation could take place in the catchment area.

The limited rainfall data for the calculation for R Factor may hamper in the determination of accurate sedimentation yield for the study area. Also, the data for soil map is extracted from HWSD which is generalized data of the study area and does not always account for accurate results.

For the land use/cover map (C Factor), the data is acquired from an old data which did not reflect the actual day to day real changes which might have occurred on the ground.

The model helps in mapping of soil erosion vulnerability zones of the catchment area, proper and correct rainfall intensity data and detailed soil map and actual field measurements on the ground can augment the accuracy and prediction capability of GIS based analysis.

## References

1. Westen, c. Van. "Remote Sensing For Natural Disaster Management." International Archive of Photogrammetry and Remote Sensing , Amsterdam, n.d, vol.XXXIII.
2. Wischmeier, W. H, and D. D Smith. Predicting Rainfall Erosion Losses- A Guide to conservation Planning. Washington D.C: Agriculture Handbook No.537, 1978.
3. Agor, R. Surveying and Levelling. Dehli: Khana Publisher, 2010.
4. Alemaw, B. F, M Majauale, and T Simalenga. "Assessment of sedimentation Impacts on Small Dams-A Case of Small Reservoirs in the Lotsane Catchment." Journal of Water Resource and Protection, 5 December: 1127-1131.
5. Amsalu, T, and A Mengaw. "GIS Based Soil Loss Estimation Using RUSLE Model : The Case of Jabi Tehinan Woreda, ANRS, Ethiopia." Journal of Natural Resources, 2014: 616-626.
6. Ashiagbor, G, E. K Forkuo, P Laari, and R Aabeyir. "MODELING SOIL EROSION USING RUSLE AND GIS TOOLS." International Journal of Remote Sensing & Geoscience, 2013: 7-17.
7. Engineers, US Army Corps of. Engineering and Design, Control and Topographic Surveying. Washington, 2007.
8. Duba, C. "Reservoir Sedimentation Study for the Bunakha Hydro-electric Project." 2016.
9. Ganasri, B. P, and H Ramesh. "Assessement of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi." Geoscience Frontiers, 2016: 953-961.

10. Gelagay, H.S. "RUSLE and SDR Model Based Sediment Yield Assessment in a GIS and Remote Sensing Environment; A Case Study of Koga Watershed, Upper Blue Nile Basin, Ethoipia." Journal of Waste Water Treatment & Analysis, 2016.
11. George, J, J. G Kalambukattu, and S Kumar. "Modelling Soil Erosion Risk in a Mountainous Watershed of Mid-Himalaya by integrating RUSLE model with GIS." Eurasian Journal of Soil Science, 2017.
12. Hussein, M. H, I. M Amien, and T. H Kariem. "Designing terraces for the rainfed farming region in Iraq using the RUSLE and hydraulic principles." International Soil and Water Conservation Research, 2016: 39-44.
13. Hassan, F, H Karimi, and S. M. Alibakhshi. "The estimation of erosion and sediment by using the RuSLE model and RS and GIS techniques(case study: Arid and semi-arid regions of Doviraj, llam province, Iran)." International Journal of Agriculture and Crop Science, 2014: 304-314.
14. Karaburun, A. "Estimation of C factor for soil erosion modeling using NDVI in Buyukcekmece watershed." Ozean Journal of Applied Sciences, 2010: 77-85.
15. Kinley, Photograph by. "CST Project." 2017. Phuentsholing, 2017 йил 4-3.
16. Kim, Y. "Soil Erosion Assessment Using GIS and Revised universal Soil Loss Equation (RUSLE)." Journal of Water Resources, 2014.
17. NLC. "Empowering Land Governance through Sustainable Geo-information Management." Thimphu, 2012.
18. NLC. "Measuring Towards Perfection." Thimphu, 2008.
19. NLC. "The proceedings and Resolutions of workshops on the Capacity Development of Local Government in Land Governamce." 2013.
20. Prasannakumar, V, H Vijith, S Abonod, and N Geetha. "Estimation os soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology ." Geoscience Frontiers, 2012: 209-215.
21. Source: Google Earth. Satellite image. Phuentsholing, 2017 йил 4-3.
22. Renard, K, G Foster, G Weesies, D McCool, and D Yoder. Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised universal Soil Loss Equation (RUSLE). Agriculture Handbook No.703, USDA-ARS, 404pp, 1997.

# Authors' Profile

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