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Inter and Intra Micro Watershed Analysis of Land Use Change An Appraisal on Sustainability, Southern Sikkim, India

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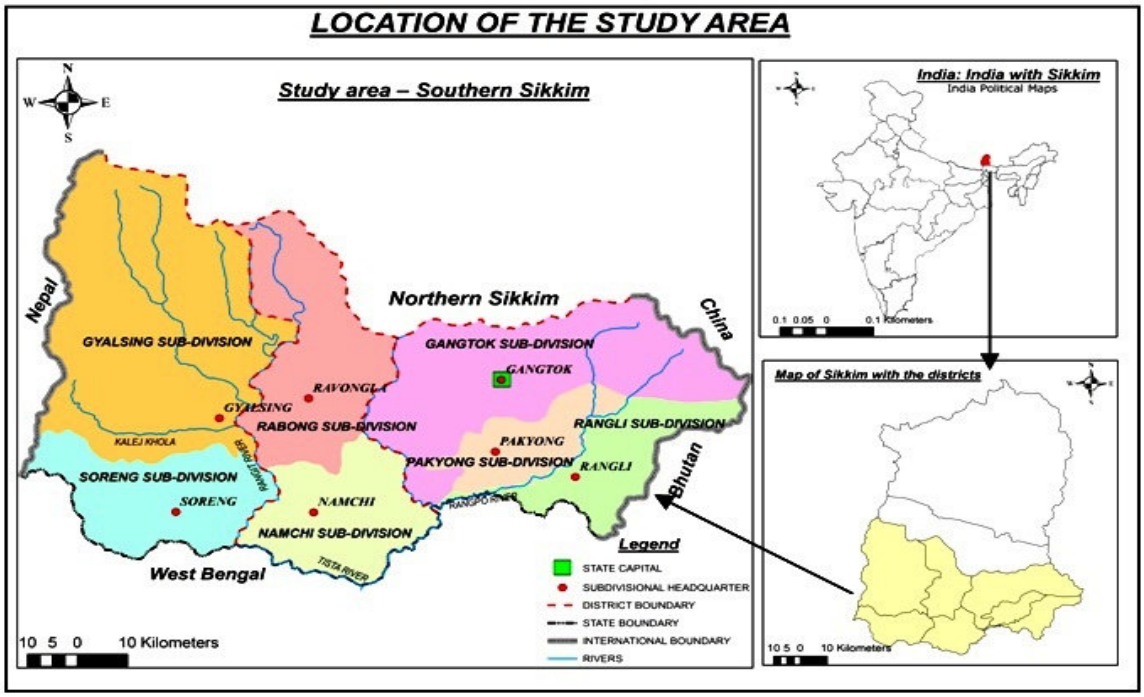
Abstract
Systematic watershed analysis is now a rational track for development strategies. Natural forms and factors in terms of location had been in the way of the major land use change for a long time especially in the area of the present study. However, through time the dynamicity has increased to such an extent that a close scrutiny and relevancy of management for sustainability issues have invited the present study. The southern part of the state, with maximum physical and social alteration, has been taken in the present context to assess the changes of land use in the different micro watersheds within this area. The topography of the southern three districts is characterized by a host of different landform features. There are sharp, rugged, snow bound mountains with inaccessible scarp faces at higher altitudes. The present study area takes into consideration 12 watersheds, as geographical subdivisions, extending over the entire southern part of the state. Recently, sudden influx of population has evidently maneuvered the ground for land use changes in the comparatively favourable pockets within the southern half bringing inter and intra watershed differences in land use pattern and change. Field observation in association with all possible reports and records with analytical treatment, have been some essentials to fulfill the need of the study.

Introduction
Essentially a Himalayan Kingdom, Sikkim became the 22nd state of Indian Union only in 1975, which laid down the foundation stone for successive changes that swept this mountainous land in every sphere within a very short span. Sikkim's story has always been unique, as this region is one of the most diverse and dynamic in terms of its natural assemblage as well as the anthropogenic built up. However, the intra regional contrast in terms of this dynamicity offers maximum in the southern half of the state comprising of the three districts viz. east, west and south districts. The topography of the southern three districts is characterized by a host of different landform features. There are sharp, rugged, snow bound mountains with inaccessible scarp faces at higher altitudes. This intensely depicts the presence of numerous rivers and streams all over, all joining the principal drainage channel of Teesta to form an intricate network in this landmass. The southern part has more landscape forms due to the prominence of the causative factors of river erosion and deposition away from the source. Hence it is evident that this part can be divided into maximum number of river basin areas demarcated by individual network of drainage basins. The present study area takes into consideration 12 watersheds, as geographical subdivisions, extending over the entire southern part of the state. Each landscape has given way to the development of different natural land cover and man's land use type in the watersheds. The fact that is concerning is that the land cover is rampantly under modification by land use change due to increasing human interference. Southern Sikkim, being more amenable for such change has invited scopes and concerns for regular watershed management plans and policies to sustain the natural earth. The human influx in the southern Sikkim since the time of its merger with India and mostly in the recent times due to various factors of life and livelihood has made the area a progressively populous part. This has evidently maneuvered the ground for land use changes in the comparatively favourable pockets within the southern half bringing inter and intra watershed



differences in land use pattern and change.

Location and Environment of the study area:

Sikkim is a small but magnificent mountainous region in the East Himalayas. There is marked contrast with the size and scope of the landmass. The large heterogeneity of the characteristics of the area's physical and socio-cultural aspects is just opposite to the smallness of the geographical area. The present study area covers the entire southern half of the state which roughly extends over 27 ◦ 04'46''N to 27 ◦ 35'01''N and 88 ◦ 00'58''E and 88 ◦ 55'25''E longitude. The total geographical area in this part is 2870 sq. km. approximately; running approximately 57 km north-south and 64 km. from east to west. The north is bordered by the North district and the south by another Indian state, West Bengal. The east and the west boundaries are international borders, viz. in the west Nepal borders the region; South-East is bordered by Bhutan and North east of the study area by China. The study area falls under the Lesser Himalayan zone and is hence comparatively less rocky and accessible, but very fragile. This has resulted in a quick influx of population in this part and a resultant instability of the geo-environment due to such pressure and change of the natural cover.

The map above shows the location of the present study area. In the present context of the study it can be mentioned that around 90% of the total population of the state is concentrated within this southern half and more precisely in some of the watersheds. This has created an imbalance in the change scenario. This apart, the entire study basin is covered with forests and rivers throughout. Teesta and its main tributary Rangit extends from almost all possible corners of the area. However, towards the extreme east a small area of drainage is under a tributary of river Brahmaputra. Hence the following map depicts the different watersheds in the southern half of the state, which roughly coincides with the political boundaries separating the north district from the south, east and west district. The 12 micro watersheds under the study area are: - ***01. Prek Chhu, 02. Relli Chhu, 03. Rathong Chhu, 04. Dik Chhu, 05. Rangpo Chhu, 06. Rangit River, 07. Kalej Khola, 08. Ramam Khola, 09. Manpur Khola, 10. Teesta (Lower Part), 11. Rani Khola, 12. Jaldhaka (part of a small sub-tributary).*** We can get a bird's eye view of all those micro-watersheds within the following compact network of Tista drainage system.

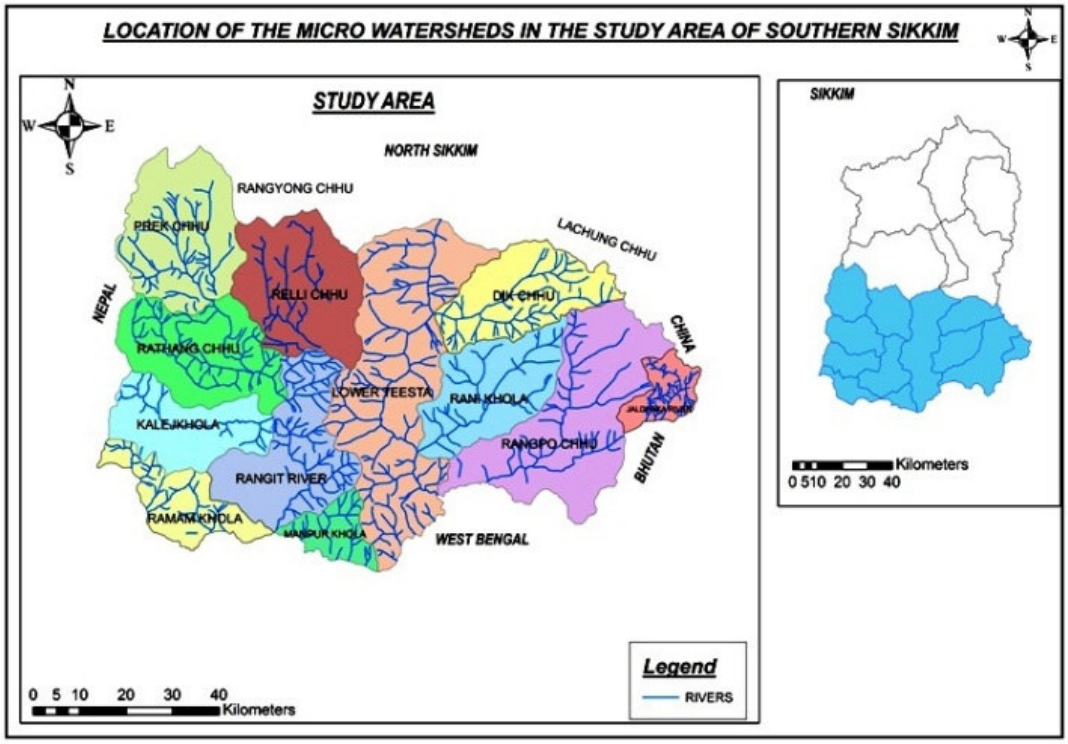
Objectives:

The southern part of Sikkim and the study area in the present context is the major hub of all socio-cultural growth and changes impacting the landmass for some time. In this connection there has been a considerable change taken place in the land use pattern in this part. The southern half of the state of Sikkim provides wide scope for such study of the watersheds, especially when, there is constant trigger for change in the fragile land due to various land use change. ***Hence the primary objectives of the study are:*** *(i)* ***to assess the land use pattern of the different micro watersheds; (ii) their intra and inter correlation of changing pattern of land use scenario and (iii) finally to ascertain the status of the watersheds and subsequently to analyze the aspects of change and inter connection of the demographic and physical condition to carve out a balance for such***

change in land use.

Methodology and study materials:

In view of fulfilling the major objectives of the study, suitable data and information have been gathered from both primary and secondary sources. Field observation as well as analyzing the data from published and unpublished records, memoires, reports and maps and images have been some essential to fulfill the need of the study. Modern and interactive analytical techniques and software tools have also been applied in suitable GIS environment to analyze and interpret all those reports and resultant data to make fruitful inferences of the study. Modern mapping tools have also been used to represent the data and to prepare the interactive maps of the area.



Results and Discussion:

The study area represents a bunch of diverse and unique characteristics of the physical and cultural environment. The lithospheric, atmospheric, hydrospheric and the biotic environment through constant interplay have made this part a unique hotspot. Hence in the natural cover of land, forests, water bodies, glaciers, etc. have been greatly impacted and modified through land use change by the dominant species of biotic environment-man. The resultant outcome is witnessed in the major land under the utilization of cultivation, settlement, roads and railways, etc. The study of the land use and land cover of the 12 micro watersheds in the study area generated from the present image and reports exemplifies the following characteristics pattern of land use and land cover. Following table depicts the land use scenario of the present study area that also highlighting the potentials for development of the studied area.

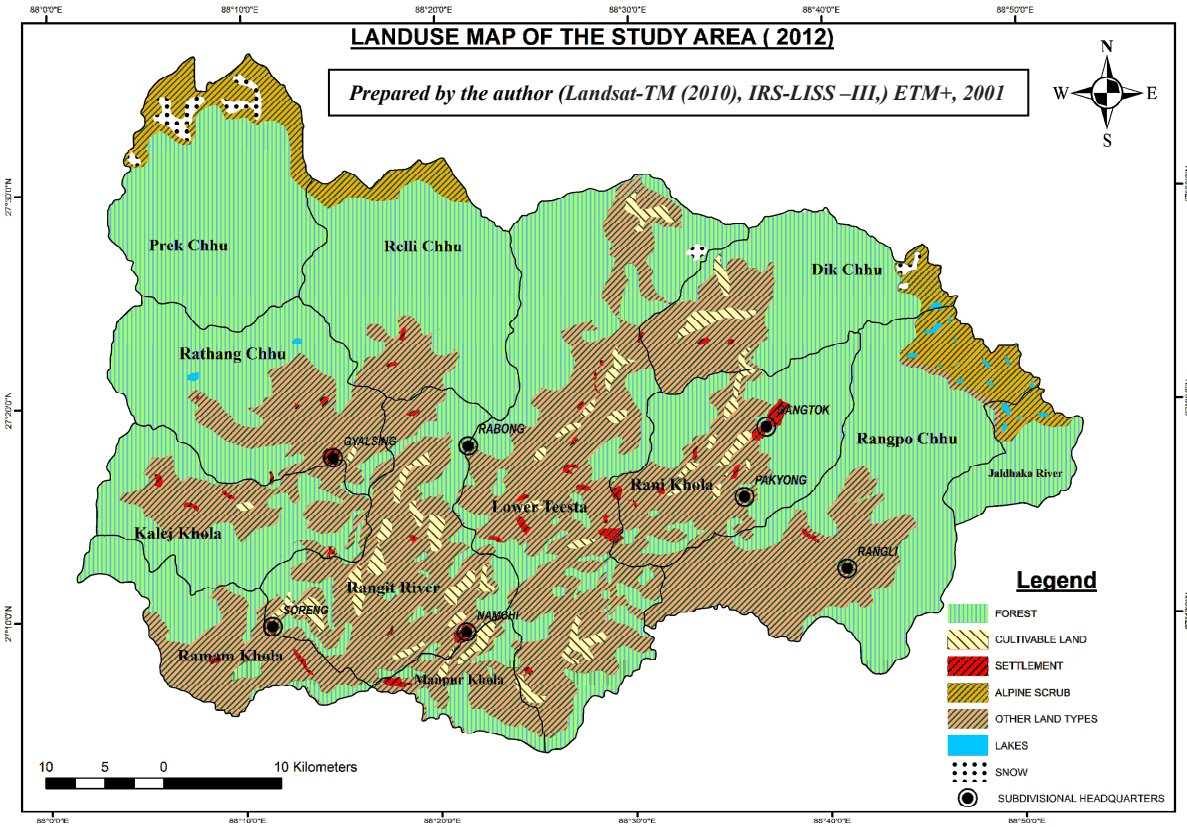
From the varied characteristics of the land in the watersheds, it is clear that most of the areas in the watersheds have a rich land cover with a few exceptions. However, due to topographic contrasts and terrain character, sizable amount of land remains unavailable for utilization purpose. Besides, as part of the policy of the state, major land under forests are still literally unutilized. This is creating a havoc pressure on the available small areas of land under human habitation. Regular exploitation and increasing utilization spree due to ever increasing population is leaving these areas disfigured, in the sense that the natural face is swiftly giving up in the hands of the alteration brought by human agency. Thus there is an apprehension about the durability of the existing artificial makeover. Moreover, due to scarcity of land, there is a regular contemplation of the idea of putting the land resource under varied land use scheme in the most effective manner. But, to what extent these planning can serve the purpose of long standing sustainability is a cause of concern. The land use pattern under various purposes can be taken up separately to frame an understanding of this debate.

Table: 01- Existing Scenario of Land Use and Land Cover of the Study Area

WATERSHEDS	Area(Sq.km)	Open Forest	Dense Forest	Temperate and Scrub	Alpine Scrub	Barren and Rocky area and Moraine	Glacier and Snow Covered	Settlement & Cultivation
Prek chhu	307.34	00	25.7	00	00	51.2	13.9	00
Relli Chhu	299.56	48.67	18	00	00	14.28	3%	00
Rathong Chhu	278.82	44.6	18	14.39	6.4	10.2	00	00
Dik Chhu	235.52	44.4	23.3	8.3	8.4	11.4	00	2.0
Rangpo Chhu	437.64	35.9	24.3	11.6	6.9	18	00	3.5
Rangit River	282.58	35.6	30.7	15.5	4.5	9.1	00	9.0
Kalej Khola	200.51	48.71	24.5	12.52	00	7.2	00	3.6
Ramam Khola	146.48	35.4	26.6	20	00	00	00	7.9
Manpur Khola	79.16	00	45	23.8	00	00	00	00
Teesta (Lowr)	581.66	38	33	13	00	6.3	00	9.4
Ranikhola	246.36	00	49	23.9	00	00	00	19.3
Jaldhaka	74.23	49%	52	00	14	34	00	00

Here is a bird's ***eye view of the land cover and land use of the present study area*** and it is to note that the present study has been recorded the temporal scenario of the studied area for the year of 1995 and 2012 and highlighted many significant fact on the changing coverage of the of the land use and land cover of the studied area. However the results are represented are highly interesting to note that the area under study has been marked as developed tourist growth centre and many of such centres are spreaded all around the area as a mark of economic development. So, in this respect, serine environment and virgin lands are always paying for the same. However, the analysis and subsequent discussion is mostly need for holistic development of the area.

Comparative Temporal Scenario of Land Use – (1995 – 2012)



Source-Extracted from LANDSAT-TM and other relevant maps

The following table also shows the total area under different categories of land use in the 12 watersheds of the study area. Hence a **comparative picture can be established from the same regarding the difference of the land use in these watersheds.** It has been extracted from this scene that remarkable decrease of forest area is noted especially in and around the tourist spot and growth centers; subsequently sliding, slipping and similar such geomorphic hazards are occurred frequently that spontaneously sending land into ditches. It can

also be seen that the intra dimensional gap in most of the watersheds in terms of the different land use categories throughout each of the watersheds have also been quite contrasting. The responsible factors at some places have been wholly natural which have affected the human factor to impact upon such differences.

Watersheds	*1995 Land Use And Land Cover (Area In Sq.Km.)*						
	Forest	*Cultivation Land*	*Settlement*	*Lake*	*Snow*	*Alpine Scrub*	*Other Land(s)*
Dik Chhu	186.69	7.68	2.35	0.56	1.11	11.66	47.14
Jaldhaka	69.89	-	-	1.25	-	5.61	-
Kalej Khola	121.22	5.68	3.25	-	-	-	88.22
ManpurKhola	36.25	4.65	0.23	-	-	-	47.80
Prek Chhu	264.23	-	-	-	11.56	54.67	-
Ramam Khola	69.65	-	0.22	-	-	-	77.04
Rangit River	74.65	25.68	1.36	-	-	-	224.97
Rangpo Khola	319.56	2.25	1.22	2.29	-	39.58	84.26
Rani Khola	141.65	7.56	4.22	-	-	-	116.49
RathangKhola	195.33	0.23	0.23	1.23	-	-	81.95
Relli Chhu	263.54	-	0.21	-	-	-	36.22
Teesta Lower	237.24	22.25	9.65	-	-	-	376.32

Table: 03-- Land Use and Land Cover Scenario, 2012

Watersheds	2012: Land Use And Land Cover (Area In Sq.Km.)						
	Forest	Cultivated Land	Settlement	Lake	Snow	Alpine Scrub	Other Land
Dik Chhu	169.63	10.536	3.2241	0.4689	1.4154	11.6687	67.2468
Jaldhaka River	58.287	-	-	1.213	-	17.181	-
Kalej Khola	110.1	108365	5.0486	-	-	-	87.463
Manpur Khola	29.459	5.271	1.2466	-	-	-	56.2186
Prek Chhu	248.774	-	-	-	9.2568	67.8228	-
Ramam Khola	58.403	-	1.4177	-	-	-	89.4947
Rangit River	68.28	31.79	3.3181	-	-	-	231.7589
Rangpo Khola	305.68	4.353	3.3928	2.2017	-	39.5835	102.324
Rani Khola	133.31	11.791	7.4889	-	-	-	132.3299
Rathang Khola	178.52	2.482	2.4156	1.2354	-	-	89.354
Relli Chhu	250.396	-	1.1621	-	-	-	50.3261
Teesta Lower	227.117	27.4069	13.3539	-	-	-	395.3038

Source: Calculated from satellite image - LANDSAT TM 7 and DESME, Sikkim

Conclusions and suggestions:

From the analysis of the temporal scenario of land use pattern of the different watersheds it becomes quite vital to understand that the watersheds under massive human interference as is highlighted from the total area under direct human use as settlement, cultivations etc. are the regions which calls for immediate attention. The water usage in the recharge basins forms vital aspect for the stability and management of the watersheds. The Supply of water during various seasons for cultivation in the form of irrigation supply; the domestic requirement of water; and most importantly there is a huge pool due to the tourist industry. All these factors have essentially meant the need of water resource management, together with watershed development and management strategies to sustain each of the units. It is already evident that there is a huge contrast in the intra and inter-watershed land use types. For example Ranikhola has the highest area under settlement cover, where as there is very meager settlement in Rangpo chhu, even though it is much larger area than Rani Khola. Hence the pressure is diverse. Moreover, the density difference within each of the watersheds in terms of population or demographic order due to birth, death and migration is different due to differential environment and land character, for example, the southern part of Dik Chhu witnesses growth of settlement whereas the eastern part does not, due to its strategically sensitive location and other physical factors and the considered Jaldeka watershed is totally uninhabited and actually not suitable for human activities. Thus the vulnerability of the favorable parts constantly becomes higher than the other. For better understanding about the suitability of the watersheds a number of components are considered relating to aspects of relief, slope and roughness and land related aspects which may be the major determinants of the suitability of the considered watersheds.

Table – 04--Relief and Land Use-Land Cover Related Component considered, Extracted by the Authors

Watershed Name	Relative Relief (m)	Relief ratio	Road Density km/sq.km	Drainage Density km/sq.km	Stream frequency	Form Factor	Basin Perimtr. (km)	%Forest	%cultivation lands	% Settlemen	(Av)No of land slides
Dik Chhu	4330	17.52	0.27	0.75	0.23	0.0029	77.54	72.02	4.47	3.22	8
Jaldhaka	2172	25.09	0.16	1.97	1.31	0.0024	44.27	78.50	00	00	2
Kalej	2931	15.04	0.46	0.81	0.25	0.0038	75.87	54.91	5.40	5.05	3
Manpur	1855	11.92	0.41	0.68	0.25	0.0026	47.28	37.21	6.66	1.25	1
Prek Chhu	4668	26.00	0.23	0.76	0.24	0.0047	78.94	80.94	00	00	2
Rammam	2940	12.12	0.34	1.03	0.44	0.0020	80.04	39.87	00	1.42	2
Rangit	2912	8.71	0.64	0.96	0.36	0.0021	91.82	24.16	11.25	3.32	4
Rongpo	4163	10.79	0.43	0.51	0.13	0.0025	128.79	69.85	0.99	3.39	12
Ranikhola	3486	31.46	0.35	0.50	0.13	0.016	76.59	54.11	4.79	7.49	11
Rathang	4080	15.01	0.27	0.97	0.34	0.003	79.65	64.03	0.89	2.42	1
Relli Chu	4897	15.85	0.20	0.61	0.21	0.0023	79.85	83.58	00	1.16	2
L_Teesta	3418	4.93	0.45	0.73	0.19	0.0011	149.36	39.05	4.71	13.35	18

With the help of bi-Variate and multi-Variate analysis involving the considered variables following results are drawn and subsequent inferences are also incorporated twelve ***physical units (watersheds) of the study area, have been studied distinctly by every aspects of their natural built up and existing climatic trends and resource bases***, which categorically settled the understanding of the inclination of natural repulsion and attraction by the human world, as an environmentally favourable area generally draws more settlements and vice versa.

Bi-Variate Correlation Matrix

	VAR01	VAR02	VAR03	VAR04	VAR05	VAR06	VAR07	VAR08	VAR09	VAR010
Var01	1	.135	-.350	-.482	-.499	.386	.603*	-.434	-.010	.190
Var02	.135	1	-.593*	.181	.258	-.548	.549	-.306	-.298	-.199
Var03	-.350	-.593*	1	-.324	-.379	.420	-.830**	.798**	.452	.396
Var04	-.482	.181	-.324	1	.981**	-.446	.125	-.182	-.355	-.389
Var05	-.499	.258	-.379	.981**	1	-.490	.187	-.222	-.388	-.364
Var06	.386	-.548	.420	-.446	-.490	1	-.194	.022	.706*	.792**
Var07	.603*	.549	-.830**	.125	.187	-.194	1	-.745**	-.417	-.169
Var08	-.434	-.306	.798**	-.182	-.222	.022	-.745**	1	.354	.213
Var09	-.010	-.298	.452	-.355	-.388	.706*	-.417	.354	1	.788**
Var10	.190	-.199	.396	-.389	-.364	.792**	-.169	.213	.788**	1

.603* *Correlation at 0.5% significant Level*

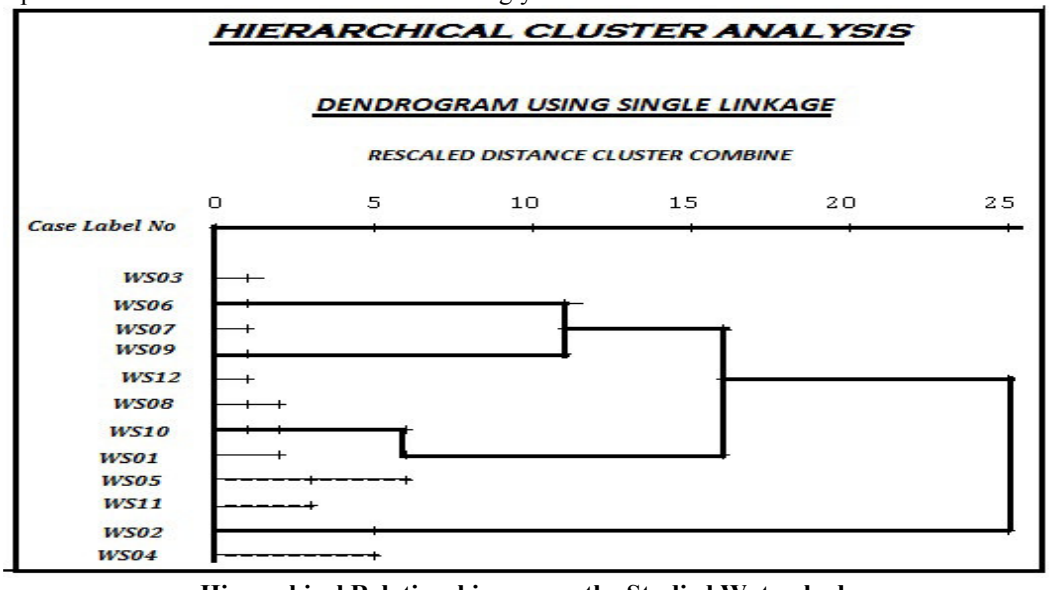
*- Level of significance 0.05 (95%) and ** denotes 0.01(99%)

Cluster Members among Watershed Parameters			
Water Sheds	5 Clusters	4 Clusters	3 Clusters
Dik Chhu (1) **	1	1	1
Jaldeka (2)**	2	2	2
Kalej Khola (3)	3	3	1
Manpur Khola(4)	3	3	1
Prek Chhu (5) **	1	1	1
Ramam Khola (6)**	1	1	1
Rangit River (7)	3	3	1
Rongpo-Rangit (8)**	1	1	1
Rani Khola (9)	4	1	1
Rathang-Rimbi (10)**	1	1	1
Ralli Chhu (11)**	1	1	1
Teesta Lower (12)	5	4	3
** *Common to all Clues*	*Watershed status determined according to all Cluster*		

First Cluster – 1, 5, 6, 8, 10, 11, Second Cluster includes -2 only
Third Cluster -- 3, 4, 7, Fourth Cluster includes – 9 only
Fifth Cluster – 12 only

Status of Cluster Combination

It has been ascertained from the results that – i) In the bi-Variate analysis we like to consider here 0.05 level of significance for getting no risk as well as to achieve the stable result verifying the ground truth, because 0.01 level may restrict the resolution of ground reality and will be always tried to restrict its area within the abstract value; **ii) In the Clustered and PCA also conform** to this results almost in the same line of sight. Here, it has been observed that considered watersheds 01, 05, 06, 08, 10 and 11 constituting a group of similar category of watersheds, so a great number of watersheds in the studied area are similar in terms of their environment and development so far as the estimated variables are concerned; **iii)** whereas, **other clusters excepting 02, 09, and 12 also offering a bit of dissimilarity** in comparison to first cluster; **iii) but, clusters 02, 09 and 12 which are constituting second, fourth and fifth clusters** are representing as single member in the representation and offering some distinct kind of differentiation in terms of suitability of development and so, levels of prioritization have been determined accordingly.



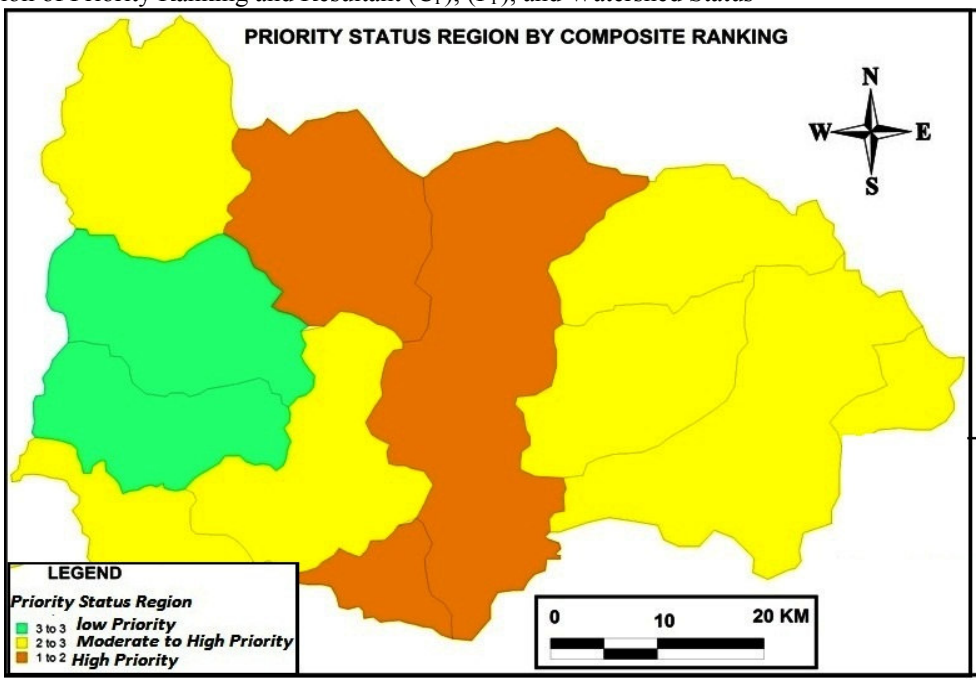
Hierarchical Relationship among the Studied Watersheds

Accordingly, the suitability status map has been prepared **based on priority ranking of the considered**

variables for getting the best possible measures of the development perspectives for the studied micro-watersheds, because in the present system of development micro-level policy making and subsequent re-organization proved the best way of micro-level development planning.

Watershed Name	Relative Relief	Relief Ratio	Road Density	Drainage	Stream Frequency	Form Factor	Basin Perimeter	Forest	cultivation	Settlement	land	*Composite Index (C_I)*	*Priority Index (P_I)*	*Watershed Status*
Dik Chu	*10*	*9*	*5*	*6*	*6*	*9*	*8*	*4*	*6*	*6*	*5*	*72*	*2*	***Moderate to High***
Jaldhaka	*2*	*10*	*1*	*12*	*12*	*6*	*12*	*3*	*10*	*1*	*2*	*71*	*2*	
Kalej	*4*	*6*	*11*	*8*	*8*	*11*	*10*	*7*	*3*	*9*	*3*	*80*	*3*	***Low***
Manpur	*1*	*4*	*8*	*4*	*4*	*7*	*11*	*11*	*2*	*3*	*1*	*56*	*1*	***High***
Prek Chhu	*11*	*11*	*3*	*7*	*7*	*12*	*7*	*2*	*11*	*1*	*2*	*74*	*2*	***Moderate to High***
Rammam	*5*	*5*	*6*	*11*	*11*	*4*	*4*	*9*	*9*	*4*	*2*	*70*	*2*	
Rangit	*3*	*1*	*12*	*9*	*9*	*5*	*3*	*12*	*1*	*7*	*4*	*66*	*2*	
Rongpo	*9*	*3*	*9*	*2*	*2*	*8*	*2*	*5*	*7*	*8*	*7*	*63*	*2*	
Ranikhola	*7*	*12*	*7*	*1*	*1*	*1*	*9*	*8*	*4*	*10*	*6*	*66*	*2*	
Rathang	*8*	*7*	*4*	*10*	*10*	*10*	*6*	*6*	*8*	*5*	*1*	*75*	*3*	***Low***
Relli Chu	*12*	*8*	*2*	*3*	*3*	*3*	*5*	*1*	*12*	*2*	*2*	*53*	*1*	***High***
L_Teesta	*6*	*2*	*10*	*5*	*5*	*2*	*1*	*10*	*5*	*11*	*8*	*65*	*1*	

**Calculation of Priority Ranking and Resultant (C_I), (P_I), and Watershed Status



The land morphology depicts the scene of the order of the watersheds in terms of such favourability. In a brief, the findings of the study conducted so far, show that the overall condition of the study area can be divided into two parts - **i) the natural environment and their potentialities and explorative status in terms of the natural boundary, and ii) The human environment and their change and establishment in the present area in relation to past, existing and potentials of land,** and with the essence of both the answer to the present problem of the study is sought. In order to do away with this problem of contrast, suitable strategies of management are vital for striking a balance of the environment and achieve sustainability. **Some of the elements of sustainability measures that deems essential are:**

1. In-situ moisture conservation, development and sustainable management of natural and social resources including their rational and sustainable use.
2. Enhancement of agriculture productivity and production in a sustainable manner especially for boosting of land suitability.
3. Restoration of ecological balance in the degraded and fragile rainfed eco-system by greening tree areas through appropriate mix of trees, shrubs and grasses.
4. Reduction in regional disparity between irrigated and rainfed areas,

5. Creation of sustainable farming system and generation of other employment for avoiding the overburden on the land.
6. Opportunity for rural community including the landless and to increase the awareness about the fragile character of the land that may bring their danger and may throw their fate into hilly ditch.
7. Equity for resource poor and empowerment of women. Besides these above strategies planning related to reduction of surface runoff, stream water conservation, reclamation of land for increasing productivity for meeting increasing demand, going for more eco-friendly means for agriculture with suitable measures of sustenance are extremely essential for this part of the area, an environmentally sensitive but uniquely picturesque domain.

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