Environmental Science

Some Theoretical Background and Applications

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Tribhuvan University
Kirtipur, Nepal

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ICIMOD

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EDITORIAL

The human influence on the natural world and its ecosystems has never been more prominent or problematic than it is today. It is feared that the continued pace of the environmental degradation, if not corrected on time, will eliminate the human race along with many others from the face of the earth earlier than one would imagine. The environmental approach adopted by various other disciplines (multidisciplinary) and bringing the knowledge and tools of those disciplines to the study of environmental science (interdisciplinary) is also the manifestation of this realization. The more we wait for is a universal consensus of environmental worldview to secure the mother earth and its children.

Thanks are to the academic programmes offered in all the renowned universities in the world, which are not only producing professionals of environmental science or environmental studies/ engineering/management but also bringing environmental awareness around world at all levels. In Nepal, the Central Department of Environmental Science (CDES), under the aegis of Tribhuvan University, Institute of Science and Technology (TU-IOST) is the pioneering institution offering courses in environmental science and research. In 1997, it introduced Bachelors' of Science majoring environment, and in 2001 the Master's programme. Having one of the huge applications for enrollment, the BSc in Environmental Science is one of the most popular college degrees in the country today.

In 2012, the TU-IOST upgraded the BSc Environmental Science to four-year degree that was three-year in the earlier years. Thus, a good part of MSc syllabus was incorporated into BSc. With successful completion of the four-year course, the TU-CDES took an immediate step in reviewing its curricula in MSc Environmental Science: sub-groups of major themes comprising experts and faculty were formed, which indulge on rigorous exercise; consultations were done with experts and educationists as well; and the subject committee thoroughly discussed on the revised draft before sending to TU-IOST for the approval by TU academic council. The new revised syllabus, both for BSc and MSc Environmental Science are in effect now.

While taking lead in teaching the revised syllabus, the faculty members felt it a dire need to have resource materials. Although, the internet world has made the materials available much easy, it is important that we keep the course delivery uniform and delineate its scope according to the credit hours; after all it is a degree programme that a student has to take examinations and pass. Thus, the idea of preparing resource book/s was proposed. The International Centre for Integrated Mountain Development (ICIMOD) showed its keen interest and offered support in this academic endeavour of strengthening our course delivery.

This resource book entitled **Environmental Science: Some Theoretical Background and Applications** contains eight chapters that bring theories, approach and application from a wide range of disciplines. Four of the chapters deal with theoretical background of emerging concepts such as environmental economics, ecosystem based adaptation, payment for ecosystem services and environmental management. Similarly, three chapters cover conventional topics of environmental science: geological and hydrological processes, fresh water resources and waste management. A chapter on newly introduced topic of gender and social inclusion elaborates how such cross-cutting issues are important in environmental decision making. Each chapter brings some case studies of learning, that of Nepal, where available.

The book chapters are prepared by a team comprising university faculty and subject experts affiliated with environmental science. The chapters are the collection of published materials relevant to the subject, and summarized with suggested references for details or further learning. The revised MSc Environmental Science curriculum contains 20 theory papers (10 compulsory and 10 specialized/electives). Altogether there are 102 units in these theory papers. We confess that the present volume of book only serves a small portion of this total requirement as rendered by the curriculum in its contents and references. The users, both the faculty and graduate students may take it as an indicative resource rather than a complete subject chapter. Their suggestions and feed backs will surely be valuable in bringing publications of similar kind but in better shape in the future.

DRB, MK and RN

FOREWORD

As an academic subject, environmental science plays a crucial role in our ability to address present and future environmental challenges. A solid understanding of natural laws and processes of the ecosystems and their components provides the foundational knowledge to analyze the complex and multi-faceted relationships between nature and humans. In fact, humans and nature are so closely conjoined in the study of environmental issues, we might say that environmental science transcends traditional disciplinary considerations and constitutes, in fact, a way of thinking about the world and our connections to it.

The interdisciplinary nature of environmental science has made it a common platform for many fields of study from across the academy, appreciating that environmental challenges are as much scientific and they are social. At the graduate level, we expect that students take the rudiments of environmental science and develop a deeper understanding for the purpose of generating knowledge and synthesizing it with what we already know. This is the essence of higher education. For this reason, the International Centre for Integrated Mountain Development (ICIMOD) is partnering with and supporting universities to strengthen their course curricula and research capabilities. The Himalayan University Consortium (HUC), with the Secretariat at ICIMOD, has been supporting universities in the Hindu Kush Himalaya to build the academic and research capacities through exchanges, networking and technical support. The collaboration with the Central Department of Environmental Science at Tribhuvan University (TU-CDES) is a recent such example.

We are pleased to know that the TU-CDES has revised its Master's degree course to incorporate recent developments in environmental science and keep its course of study on par with international standards. The revised course seeks to balance its components in the physico-chemical, biological and social sciences. We know that the revision of course curricula is a rigorous process involving faculty and experts from many disciplines, yet the more challenging task is to provide students with appropriate references. We hope that the publication of this resource book will serve as one important step in fulfilling this need. And ICIMOD is happy to be a part of this endeavour.

David J. Molden, PhD
Director General, ICIMOD

August 2017, Kathmandu

ACKNOWLEDGEMENTS

Environmental science is perhaps the most dynamic discipline in the academic arena today. As our environment continues to degrade and deplete, new knowledge to diagnose its cause becomes an urgent task in search of the remedy. Only such updated knowledge will prepare our graduates professionally sound and universally competent. Since the Tribhuvan University Institute of Science and Technology (TU-IOST) introduced its MSc programme in Environmental Science in 2001, the Central Department of Environmental Science has thoroughly revised and updated the curriculum at least two times, one in 2012 and the next in 2016.

A general objective of the MSc Environmental Science has been to produce a workforce of capable, passionate thinkers trained in an interdisciplinary field who are determined to solve some of the world's most complex and challenging issues. Ranging from forest biodiversity to climate change adaptation and from ecosystem health to human population growth, the world needs people who are knowledgeable of the social, economic, geopolitical and environmental considerations of these issues and who can develop and implement solutions to them. Thus, our prime interest is to introduce these subject to our students and motivate them to explore more such knowledge.

The revision of syllabus in 2016 was essential also to integrate and upgrade new courses, as the Tribhuvan University had its first product of four-year BSc programme, which was of three years' course earlier. The untiring support of the faculty members and experts affiliated with TU-CDES and its subject committee made the hectic task of course revision a success. However, the next challenge was to produce and provide resource materials appropriate to the revised new course, at least on those which are unique and specific to Nepal problems.

To our great relief, the International Centre for Integrated Mountain Development (ICIMOD) came up with generous technical and financial support in materializing the idea of producing resource book/s we had been planning and coveting desperately. We express our sincere thanks to ICIMOD- Himalayan climate change adaptation program (HICAP), Kailash landscape conservation and development initiative (KSLCDI) and Koshi Basin Program (KBP), and their team members for their best support at the time of need.

Finally, my thanks and appreciations are to all the chapter contributors and editors who have compiled and prepared the book chapters in such a lucid way and short time period.

Kedar Rijal, PhD

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Chapter 1

Environmental Earth Science: Materials and Process Examples

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1. Geological Materials and Structures

1.1 Measuring Geological Features

Introduction to Dip, Strike and Outcrop

The main aim of field geology is to observe and collect data from rocks and/ or unconsolidated deposits which will further enhance the understanding of the physical, chemical and biological process that have occurred over the geological time. Measuring geological feature is the basic component in geology. These features can be measured with the help of geological compass. The compass is used to measure the orientation of geological plane as well as lines with respect to north. It also helps to measure the angle of dip of geological features with respect to the horizontal. These features lead to the wide interpretation of the strata and rock exposure. It also helps to evaluate the mechanism of origin of exposure in the past and shows the path for future prediction. These feature can be strike, dip direction, and dip amount and lineation/foliation in metamorphic rocks. Geological features like bedding, foliation, cleavage, veins, limbs of folds, axial plane of a fold, etc. are planner features while the lineation (stretching lineation, intersection lineation, mineral lineation, etc.), fold axis, striations, etc. refers to linear features. Planar features are described by strike/dip/dip direction or simply dip direction/dip while the linear features are described by their trend and plunge.

Strike: A planar structure such as bedding, foliation, joint, cleavage, axial plane or fault can be completely defined by its attitude i.e. strike, dip and dip direction (Figure 1). Strike is the horizontal direction of slope. More precisely, strike may be defined as the direction of a line formed by the intersection of the bedding (or foliation) with a horizontal plane. In simple term, strike is the extension of a bed and it is perpendicular to the dip direction. The direction of strike is measured by compass with reference to the true north and south.

Dip: The inclination of the bed or foliation or joint or any feature is called its dip or it is the acute angle between the bedding and a horizontal plane. The beds of undisturbed sedimentary rock formations generally occur in horizontal deposition. During earth movements, the strata may be tilted out of the horizontal. Such inclined rock beds are said to have a dip.

Apparent Dip and True Dip: The true dip is defined as the maximum angle of dip on a rock bed. It is measured in the direction at right angles to the strike. A dip measured in any other direction than the true dip is called the apparent dip. An apparent dip will always have a value less than the true dip. The amount of dip decreases as the direction of dip moves round towards the strike direction. Along the strike direction, however, the dip will be zero.

Dip direction: It is the perpendicular direction of strike which is easily determined by the flow of fluid in the field or it is the direction of slope of mountain or bed or foliation.

A special dip strike symbol is used on geological maps to show the attitude of beds. Usually, the longer line is parallel to the strike of the bedding and the shorter line for direction of dip and the value written at the top of line is dip amount. For example, |- 60^0 if N is upward, it means strike is N-S, dip direction is east and dip amount is 60^0. For horizontal strata, a special symbol Å is used while for vertical bed, a long line gives the strike and a short crossbar for dip i.e. + means 90^0.

Attitude= strike/dip, dip direction

For example: N 20^0E/40^0SE

Method of Writing: $120^0/45^0$NE, it means a plane with a strike of 120^0 and a dip of 45^0 in NE direction. Similarly, another way is $100^0/35^0$, it means a dip angle of 35^0 towards azimuth (dip direction) 100^0. The objective of measuring dip and strike of rocks is to obtain information on their three dimension position.

Outcrop: The exposed part of rock sequence is called outcrop. The attitude of beds are measured on outcrop. In cut section by rivers, landslides or by artificial activity like road construction, outcrops may expose. Except attitude, bedding thickness, joints, bedding nature (wavy, parallel, curved, etc.), microfolding, faulting and associated features, etc. can be examined on the outcrop. On the basis of outcrop study, geological, engineering geological as well as environmental geological maps are prepared, rock samples and fossils are collected. Some fundamentals of rock classification and structural features found in the rocks are described in Paudyal (2005).

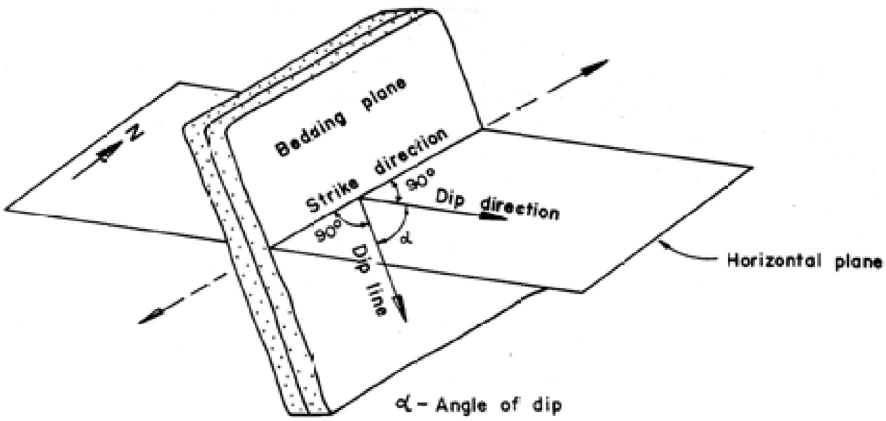

Figure 2: Strike and dip of an inclined bed.

1.2 Lineation and Foliation in Metamorphic Rocks

Lineation: It is any linear feature or element in a rock and can produce as a product of tectonic, mineralogical, sedimentary or geomorphic processes. They usually result from the elongation of minerals or mineral aggregates. Stretched pebbles in deformed conglomerates is a common example. Lineations may also result from parallel growth of elongate minerals, fold axes, or intersecting planar elements (Figure 2) like beddings, foliations or cleavages.

Foliation: The term comes from the Latin 'folium' meaning 'leaf' and refers to the sheet-like planar structure. It refers to repetitive layering in metamorphic rocks. In other word, foliation is any penetrative set of more or less parallel surfaces. Each layer may be as thin as a sheet of paper, or over a metre in thickness. Foliation can be seen in outcrops, hand samples as well as under thin sections (Figure 3). Foliation is the result of deformation caused by tectonic activities prevailing to the terrain. Several sets of foliation means the poly-deformation and hence poly phase metamorphism (Winter, 2012).

Figure 2: Outcrop view of well-lineated rocks from Tatopani area of Kaligandaki section of Myagdi district (Photo: Kabi Raj Paudyal).

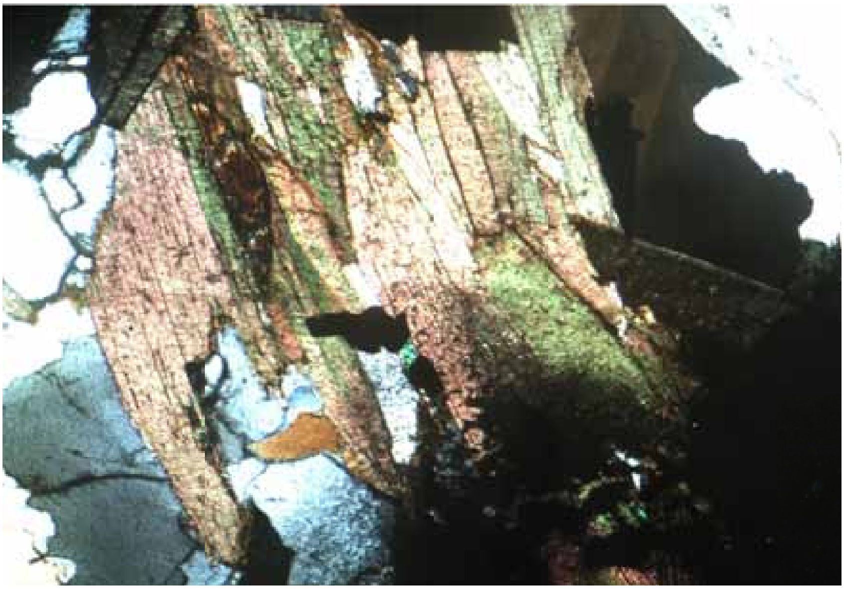

Figure 3: Fibrous mineral showing the preferred orientation indicating one set foliation

1.3 Geologic Observation and Field Note

Field observation is the prime key of geological investigation. Outcrops or exposures consist of earth materials that can be examined in place. Examining them is the most fundamental procedure of field geology. All the information is sometimes difficult to collect in the limited outcrops. Topographical maps and aerial photographs reflect the regional picture of the terrain.

The primary physical operation in studying outcrops is looking. Most outcrops have much to observe, and the challenge is to look carefully enough to see as much as possible. The first detail observation takes longer time. The following processes are recommended while examining the outcrops:

i. Look over the outcrop and nearby it broadly to get the idea on rock type and other materials. Walk around or over large outcrops several times and view them from various distances. Look for their continuity, lithological contacts, intrusive contacts, deformation and folding, weathering and soil formation process, etc.

ii. Continue to study the outcrops from a moderate distance. Examine as the rock bodies are tabular, irregular, lenticular, or with other distinctive shapes. Note the orientation and dimensions. Are they internally layered or not?

iii. Go near to the rock bodies and examine the contacts between the rock layers, texture, structure, colour, variation in grain size, bedding or foliation related features, etc.

iv. Break off the representative samples of the main material and examine weathered as well as fresh surfaces with a hand lens. Identify the constituent mineral and rock grains, and note their sizes, shapes, and surface features, as well as their part in the overall fabric and porosity of the rock or deposit. To assess the soft grains or carbonates, test the grains with hardness box and apply dilute HCl. Try to give the name of rock materials based on mineral composition and texture in case of igneous rocks, and texture and structure in case of metamorphic rocks. Size of grains, composition and sedimentary features help to name the sedimentary rocks in the field.

v. Now examine the rocks closely for primary fabrics and structures. Look especially for structures that establish tops and bottoms of deposited layers that were once sediments or igneous deposits. Look for all features indicative of depositional current direction or direction of magma flow.

vi. Now, to examine deformation features like micro-folds, faults, set of joints, shear zones, brittle shearing, folded veins, lineations, cleavages, shear sense indicators, etc. useful for the interpretation of deformation and tectonic history in the area. Don't miss to examine the fault related signatures like fault breccias, fault gouge, striations, step-marks, etc. Are the faults younger than other tectonic features? Examine the cross-cutting relations.

vii. Test the degree of compaction and cementation by hefting dry samples in the case of sedimentary rocks. Soak up water test can be carried out to test the porosity. Depth and strength of weathering generally increase with porosity and permeability.

viii. Now, systematically record and measure the information that you noticed. Record the colour, texture, structures, bedding/foliation thickness, thickness and colour of lamina, structural attitudes of all primary structures as bedding, and attitudes of all secondary features as folds, faults, veins, etc.

ix. Now start your observation to find the fossils (trace fossils, invertebrates, plants, vertebrates). Try to find the fossiliferous horizons and good samples for the palynological studies or other micro-fossils, as such fossils are very useful for the palaeo-climate and palaeo-environmental studies.

x. Similarly, based on your objective, you can observe the metallic or precious mineral resources in the outcrops. As we know, valuable gemstones are hosted with the rocks.

xi. Finally, don't forget to collect the useful samples from the outcrop. Mark the sample number by using permanent marker and keep in sample bag.

xii. The most interesting and first hand presentation material is photographs. Take several photographs of several features with scales. Maintain the distance between the object and camera so that the detail features of both large to small features are equally emphasized.

Taking Field Notes

All observations and interpretations are recorded in the field notes which should be well organised so that all examinations seem more or less complete. Each page of notes must be numbered for a given project or field work and must be headed by geologist's name, date and location area. The number of the map sheet or aerial photograph must be recorded. Field locations are numbered strictly. Points of unusual interests, such as specimen locations and critical relations or questions should be noted in the left margin or flagged by a coloured line or a box.

The descriptive parts of the notes should present facts and thus be kept as free as possible from terms that are basically genetic. Rocks and structures identified with certainty can be given firm names, but other identifications should be quarried noted as problems or simply stated as unknowns. Interpretation part should be mentioned using next colour inside the box so that they will not later be read as facts. Writing the information should be made in order so that same information from different outcrops can be extracted or compared easily and quickly. Sketches and schematic diagrams or profiles will often be helpful. The gaps or doubts in the interpretation of each outcrop are noted so that these can be fulfilled in the next outcrops. Attention should be paid whether similar outcrop is repeating or it is changing. The following outlines suggest items that might be included in the field notes:

i. Stratigraphic name of the geological unit

ii. Nature of the terrain as its topography, soils, vegetation, and outcrops

iii. Structure, shape, thickness, type of rocks, primary structures and fossils

iv. Description of rocks in the order as colour, weathering condition, grain size, fabric, contacts, and secondary structures

v. Interpretations like depositional environment, genetic relations, later modifications like cementation, compaction, auto-metamorphism, and recrystallization

vi. Meso- and micro-scale observations, folding, fracturing, and stress conditions

vii. Age relations of the unit

viii. Photographs and sample catalouging or logs, etc.

1.4 Preparation of Geological Report

Preparation of geological report includes two parts: map preparation and laboratory analysis side by side. Map preparation starts from the preparation of final route maps, columnar sections, and geological data transformation on topographical maps and preparation of geological maps. Then, accurate cross-sections are required to interpret both the stratigraphic setting and geological structures. Note that maps, cross-sections, and columnar sections convey most of the data in geological reports. If they are prepared before the report is written, the report is likely to be more accurate, not to repeat the information, and vector based description. If pencil drafts of the illustrations have not been completed in the field, they should be completed before summarizing the field study. The final illustrations should meet the needs of the project and then only write up should start. If the map and cross-sections are placed on the table, readers can visualize the geology in three dimensions conveniently. Supporting illustrations, sketches and route maps add more confident for the visualization of map and cross-sections. Maps are of various types during report preparation like documentation maps (that show locations of measurements, samples, or observations as well as data obtained), derived maps (which show information extrapolated over relevant areas, generally by colours, patterns, or contours), structural contour maps (which shows elevations on a unit contact or other surface of interest) and isopach maps (which shows thickness of a unit or of overburden). Then, literature collection and write up proceed simultaneously with map and sketches digitization. If the aim of the project is to prepare the engineering geological mapping, then the process is similar to general geological mapping. Similarly, the nature of work matches for the mineral prospection, exploration or mining works, hydrogeological works, environmental assessment works or hydropower survey. Results of primary data collection and results obtained from the laboratory analysis of rocks, minerals, soils or engineering properties should be compatible in many aspects. If the data mismatch, innovation interpretation is required. It may either be due to missing the facts due to work error or wrong methodological approach.

2. Landslides: A Case Examples of Process

2.1 Introduction

The downward and outward movements of slope forming materials along surfaces of separation by falling, sliding, flowing or combinations of these, at a faster rate is called landslide. The influence of gravity is a constant operation for such movements. Although landslides are primarily associated with mountainous regions, they can also occur in areas of low relief especially in surface excavations for highways, buildings and mines. The geological history and human activities often cause unstable conditions that lead to landslides. Landslide is one of the most effective and widespread mechanism by which landscape is developed. Large landslides move hundreds of cubic metres of material. These slides are capable of destroying large structures and sizable human settlements and profoundly modifying landscapes and drainage systems.

The force of gravity acts to tear the mountains down causing a variety of phenomena collectively called mass wasting or mass movements, whereby geological materials are moved downward from one place to another. The movement can be sudden, swift and devastating, as in a rockslide or avalanche. Landslide is a general term for the results of rapid mass movements along the surfaces of separation. Mass movement refers to all types of movements either slowly or quickly and with or without failure plane. But to say strictly landslide, there should be failure plane.

2.2 Features and Dimensions

A typical slide exhibits the following parts or features (Figure 4):

Crown: The upper portion of the slope still in place from which solid rock and soil materials are torn away from the rest of the slope.

Main Scrap: Steep surface on undisturbed ground at upper edge of landslide caused by movement of displaced materials.

Top: Highest points of contact between displaced material and main scrap.

Head: Upper part of landslide along the contact between displaced material and main scrap.

Minor Scrap: Steep surface on displaced material of landslide produced by differential movements.

Main Body: Part of displaced material that overlies surface of rupture between scrap and toe of surface of rupture.

Foot: The line of intersection of the lower part of the slip plane and the original ground surface.

Tip: Point on toe farthest from the top of landslide.

Toe: The lower portion, usually curved margin of displaced material of landslide, most distant from main scrap.

Surface of Rupture: Surface that forms lower boundary of displaced material below original ground surface.

Displaced Materials: Materials displaced from its original position on slope.

Zone of Depletion: - Area of landslide within which displaced material lies below original ground surface.

Zone of Accumulation: - Area of landslides within which displaced material lies over original ground surface.

Flanks: Sides of a slide i.e. left flank and right flank.

Original Ground Surface: Surface of slope that existed before landslide took place.

Transverse Ridges: Terrace or step like pressure or compression ridges.

Landslide Dimensions

Width: Maximum breadth of displaced mass perpendicular to length.

Length:

i. **Total Length:**Minimum horizontal distance from tip of landslide to crown.

ii. **Length of Displaced Mass:** Minimum distance from tip to top.

Depth: Thickness of the slide mass between crown and foot.

Height: Vertical distance, crown to toe.

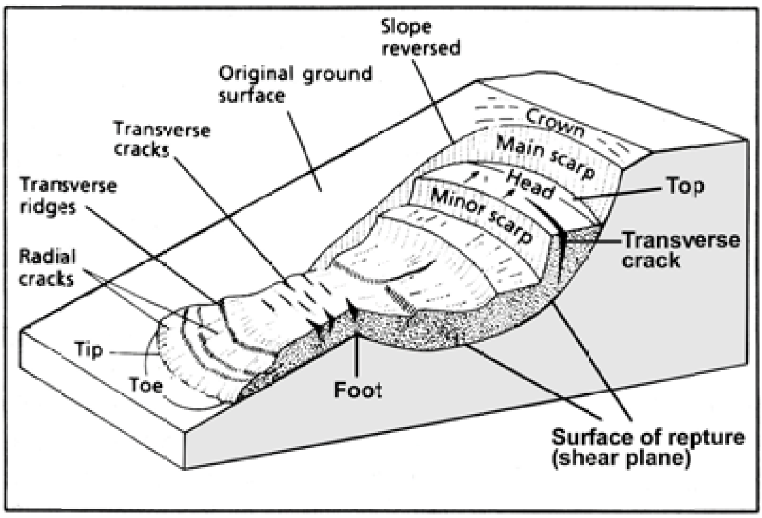

Figure 4: Parts of an ideal landslide

2.3 Types of Landslides (Classification)

Varnes (1978) classified landslides on the basis of type of movement and material (Table 1). Movement types are divided into five main groups: falls, topples, slides, spreads and flows. A sixth group, complex movements include combination of two or more of these types of movements. Similarly, materials are divided into two classes: rock and soil. Soil is further subdivided into debris and earth based on the grain size. Earth describes material in which 80 percent or more of the particles are smaller than 2 mm (i.e. predominantly fine) and debris describes material in which 20 to 80 percent particles are larger than 2 mm and remainder are less than 2 mm (i.e. predominantly coarse).

Table 1: Classification of Landslides (Varnes, 1978)

Type of Movement		Type of Material		
	Bedrock	Rock	Engineering Soil	
		Bedrock	Debris	Earth
Falls	Rock fall		Debris fall	Earth fall
Topples	Rock topple		Debris topple	Earth topple
Slides	Rotational slide (few units)	Rock slump	Debris slump	Earth slump
	Translational slide (many units)	Rock block Slide rock Slide	Debris block slide Debris slide	Earth block slide Earth slide
Spreads		Rock spread	Debris spread	Earth spread
Flows		Rock flow (Deep creep)	Debris flow	Earth flow
Complex		Combination of two or more principal types of movement		

2.4 Causes of Landslides

A landslide occurs when part of a natural slope is unstable and unable to support its own weight. There are several causes of landslide. All slopes are under stress due to the force of gravity. When the forces acting on a slope exceed the existing strength of the materials that form the slope, then the slope will fail and movements will occur. Either internal changes (e.g. chemical weathering) and/or external changes (e.g. slope loading or shocks/vibrations) can affect the forces. Although landslides are a natural phenomenon and a normal feature of landscape experiencing dissection, their magnitude, frequency and geographical distribution have been considerably modified in recent centuries by human intervention.

Landslide can have several causes, including geological, morphological, physical and human. The various causative factors of landslide are listed below:

2.4.1. Geological Causes

a. Extensive development of weak rocks such as phyllite, slates, and schists; presence of calcareous inter layers in these rocks which leads to high porosity and void formation due to leaching and dissolution and help to initiate landslides. Thin beds of pelitic composition may buckle due to self-weight on very high slopes.

b. Weathering of rock mass

c. Sheared materials

d. Adversely oriented structural discontinuities such as bedding, joints, foliation, cleavage, schistosity and faults. If the rock beds are horizontal (dip = 0°), such rocks forming the slopes are stable at all angles up to 90°.If the layers are inclined and free from discontinuities, the stability of slope depends on the condition whether the layers are dipping backwards into the mountains or forward into the valleys or the cut. When dipping into the mountain (Figure 5a) indicates stable condition even up to nearly vertical slope but dipping into valley (Figure 5b), the tendency of the layers to slide gets free surface thereby making unstable conditions.

   The bedding plane is a plane with least cohesion in sedimentary rocks. Schistosity, foliation and cleavage structures as found in metamorphic rocks like schists, gneisses, and slates respectively, all behave as surfaces of weakness and promote the failure. This is mainly due to weathering along these planes, making the contacts quite vulnerable. Joints develop due to tension, compression or shear and occur in sets or groups and highly affect the rocks from the surface to considerable depth on macro or micro-scales. Presence of joints reduce the shear strength of mass considerably. Geometry of joints, spacing, grouping and inclination all have great importance to determine the degree of vulnerability.

e. Seismic Activity: Landslides due to seismic loading are very common especially in steep mountains like Himalaya. A number of earthquake induced landslides have occurred due to Gorkha Earthquake-2015 in central and eastern Nepal.

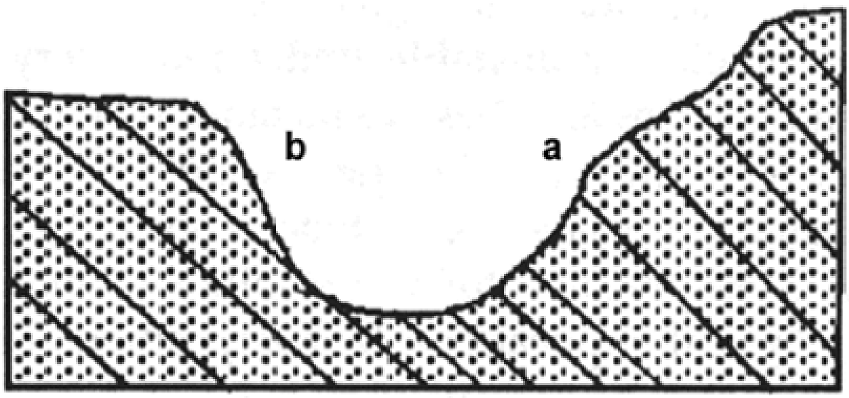

Figure 5: Rocks dipping away from the valley (condition as shown at part a) and dipping into the valley (shown in part b)

2.4.2. Morphological Causes

a. High Relief or Steep Slopes: Some slopes are very stable even when very steep (60°-90°), whereas others are inherently unstable and may fail even at very gentle angles. The nature of slope may be a deciding factor in defining the stability of the area. Nature of slope means the type of material of which the landmass is made of (soil or rock) and the angle of inclination. Any mass forming a slope is subjected to two types of forces:

- Resisting forces
- Driving forces

The most important resisting force is undoubtedly the shearing resistance of the mass, which in simplest case is given by:

$$\tau = c + \sigma Tan\phi \text{ ------------ (i)}$$

Where,

t = shearing strength

c = cohesion of the material

s = normal stress

f = angle of internal friction of the mass

Among the driving forces, the most important is the pull due to gravity which acts through the weight of the material. Any mass at a given place remains stable when resisting force is dominant or at least in equilibrium with the driving force, otherwise, mass becomes unstable. This can be explained in simple case by assuming a mass M forming a slope angle b and resting over a possible surface of planar failure (Figureure 3).

RF = CA + W Cos b + Tan f ---------- (ii)

IF = W Sin b ------------------ (iii)

Where,

A = area of block at the contact

For the analysis of factor of safety (FoS), the following relation is used.

$$FoS = \frac{CA + W\,Cos\beta + Tan\phi}{W\,Sin\beta} \text{ ---------- (iv) (from ii and iii)}$$

Conditions:

i. If FoS> 1 stable condition

ii. If FoS< 1 unstable condition

iii. IfFoS = 1 state of equilibrium

b. Undercutting (toe cutting) of banks by deeply incised rivers and streams.

c. Tectonic upliftment or subsidence

2.4.3 Physical Causes

a. Intense Rainfall (Role of Water)

Much importance is attached to the role of water-both surface and subsurface, in causing mass movement. Water may act directly to reduce the shearing strength of a rock or soil mass in a number of ways (Figure 6).

i. Water that penetrates the soil and rocks cause pore-pressure. It then reduces the normal stress (s) of the mass affecting its shearing strength adversely i.e.

$$\tau = c + (\sigma - p)Tan\phi \text{ -------(v)}$$

Where,

P = pore -water pressure.

Note only the pore-pressure upward, water accumulating at the back of the mass add directed water pressure to increase the value of driving force i.e.

Driving force=W Sinb+q

Therefore,

$$\text{FoS} = \frac{CA + (W\,Cos\beta - P)Tan\phi}{W\,Sin\beta + q} \quad \text{(From iv)}$$

Where,

q = directed water pressure

Equation (vi. shows that both pore-pressure (P) and directed water pressure (q) reduces the value of FoS thereby causing mass movement. This clearly indicates that water has great role for landslides.

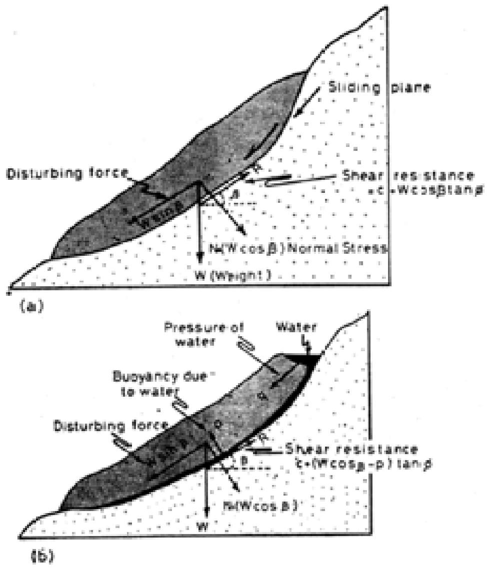

Figure 6: Diagram showing the role of water for mass movement and landslide

ii. Another way of water to weak the mass is through its repeated change of state with climate change. Water freezing (at night) within the pores exert mechanical pressure due to increase in volume while in melting chemical weathering cause instability. In cold regions, frost action has been found to be the primary cause for rock falls from high steep slopes.

iii. Groundwater may cause disintegration of rocks by its flow velocity within the cracks, joints and pore-spaces. This may be particularly prominent in weakly cemented rocks. The solvent action of water should also not be underestimated. In rocks like gypsum and limestone, or in those rocks which have soluble minerals, water may gradually remove the soluble components reducing the shearing strength of the mass.

iv. Water also facilitates mass failure through its lubricating action. When water moves along a plane of weakness e.g. a joint set, a fault plane, shear zone or a bedding/foliation/cleavage planes, that plane gets lubricated thereby decreasing the frictional forces and promoting failures.

b. Rapid snow melt or Glacier Lake Outburst Flood (GLOF) activation

c. Volcanic eruption, etc.

All the above mentioned activities ultimately reduce the shearing strength of the rocks.

2.4.4 Human (Anthropogenic) Causes

a. **Deforestation:** It makes the area bare and loose thereby accelerating soil erosion and landslides. As we know, the roots of plants bind the soil and increase soil shear strength. They also help to reduce the pore-water pressure by evapo-transpiration process. The leaves and branches intercept the direct impact of raindrops and hence check the rate of sheet erosion. Plants also retard direct runoff over land. Litter absorbs water or moisture. They also provide surface cover against surface erosion.

b. **Improper Land Use:** This includes agricultural practices on steep slopes, irrigation on steep and vulnerable slopes, overgrazing and quarrying or mining for construction materials without consideration of terrain condition.

c. **Construction Activities:** Placement of infrastructures such as roads, canals on hilly regions without terrain capability evaluation may result in many types of landslides. During construction, marginally stable slopes become unstable and blasting vibrations make the rocks weak.

d. Water leakage from utilities is equally significant for many types of landslides in hilly areas.

2.5 Triggering Factors of Landslides

The major causes of landslides are not the same as the causes of triggering (unexpected incidence or initiating factors) of slides. The main triggering factors are:

i. Cloud burst (200-1000 mm per day)
ii. Uncontrolled flow of water on slope
iii. Toe cutting by rivers
iv. High strength quake
v. Blasting vibrations
vi. Flash floods
vii. Failure of landslide dams, etc.

2.6 Slope Stability Analysis (Rock Slope Failure)

Rock slopes usually fail as a result of the presence of structural weaknesses in the rocks. A brief description of theoretical background of various types of failures is given in Figure 7.

Plane Failure: This type of failure occurs mainly in stratified rocks when the strata dip towards the slope and the daylight in the slope. The plane on which sliding occurs must strike parallel or nearly parallel to the slope face. Second most important point is that the failure plane must daylight on the slope. In other word, the dip of strata should be smaller than the dip of the natural slope. Similarly, when we consider the friction, the failure plane must be greater than the angle of friction of this plane (Figure 8).

Wedge Failure: The conditions for this type of failure are (i. the line of intersection of the two planes on which sliding is to take place should be exposed to the slope, (ii. the dip of line of intersection of the two planes must be greater than the angle of internal friction (Figure 9).

Toppling Failure: For the case of toppling, the dip direction of natural slope and the slope of bedding, foliation or discontinuity plane should be in opposite direction and the dip amount of the discontinuity plane or bedding plane should be steeper than the natural slope (Figure 10).

Circular or Rotational Failure: It occurs along a surface that develops only partially along joints, but mainly crosses them. This failure can only happen in heavily jointed rock masses with a very small block size and/or very weak or heavily weathered rock mass. It is essential that all the joints are oriented favorably so that planar and wedge failures or toppling is not possible.

The mechanics of different types of failure is described in considerable detail in Hoek and Bray, 1981.

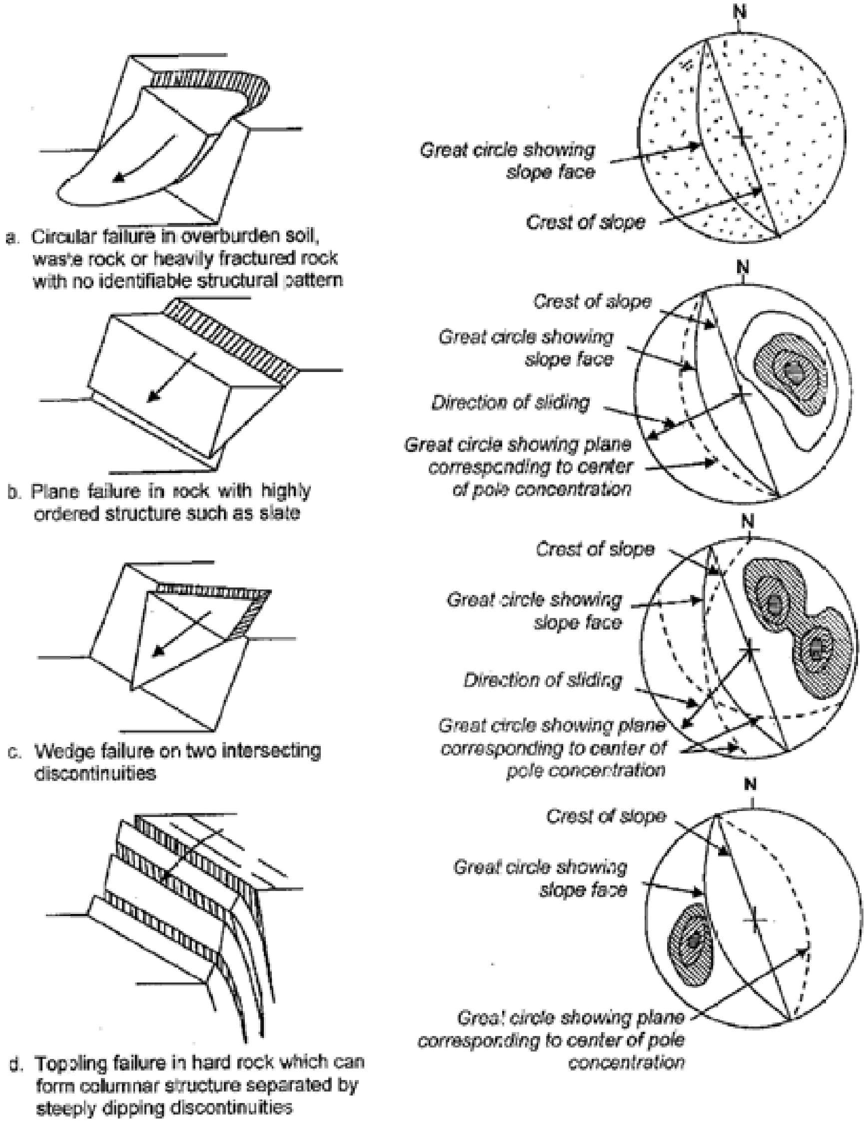

Figure 7: Sketches showing the condition of plane, wedge and toppling failures in nature

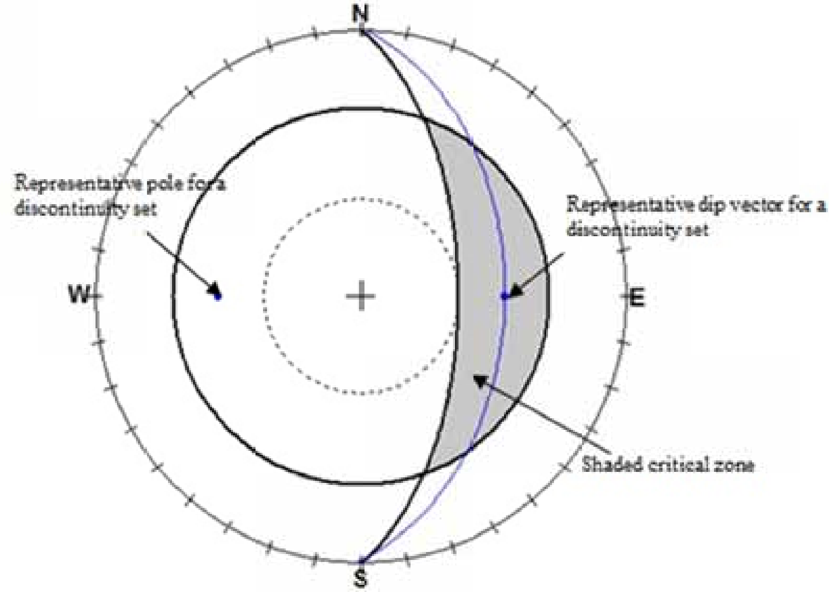

Figure 8: Stereographic projections showing the condition of plane failure

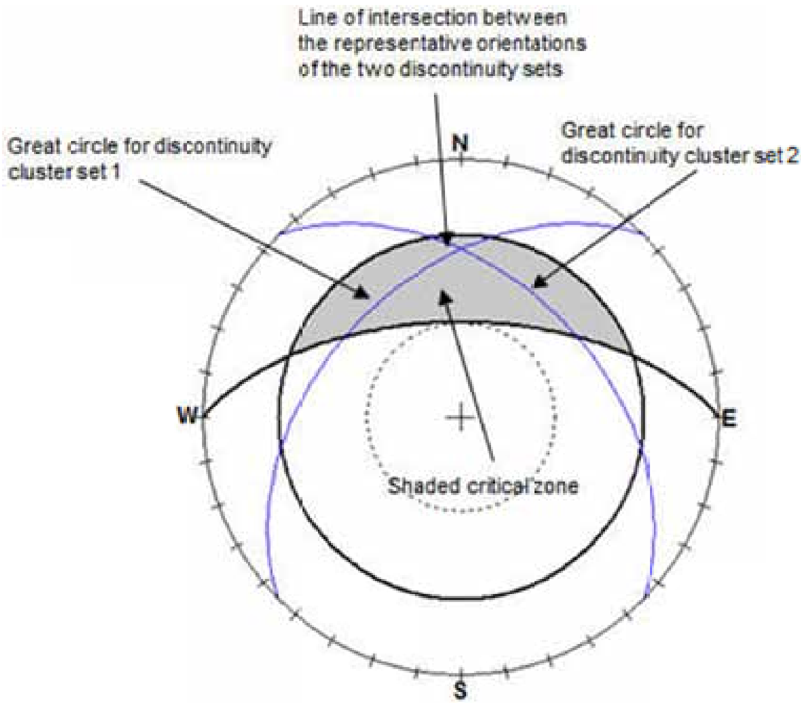

Figure 9: Stereographic projection showing the condition of wedge failure

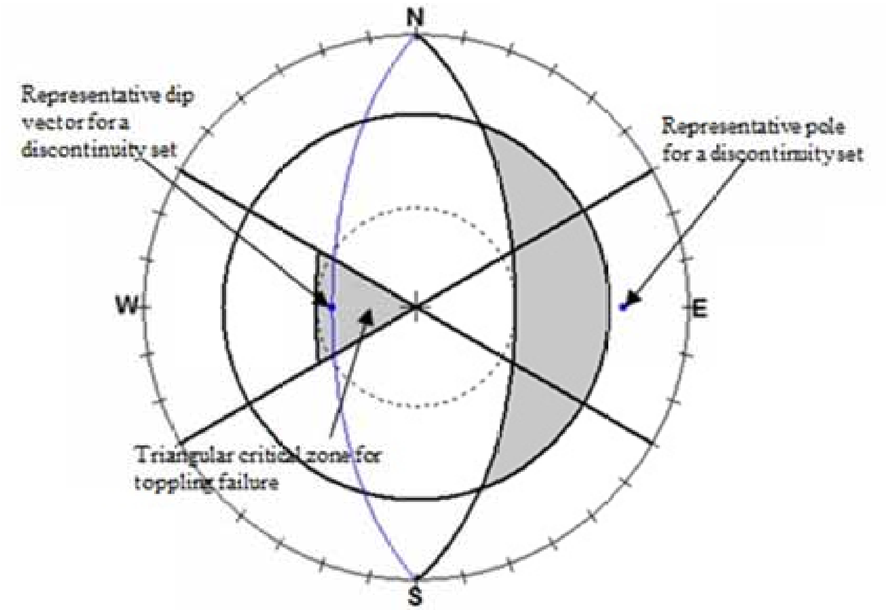

Figure 10: Stereographic projection showing the condition of toppling failure

2.7 Preventive Measures for Landslides

The preventive measures are based on:

i. Possible damage on human life

ii. Damage on public structures like buildings, roads, canals, bridges, hydropower, etc.

iii. River flooding due to river damming

Activities

i. First of all, landslide hazard mapping is essential. It helps to identify the hazardous zone. Details of preparation of hazard map is given in Anbalagan (1992) and Deoja et al. (1992).

ii. Geophysical surveys especially resistivity or seismic refraction methods are required to find the slip surface (if present), ground water table, moisture condition, bed rock depth, etc.

iii. Engineering geological as well as geological map should be prepared and analysed.

iv. The dimension of slide, potential failure, causes and types of landslide should be identified.

(v) Based on above investigation and data collection, the way of controlling the landslide can be decided properly.

The main methods are described briefly as follows:

i. Drainage Management: Water is always the cause, and drainage is the first cure for landslide. Management of both surface and sub-surface water by drainage and river training system reduces slope movement.

ii. **Use of Retaining Structures:** These increase the resisting force and support, e.g. gabion walls, reinforced walls, breast walls, etc.

iii. **Slope Reinforcement by Rock Bolting:** Rock bolts work best in rocks that are jointed or bedded with planes of discontinuity inclined down slope. They are usually composed of steel rods, drilled and inserted at angles to the planes of weakness, and contain a wedge or expansion device to secure them to the rock.

iv. **Slope Treatment**

a. By fattening the slope to ensure stable limits.

b. Decreasing the load from the slope.

v. **Afforestation**

Plants reduce the rate of infiltration. It also contributes to the loss of moisture by evapo-transpiration thereby reducing the volume of water for causing failure.

vi. **Bioengineering (Biotechnical Stabilization)**

a. Provides cover against soil erosion

b. Increase shear strength of soil

c. Reduce groundwater table or moisture content

d. Stop gulley erosion, etc.

vii. **Terracing of slope and grass planting**

2.8 Landslide in Nepal

The Himalaya is said to be the most active and fragile mountain range in the world, it is a live mountain with active tectonics. The rocks of the Himalaya are moving upwards as well as horizontally southwards along the major thrusts like the Main Central Thrust (MCT), the Main Boundary Thrust (MBT) and The Himalayan Frontal Thrust (MFT). The compression resulting from the northward movement of the Indian Plate against the rigid Tibetan Plate has also given other faults and folds except these three master thrusts of the Himalaya. Some of these adverse geological structures are small whose extension is limited to the local area while others are large and extend regionally. Some of the faults and thrusts are still active while some are inactive and of various orientations. In general, the presence of a large number of thrusts, faults, folds and joints makes the rocks of the Himalaya inherently weak. Rocks lying at and adjacent to the faults or thrust, lying at the core and axis of folds, and those that are highly jointed, fractured and sheared are particularly weak. The major causes of landslide may not be similar in different geomorphic or geological zone of the Himalaya. The major causes of landslide in different geomorphic zones is briefly described as below.

Tarai Zone: This zone represents the northern edge of the vast alluvial Indo-gangetic basin. It is the southernmost tectonic division of Nepal. In the north, it is bounded by the Main Frontal Thrust (MFT) or also called the Himalayan Frontal Thrust (HFT). Within Nepal, the Tarai plain gradually rises about 100 m in the south to 200 m in the north. It is made up of Pleistocene to recent alluvium with an average thickness of 1500 m. The Tarai Zone shares a significant proportion of current Himalayan stress accumulation which has resulted in several thrust and folds beneath the sediments. Tarai zone of Nepal is safe from landslides.

Siwalik Zone: Physiographically, Chure Pahad and Dun valleys lie on the Siwalik zone. It is bounded by the Main Boundary Thrust (MBT) to the north and the MFT to the south. It constitutes the southern foothills of the Himalaya. They are generally covered with thick forest and comprise the youngest sedimentary rocks in the range. In general, the rocks dip northwards and the overall strike is East-West.

Rocks of this zone are divided into three parts:

i. The Lower Siwaliks: consisting of fine grained sandstone, mudstone, siltstone and shale.

ii. The Middle Siwalik: is marked by medium grained, thick sandstone beds. Compositionally, sandstone contains abundance of biotite (black colored) and light-colored quartz and feldspar. These sandstones have acquired the nick name 'salt and pepper' sand stone.

iii. The Upper Siwalik: is characterized by very coarse grained rocks such as boulder conglomerates.

Geomorphologically, the Siwalik hills exhibits a very immature topography with highly 'rugged terrain'. Rocks are soft and fragile in nature. Most of the Siwalik rivers are seasonal. There are several both regional and local folds and faults in the area. The major hazard of the region is landslide. The main causes of landslides are soft and fragile nature of rocks, high slope, active tectonic stress (MFT), immature topography, toe cuttings of rivers, hill cutting during road constructions and infrastructural developments, etc.

Lesser Himalayan Zone: It is bordered to the south by the MBT and to the north by the MCT. Three physiographic units i.e. the Mahabharata Range, Midlands and frontal parts (southern part) of the Fore Himalaya belong to the Lesser Himalayan zone. The zone is made up of mostly unfossiliferous meta-sedimentary and metamorphic rock such as shale, sandstone, limestone, dolomite, slate, phyllite, schist, marble and quartzite, ranging in age from Precambrian to Eocene-Oligocene. The rocks in this zone are highly folded and faulted, hence have developed very complicated structures. It is also described by a word fold-and-thrust belt in the Himalaya. The Lesser Himalaya of Nepal shows much variation in stratigraphy, structure, and magmetism. Topographically, the Mahabharat Range has rugged terrain but the Midlands, in contrast to other physiographic divisions, exhibit a mature topography. The main hazards in the region are landslide mainly slope failure and debris flow, soil erosion, toe cutting action of rivers, etc. The major causes of these landslide related hazards are due to high slope, presence of geological structure such as folds, faults, joints etc., activity of MBT and MCT, inherently weak geological setting, concentrated precipitation within three months, deforestation and improper land use.

Higher Himalayan Zone: The hills of the Fore Himalaya give way to the snowcapped peaks of the Higher Himalaya to the north. Nepal not only contains the highest peak of the world (Mt. Everest 8848 m) but also the greatest number of peaks over 8000 m altitude. A few major rivers originating north of the Higher Himalaya dissect these ranges forming some of the deepest gorges in the world. Topographically, this mountain range shows extremely rugged terrain, with very stiff slopes and deeply cut valleys. Generally, all terrain above 5000 m may be considered the Higher Himalaya. The southern faces of the Higher Himalaya and Fore Himalaya receive heavy precipitation (2000 mm). on average to nearly 5000 mm south of the Annapurna range). Geologically, the Higher Himalaya is bounded by the MCT in the south and a Normal Fault in the north. This normal fault is called 'The South Tibetan Detachment System (STDS)'. This zone consists of 10-12 km thick succession of high-grade metamorphic rocks. The rocks include gneisses, migmatites, schist, quartzite and marbles. Main hazards in the region are rock fall and GLOF. Major causes of these are due to steep slope and high altitude.

Tibetan Tethys Zone: This zone is the northern part of the STDS and extends to Tibet. This zone is composed of sedimentary rocks such as shale, limestone and sandstones, ranging in age from Cambrian to Cretaceous. In Nepal, the fossiliferous rocks of this (Tethys Himalayan) zone are well-developed in Thak Khola-Manang, Mustang, and Dolpo areas. Most of the High Himalayan peaks of Nepal, including Everest, Manaslu, Annapurna and Dhaulagiri are made up of these Tethys Himalayan rocks; young granites are intruded into them. Lying in the rain shadow of the Himalaya, with an average annual rainfall of less than 250 mm, Inner and Trans Himalayan valleys within this zone experience less frequent landslide than other areas. The most common cause of landslides in this region is the failure of colluvial and moraine/till material on steep valley slopes.

3. Urban Hydrology

3.1 Introduction

The internationally accepted definition of hydrology is "the science that deals with the waters of the Earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reaction with the environment, including their relation to living beings". It provides the scientific basis for explaining and understanding the whole range of water-related activities.

As opposed to conventional hydrology, urban hydrology is a distinctive branch of the broad field of hydrology because the complex interactions of human activity with air, water and land must be collectively taken into account in concentrated settlements (Mc Pherson, 1979). As urban development everywhere has been in continuous states of expansion and flux, urban hydrology contends with the dimension of dynamic change. It is a science investigating the hydrological cycle and its change, water regime and quality within the urbanized landscape and zones of its impact. Urban hydrology is not a new field; it is defined as the interdisciplinary science of water and its interrelationship with urban population. Simply, it means the investigation of hydrological cycle, water regime and quality of water in urbanized territory (Patil, 2015). Urban hydrology is a link in a number of sciences dealing with the problems of ecology, environmental protection, conservation and rational use of the water resources of the Earth (Kupriyanov, 2011). Logically, urban hydrology should be understood as an application of hydrology to phenomena restricted to the urban region.

The processes occurring in the urban hydrological environment shall be understood through urban hydrology. This environment includes the existing metropolitan area, the area for expected future expansion, and the surrounding area which influences the urban water cycle. Included in the concept of urban hydrology are factors such as precipitation, surface runoff, groundwater and water supply affecting inflow to the urban hydrological environment. Evapotranspiration, stream flow, storm drainage, wastewater and groundwater as outflow from the urban hydrological environment are also needed to taken into account.

3.2 Urban Hydrological Cycle

Urban hydrology is a special case of hydrology applied for cities i.e., areas with very high level of human interference with natural processes (Niemczynowicz, 1999). Urbanization influences the land use and interaction between land and water because as urbanization proceeds, an increasing proportion of the total land area becomes covered with impermeable surfaces such as roofs and pavement. Rainfall, which formerly trickled slowly through vegetated areas or soaked into the ground, now runs quickly over the surface to streams which create the crucial difference between urban hydrology and rural hydrology. Urban hydrological cycle changes with respect to time and space, therefore, all the hydrological processes in urban areas must be considered less than the macro scale is the today's major challenge for all developing countries. Human activity in an urban environment produces large quantities of wastes that can find their way into and degrade the quality of the natural waters of the area. Hence, the hydrology of urbanized areas differs notably from that of the same land in its preceding rural condition (Patil, 2015). Principal phases of the urban water cycle are given in Figure 11.

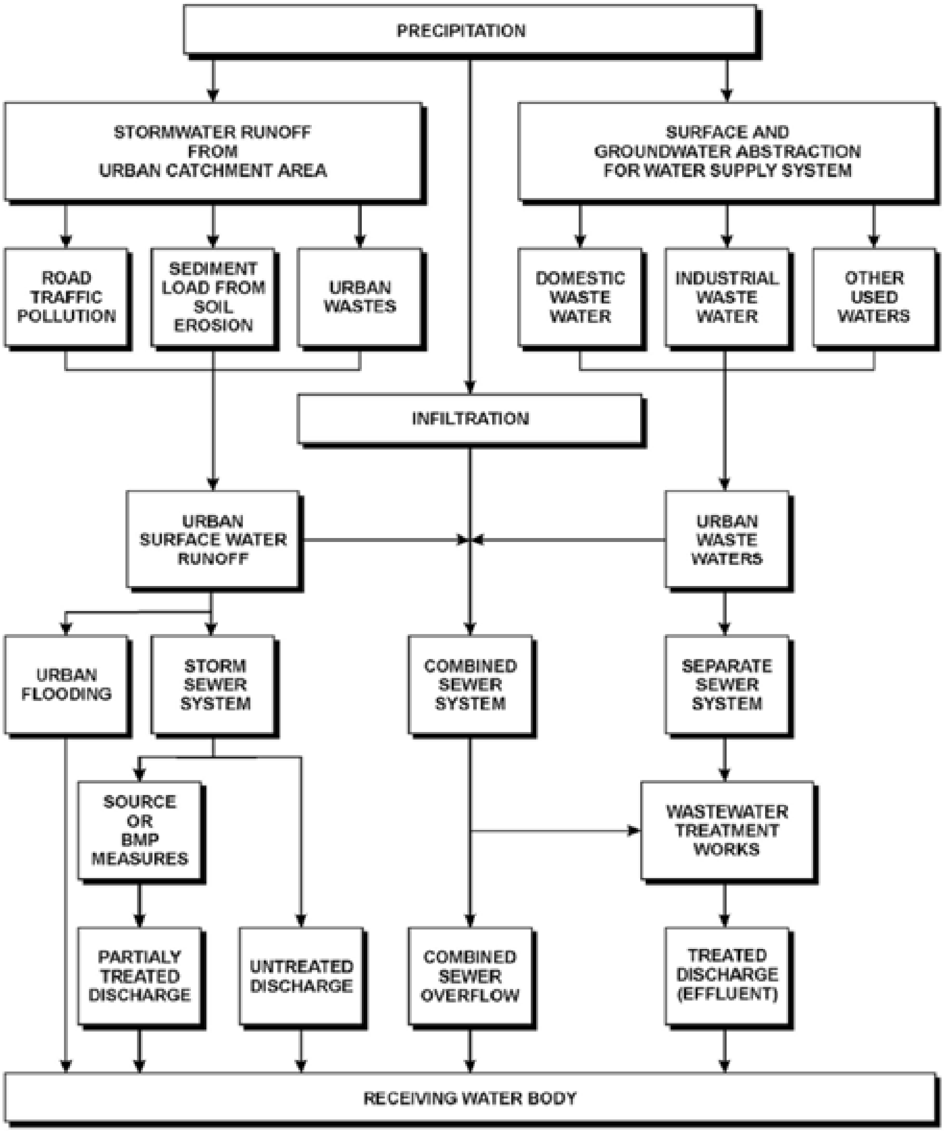

Figure 11: Movement of water in urban environment (Andjelkovic, 2001)

3.3 Changes Forced to Hydrological Setting by Urbanization

In a pre-urbanized catchment, naturally evolved surface flow drainage systems and hydrological processes prevail. Natural storage in a catchment is being made available by the effects of infiltration, vegetation wetting, interception and depression storage. Combined effects of urbanization, industrialization, and population growth greatly modify landscapes and thus the continuous circulation of water within catchments and the Earth's hydrological cycle (Aquatic Habitat, 2017). Urbanization affects the hydrological processes through the changes introduced to the parameters governing the processes. The main changes of the physical pathways of the water cycles due to urbanization include (Aquatic Habitat, 2017; IHE Delft, 2017):

- **Riparian/channel alteration:** Removal of riparian vegetation reduces stream cover and organic matter inputs; direct modification of channel alters hydrology and physical habitat.

- **Reduced interception:** With the removal of vegetation in the catchment, interception of precipitation is reduced allowing higher volume of precipitation to reach the ground.

- **Increased imperviousness:** Changes in land use by the construction of buildings, roads, parking areas and other facilities in the process of urbanization increases the impervious proportion in the land area. With the urbanization, vegetation cover is drastically reduced.

- **Faster conveyance system:** Water drainage system is improved by introducing lined canals, buried sewers to efficiently drain water out from the urbanized area to avoid inconvenience to the public. Changes in hydraulic efficiency of storm water collection systems with artificial channels, storm sewers increase the velocity of flow. In an efficient manner, storm water from roofs are conveyed to storm drains through gutters and downpipes, curbs and gutters are designed to convey storm water away from the road surface to storm drains. Thus, drainage systems quickly convey the runoff directly into receiving waters compared to pre-urbanized setting. The surface topography is altered in open areas to avoid water logging. The retention period of water is reduced.

- **Increased water supply for consumptive use:** Large volumes of piped water are supplied for municipal, industrial and other consumptive uses in an urban area. Sources for supplying this water demand can be various, from a catchment outside urban area, from the head waters of catchment of the urban area or from the area itself. If water is supplied from a source outside the catchment; it means there is more water now in the urban catchment than before. If the water is from the urban area itself, water abstraction can be from the sub-surface storages or from the surface water flow. Increased water supply changes the hydrology in the area, and the effect can be significant specially during the dry weather period.

- **Release of wastewater (urban drainage flows) and sewer systems:** Water is consumed all over the urbanized area and released as wastewater after consumptive use. Wastewater is generated from residences, business and services (e.g. restaurants), industries and released to surface water bodies.

- **Increase in material consumption and commercial activities** – Population increase leads to increase in consumption of material and increase of commercial activities. Therefore, there is an increase in the generation of municipal and industrial wastewater, and solid waste in the catchment. The sources of storm water pollutants are diffuse and highly variable.

3.4 Effects of Urbanization on Surface Flow

3.4.1 Increase in Runoff and Decrease in Time of Concentration

The volume of water available for runoff increases because of increase in the impervious cover provided by roofs of buildings, streets, paved parking lots, lined drains which reduce the amount of infiltration. Before urbanization, much of the rainfall is absorbed by the surrounding vegetation, soil and ground cover. Runoff amounts typically for 10-20% of the average annual rainfall in rural areas where as in city areas, where surfaces are highly impervious, typical runoff volumes range between 60-70% of the average annual rainfall (Aquatic Habitat, 2017).

Provision of man-made drainage systems in the urban area convey the runoff quickly into receiving waters compared to pre-urbanized setting. The retention period of water is reduced and time concentration of flow at a stream section is drastically reduced. Figure 12 shows the typical change brought to flood hydrograph at the outlet of an area due to urbanization. The hydrograph depicts the increase in flood peak due to increased runoff and the reduced time of concentration. The total volume of discharge is increased due to reduction in infiltration. The hydrograph indicates steeper limbs, i.e. the rapid increase and drop in discharge, and this steepness of the hydrograph implies the increase in flash floods brought by urbanization.

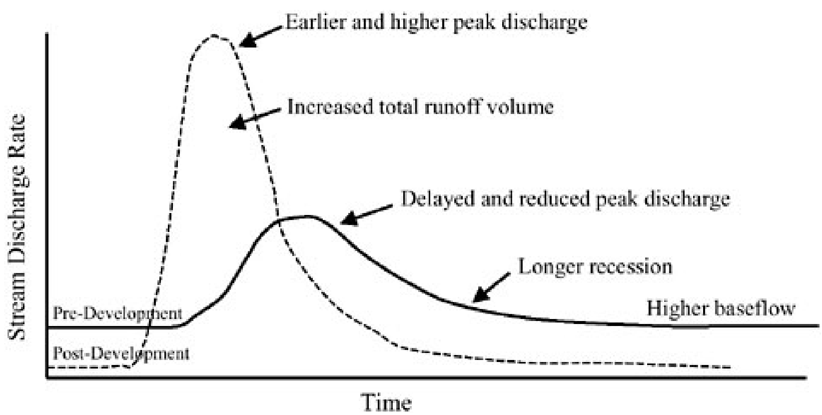

Figure 12: Effect of urbanization on stream flow (National Research Council, 2002)

3.4.2 Increase in Urban Drainage Flow

Water supplied to the urban area is discharged to the drainage system after consumptive use and creates a considerable drainage flow in the sewers. The urban wastewater flow has variations in daily, weekly, monthly, and annual scales. There is relatively little sanitary flow at night, increased flow during the early morning hours as people wake up and prepare for the day, decreased flow during the middle of the day, and finally increased flow again in the early evening as people return home (IHE Delft, 2017).

Weekly variation is mainly due to usage pattern of water that often differs during week days and weekends. Seasonal variations in urban wastewater flows is related to changes in climatic variables, such as temperature and precipitation, and also to the changing habits of customers, such as travel and other activities occurring in summer. Higher drainage flows are evident during summer season compared to winter season.

3.4.3 Changes in Dry Weather Flow

An increase in impervious surface decreases the amount of rainfall available for infiltration. In addition, the man-made drainage reduces ponding time and the detention time of water and thus reduces infiltration. The groundwater recharge is, therefore, greatly reduced and the sub-surface flow is drastically reduced. As a result, streams will lose the potential source of water, and base flow from the catchment reduces.

Dry weather flow in an urbanized catchment depends not only on the base flow but also on the contribution from wastewater flows after consumptive use or urban drainage flow. The urban drainage flow discussed above will enter into the drains and finally to the streams. Drainage flow contribution has a significant share in the dry weather flow (IHE Delft, 2017).

3.4.4 Degradation of Water Quality

Urban drainage flow is expected to be discharged to streams after treatment. However, a certain significant percentage of wastewater may be discharged without adequate water quality treatment. The water quality in the dry weather flow in urban areas can be very poor due to higher contribution from drainage flows. This is a major issue in developing countries today.

The storm runoff is directly discharged into nearby drains and finally to water bodies. Urbanization increases the amount of pollutants in storm runoff, such as sediment, nutrients, organic matter, trace metals (copper, cadmium, lead), pesticides, herbicides and hydrocarbons, and others (IHE Delft, 2017). Soil erosion is increased with the increase of flow and availability of exposed loose soil in urban areas.

Impervious cover increases air and soil water temperatures and can increase temperature in urban discharges. Stream temperature is an important parameter for aquatic habitats. Some of the indicators of the impact of urbanization on water quality include increased stream temperature and pollutants.

3.4.5 Effect on Receiving Water Bodies

Urban area is a part of the catchment of a stream or other water body at the downstream. The peak flow generated by urban areas has a significant effect on the hydraulics and ecosystem in the receiving water bodies. In the case of streams, frequent high flows cause stream bed erosion causing widening of the stream. Also, urbanization directly impacts the quality of the receiving water bodies. The pollutants and suspended matter in the storm water change the nature of the substrate in the receiving body. Habitats of aquatic life are threatened and biodiversity is affected (IHE Delft, 2017).

3.4.6 Urban Heat Build-up and Rainfall Changes

An urban heat island is an urbanized area that's a lot warmer than surrounding suburbs and rural areas. Heat is created by energy from all the people, industries, cars, buses, and trains in mega cities like New York, Tokyo, Paris, and London. Urban heat island is created in the areas having lots of human activities and people. This occurs because in urban areas, there are fewer trees, and other natural vegetation to shade buildings, block solar radiation and cool the air by evapotranspiration. In addition, the materials used in buildings, roads, etc. have significantly high thermal bulk properties, including heat capacity and thermal conductivity, and surface radiative properties (e.g. albedo and emissivity) than the surrounding rural areas. These reasons cause both surface temperature and overall ambient air temperature in an urban area to rise A typical profile of the urban heat island effect and its relationship to the urban landscape is shown in Figure 13.

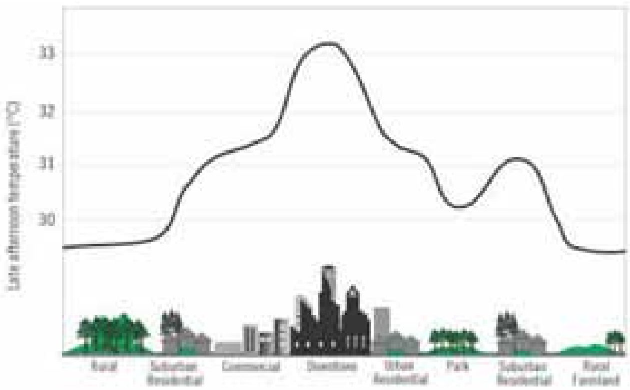

Figure 13: Urban Heat Islands Profile (EPA, 2008)

Due to release of excessive heat, mega cities cause local atmospheric flow to deflect upwards, in effect acting as virtual mountains. As mountains participate in orographic enhancement of rainfall, these convective currents also cause a significant increase of rainfall over and in the vicinity of cities. Converging air due to city surfaces of varying heights, like buildings, also promotes rising air needed to produce clouds and rainfall.

In mega cities like Tokyo, it has been established that there is a significant increase of high intensity rainfall events, and one of the major driving forces of these small-scale enhanced rain events has been identified as the urban heat island effect (IHE Delft, 2017).

3.5 Mitigation of Adverse Impacts of Urbanization

Mitigation of adverse hydrological impacts of urbanization essentially requires a multidisciplinary approach through structural and non-structural measures. The civil engineering components fall mainly to the structural measures. Non-structural measures include measures that do not involve constructions, such as building awareness among the population about the consequences of ad hoc developments on development projects, preparedness for facing floods, introduction of legislations, introduction of environmental impact assessment, etc. that contribute directly towards reducing losses of life and damage to property (Andjelkovic, 2001; IHE Delft, 2017).

3.5.1 Non-structural Measures

Non-structural measures applicable are greatly area specific and depend on the socio-economic, environmental policies of the governing local authorities. Nevertheless, the new urban development projects can be enforced with conditions to maintain natural drainage, minimize the impervious areas to be created, provide sufficient areas for infiltration and storm water storage.

Enforcement of the following provision shall be effective for storm water management (Andjelkovic, 2001):

- temporary storage of excess runoff, i.e. release of runoff during a storm is controlled by imposing mandatory storm water retention or detention facility within the premises
- provisions for floodplain zoning and regulation, i.e. to regulate land use changes, some areas will be prohibited for developments and left out for flood control
- provisions for flood-proofing of buildings, i.e. buildings are required to adopt flood proofing

techniques to cope with floods

- storm water pollution control, i.e. source is controlled by imposing quality standards for wastewater and solid waste disposals in urban environments
- provisions for development of a compatible and coordinated storm water drainage system.

3.5.2 Structural Measures

The traditional methods for urban drainage are the rapid removal of surface water through artificial drainage systems, straightening and channelizing the existing streams. But, these practices shorten the time of concentration and increases the flash floods and peak discharges at the downstream. Therefore, "water storing" approach, focusing on detention, retention and recharge shall be effective instead of traditional "efficient conveyance" approach (Methods, 2003). In most cases, the natural depressions can be used to provide storage as temporary storages or continuous storages for urban flows to relieve the drainage network and the downstream receiving bodies of excess discharges and pollutant loads (IHE Delft, 2017).

3.5.2.1 Flow Detention and Retardation Structures

Detention and retardation structures can be subdivided into storage type and infiltration type. Storage type structures can be on-site storage structures such as large scale detention ponds and retarding basins with a large catchment area or off-site storage structures such as small tanks or reservoirs located in residential units, parking areas, playgrounds, etc. to retard storm water discharges (Methods, 2003). The infiltration type structures include pervious pavements, infiltration trenches, ponds and inlets (Tucci and Porto, 2001).

Detention ponds: Detention pond or retarding basin is a facility for temporary water storage to reduce the flood peaks. When the water level in the stream rises, water spills or flows into the detention pond. When the water level in the stream recedes, water in the detention pond flows back to the stream slowly. Detention ponds are usually constructed at natural depressions.

Retention ponds: Retention pond is a reservoir to retain water and they are not emptied after storms like in the case of detention ponds. There is a residence time provided for water, for pollutants and sediments to settle down on the reservoir bed.

On-site detention ponds: These are small reservoirs or ponds provided in residential and commercial plots. These are enclosures surrounded by concrete walls to collect excess water during a storm and release gradually to the downstream drains by a controlled outlet.

3.5.2.2 Infiltration Type Devices

The main structural measures to improve storm water infiltration in urban area are described below (Tucci and Porto, 2001; IHE Delft, 2017).

Infiltration Trenches*:* Infiltration trenches are provided to enhance the infiltration of storm water into the ground. A trench is excavated in the ground and filled with crushed stone, and the top of the trench is covered by fabric to avoid sediments and debris entering into the trench. Trenches trap the storm water and facilitates infiltration of water into the soil and recharging the groundwater.

Grass Filter Strips*:* These are stripes of grassed soil surfaces introduced between the urban impervious surfaces and the storm drains to slow down and partially infiltrate runoff. This is possible when the storm water discharge can be spilled on to the strip and spread across the width of the grass strip.

Grass Swales*:* These are depressions in the grassed terrain designed to function as small unlined channels in which storm water runoff is slowed down and partially infiltrated along their course. The flow left after infiltration is conveyed to the storm drain system at the downstream.

Pervious Pavements*:* Pervious pavements are permeable surfaces where the runoff can pass and infiltrate into the ground. Pervious pavements facilitate peak flow reduction, ground recharge and pollution filtering. There are three types of pervious pavements: i) porous asphalt pavements ii) porous concrete pavements and iii) garden blocks.

Infiltration Ponds: Infiltration ponds are similar to detention ponds but they are specifically provided to infiltrate the storm water routed there into the soil. They are not usually provided with sluices for releasing water. However, spillways and low level outlets for emergency operations are provided.

Infiltration Inlets: Infiltration inlets are draining structures that replace the gulley holes, or the uptake points for conventional storm water. They are similar to infiltration trenches except that thebottom is also isolated from the soil. The main purpose of the infiltration inlet is to convey the water slowly through it to retard the arrival of water into the storm sewers.

3.5.2.3 Wetlands

Wetlands are shallow ponds with growing aquatic plants constructed across streams at depressions for removal of pollutants in water. They provide a detention time for the water to settle pollutants/sediments and for the aquatic plants to uptake pollutants. A low velocity has to be maintained through wetland and wetlands are effective at removing phosphorus, nitrogen compounds, metals and organic compounds, and sediments in water. However, the required surface area for wetland is large to treat high discharges of storm water runoff (Tucci and Porto, 2001).

3.5.2.4 Flood Proofing

Flood proofing is the use of permanent, contingent or emergency techniques to either prevent flood waters from reaching buildings and infrastructure facilities, or to minimize the damage from water that does get in.

3.6 Urban Catchment Modeling Concepts

The purpose of the urban storm water drainage system is to convey the runoff generated from the urban area safely to a receiving water body which has assimilating capacity. The urban storm water drainage system consists of structures designed to collect, convey, store, detain, treat and release the urban runoff. The urban runoff is contributed by the storm water generated by precipitation to the catchment or snowmelt and urban flows. A peak flow of runoff is required to be used as design flow of the design of storm water drainage system. It is estimated by runoff generated due to a selected storm event which is the dominant contributor and by urban flows.

This design peak flow inflicts requirement of the conveyance capacities of canals and pipes, storage capacities of retention/detention basins, discharging capacities of spillways and gates, etc. in the system. Dry weather flows depends mainly on the urban flows and are specially important in the water quality aspects of the storm water drainage system design (IHE Delft, 2017).

Urban catchment modeling involves simulation of hydrological processes of the urban catchment to derive runoff required for the design of appropriate storm water drainage system. Event-based hydrologic modeling is carried out to estimate flows due to a given storm event and is the tool used for deciding design flows of system components. On the other hand, continuous hydrologic modeling is carried out to derive long-term continuous flows and to understand the long-term variations of flows. The latter is particularly useful in water quality estimations in the system.

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Chapter 2

An Overview of Selected Environmental Management Tools

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1. Introduction

Companies and organisations are delivering different products and services for the benefit of customers. Both service and manufacturing industries are using natural capital in order to deliver their products and services. In doing so, there are chances that their actions might bring potential harmful impacts to the environment. Environmental management tools are, therefore, useful in reducing such environmental impacts while enhancing efficiency of any company or organisation. These tools can support their targets to achieve long term environmental sustainability.

Organisations have been applying different Environmental Management Tools (EMT) based on the nature of their activities. The common EMTs are Environmental Impact Assessment (EIA), Quality Management System (QMS), Environmental Management System (EMS), Life Cycle Assessment (LCA). Moreover, concepts like eco-indicator, eco-labeling and eco-marketing are also gaining popularity these days.

The International Organisation for Standardization (ISO) defines that the management system "is the way in which an organisation manages the inter-related parts of its business in order to achieve its objectives. These objectives can relate to a number of different topics, including product or service quality, operational efficiency, environmental performance, health and safety in the workplace and many more" (ISO, 2017a). Management systems help organisations to establish clear procedures while systematizing their tasks.

The United States Environmental Protection Agency (EPA) considers "an Environmental Management System (EMS) as a set of processes and practices that enable an organisation to reduce its environmental impacts and increase its operating efficiency" (EPA, 2017).

ISO's international standard provides "rules, guidelines or characteristics for activities or for their results, aimed at achieving the optimum degree of order in a given context. It can take many forms. Apart from product standards, other examples include: test methods, codes of practice, guideline standards and management systems standards" (ISO, 2017b).

Some of the common and popular management systems in practice are listed below:

- **ISO 50001 Energy management system**
  - for continual improvement of energy performance
- **ISO 31000 Risk management system**
  - to manage risk
- **ISO 9001 Quality management system**
  - to meet customers' needs
- **ISO 14001 Environmental management system**
  - to improve environmental performance

This chapter aims to provide an overview of some selected management systems in practice.

2. Members of ISO

According to ISO, the members of ISO are the primary standards organisations in respective countries. There can only be a single member per country. Each member represents ISO in its country and individuals or companies cannot become ISO members. According to ISO, there are three member categories that are listed below. The level of access and influence of different types of member over the ISO system varies (ISO, 2017c).

Full members (or member bodies) influence ISO standards development and strategy by participating and voting in ISO technical and policy meetings. Full members sell and adopt ISO International Standards nationally.

Correspondent members observe the development of ISO standards and strategy by attending ISO technical and policy meetings as observers. Correspondent members can sell and adopt ISO International Standards nationally.

Subscriber members keep up to date on ISO's work but cannot participate in it. They do not sell or adopt ISO International Standards nationally.

Box 1: ISO: a global network of national standards bodies

ISO is an independent, non-governmental international organisation with a membership of 163 national standards bodies. Through its members, it brings together experts to share knowledge and develop voluntary, consensus-based, market relevant International Standards that support innovation and provide solutions to global challenges.

ISO's portfolio of over 21,300* standards provides business, government and society with practical tools for all three dimensions of sustainable development: **economic, environmental** *and* **social**. ISO standards provide solutions and achieve benefits for almost all sectors of activity, including **agriculture**, **construction**, **mechanical engineering**, **manufacturing**, **distribution**, **transport**, **medical devices**, **information and communication technologies**, **the environment**, **energy**, **quality management**, **conformity assessment** *and* **services**.

ISO only develops standards for which there is a clear market requirement. The work is carried out by experts in the subject drawn directly from the industrial, technical and business sectors that have identified the need for the standard, and which subsequently put the standard to use. These experts may be joined by others with relevant knowledge, such as representatives of government agencies, testing laboratories, consumer associations and academia, and by international governmental and non-governmental organisations.

An ISO International Standard represents a global consensus on the state of the art in the subject of that standard.

* September 2016

For more information, please visit www.iso.org.

Source: https://www.iso.org/

Box 2: NBSM: Full Member of ISO

Nepal Bureau of Standards and Metrology (NBSM) is the National Standard Body in Nepal. It is a government organisation under the Ministry of Industry. It is also the national enquiry point/nodal point for World Trade Organisation (Technical Barriers to Trade and Non-Tariff Measures) and focal point for National Authority on Disarmament Affairs (NADA).

NBSM is a full member of International Organisation for Standardization (ISO) from January, 2014. In addition, NBSM is a corresponding member of the Organisation for International Legal Metrology (OILM), founder member of Asia Pacific Metrology Programme (APMP) and an affiliate member of International Electro-technical Commission (IEC).

The objectives of NBSM are:
- Harmonious development of standardization, marking and quality certification
- Harmonious development of scientific and legal metrology.
- To facilitate development of production and exports.

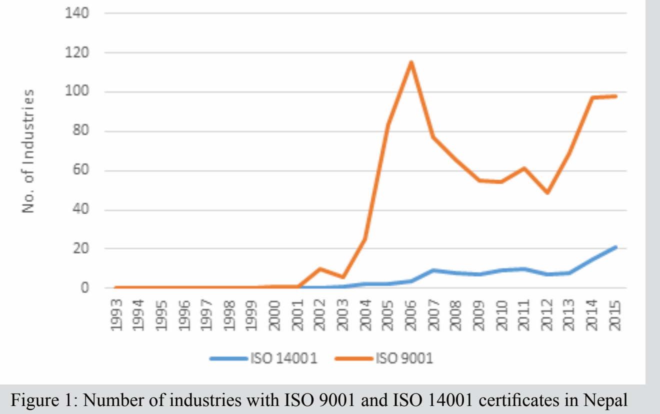

Figure 1: Number of industries with ISO 9001 and ISO 14001 certificates in Nepal (Data Source: ISO, 2016)

The main activities of NBSM are :
- To formulate national standards;
- To operate the product certification mark;
- To provide testing facilities and technical services in the fields of System for Monitoring Quality of Care (SMQC)
- To work as the third party guaranteeing agency
- To provide service for lot certification and pre-shipment inspection, as well as laboratory recognition
- To launching of consumer awareness programmes on quality
- To Provide laboratory services for testing of various commodities and
- To Involve in environment protection.

Additional activities include legal metrology and calibration services for weighing and measuring devices. Initiation on industrial and scientific metrology is in progress.

Source: NBSM, N.D., NBSM, 2017 and ISO, 2017d

3. Quality Management System

ISO 9001 series of standards set out the requirements for a quality management system. These standards are useful to companies and organisations to increase efficiency and improve customer satisfaction. ISO has launched a new version of the standard, ISO 9001:2015 replacing the previous version ISO 9001:2008.

A quality management system helps organisations to meet the requirements of its customers and other stakeholders affected by their work. ISO 9001 is based on the idea of continual improvement (ISO, 2015a). The organisations applying these standards need to specify their own objective and targets related to "quality" and make plans accordingly to meet these objectives.

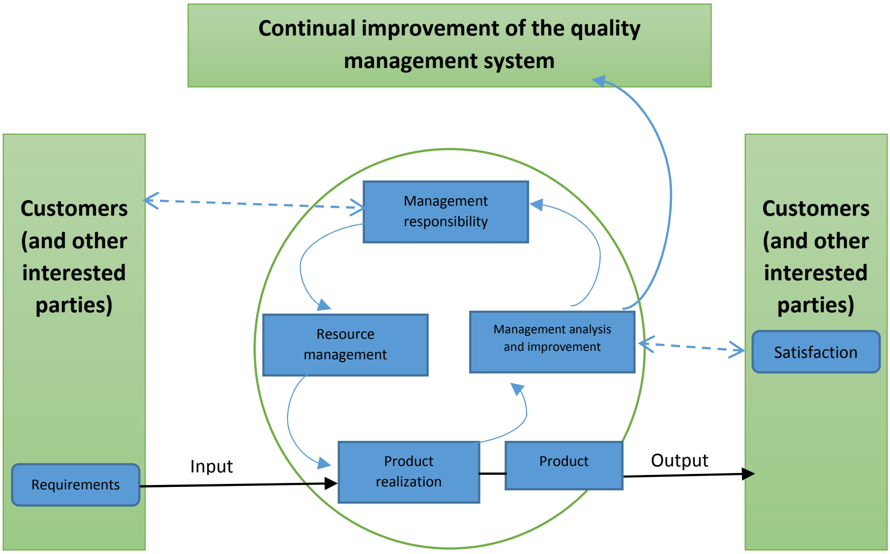

Figure 2: The ISO 9000 process approach (ISO, 2009)

The ISO 9001 is suitable for all types of organisations regardless of their sizes and sectors. The revised version of ISO standards (ISO 9001:2015) is appropriate for all types of businesses. Due to the availability of many resources to assist companies, even a small company without any dedicated staff to deal with ISO standards can implement ISO 9001:2015 standards easily.

4. Principles of Quality Management

According to ISO, "Quality management principles" are a set of fundamental beliefs, norms, rules and values that are accepted as true and can be used as a basis for quality management (ISO, 2015b). There are seven quality management principles (QMPs). All ISO 9000 series standards are based on these seven principles. Organisations firmly adopting these seven principles will find it easier to implement a quality management system.

The ISO has identified the following seven pillars (ISO, 2015b) as foundations of quality management system.

1. **Customer Focus:** The primary focus of the quality management is meeting customer needs that result in long term success of the companies. Companies not only need to satisfy the need to the customers at present but should also adapt to their future needs.
2. **Leadership:** Strong leadership is a key to the success of any company. A unified direction that usually comes from strong leadership is essential to ensure that everyone has the same understanding about company's goals.
3. **Engagement of People:** Any company can prosper if they have competent, empowered and engaged people at all levels. This helps them reach out to their customers effectively.
4. **Process Approach:** Understanding activities as processes that link together and function as a system helps to achieve steady and predictable results. The staff and the organisational processes cannot be isolated. Everyone should be familiar with the company's activities which supports in improving efficiency.

5. **Improvement:** Every organisation should emphasize on continual improvement if they want to attain sustained success. Both proactive and reactive approaches should be taken to adjust internally based on the changes in external environment. This helps companies to continue to deliver value for their customers. Hence, spontaneity matters in todays' world as conditions evolve so quickly.
6. **Evidence-based Decision Making:** Evidence based planning and decision making helps to produce the desired results more easily and thereby improves the performance of any company. Making decisions without solid evidence naturally involves a degree of uncertainty.
7. **Relationship Management:** It is difficult for companies to work in isolation or in a vacuum. Companies should identify and foster important relationships. There should be a good relationship with suppliers including other stakeholders in order to plan and manage effectively for sustained success.

Box 3: ISO 9001 and ISO 14001 - Certificates by industrial sector

EA* Code Nos.	ISO by Industrial Sector
1	Agriculture, fishing
2	Mining and quarrying
3	Food products, beverages and tobacco
4	Textiles and textile products
5	Leather and leather products
6	Wood and wood products
7	Pulp, paper and paper products
8	Publishing companies
9	Printing companies
10	Manufacture of coke & refined petroleum products
11	Nuclear fuel
12	Chemicals, chemical products & fibres
13	Pharmaceuticals
14	Rubber and plastic products
15	Non-metallic mineral products
16	Concrete, cement, lime, plaster, etc.
17	Basic metal & fabricated metal products
18	Machinery and equipment
19	Electrical and optical equipment
20	Shipbuilding
21	Aerospace
22	Other transport equipment
23	Manufacturing not elsewhere classified
24	Recycling
25	Electricity supply
26	Gas supply
27	Water supply
28	Construction
29	Wholesale & retail trade; repairs of motor vehicles, motorcycles & personal & household goods
30	Hotels and restaurants
31	Transport, storage and communication
32	Financial intermediation, real estate, rental
33	Information technology
34	Engineering Services
35	Other Services
36	Public administration
37	Education
38	Health and social work
39	Other social services

* EA = European Accreditation

Source: ISO, 2017

5. Environmental Management System

All organisations are concerned with achieving and demonstrating sound environmental performance. For this, they try to control their activities, products and services that might have direct impacts on the natural environment. Nowadays they are even trying to streamline environmental policies and approaches to reduce environmental impacts. Many organisations voluntarily conduct assessments and regular audits to assess their environmental performance. Such assessments and audits done on their own initiative may not be sufficient to provide assurance that its performance are met vis-à-vis its legal and policy requirements.

International standards covering environmental management provide organisations the basic elements of an effective environmental management system (EMS) which helps them to achieve their business and environmental goals. These standards can be applied to all types and sizes of companies located at different geographical locations and cultural and social conditions. The basis of the approach is shown in Figure 3. An EMS encourages a company to continuously improve its environmental performance.

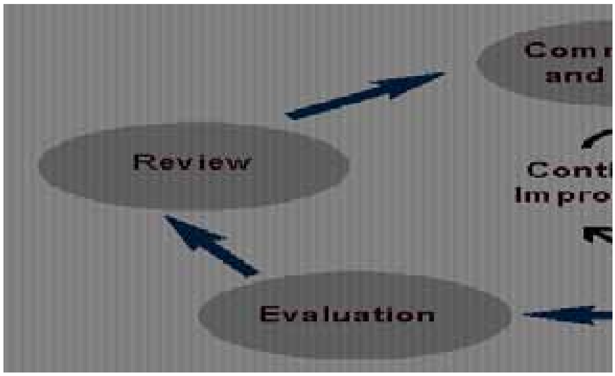

Figure 3: The continuous improvement cycle (EPA, 2017)

Figure 4 shows the evolution of environmental management since the wave of environmental awareness in the early 1960s. It illustrates the short history of the current concept of environmental management.

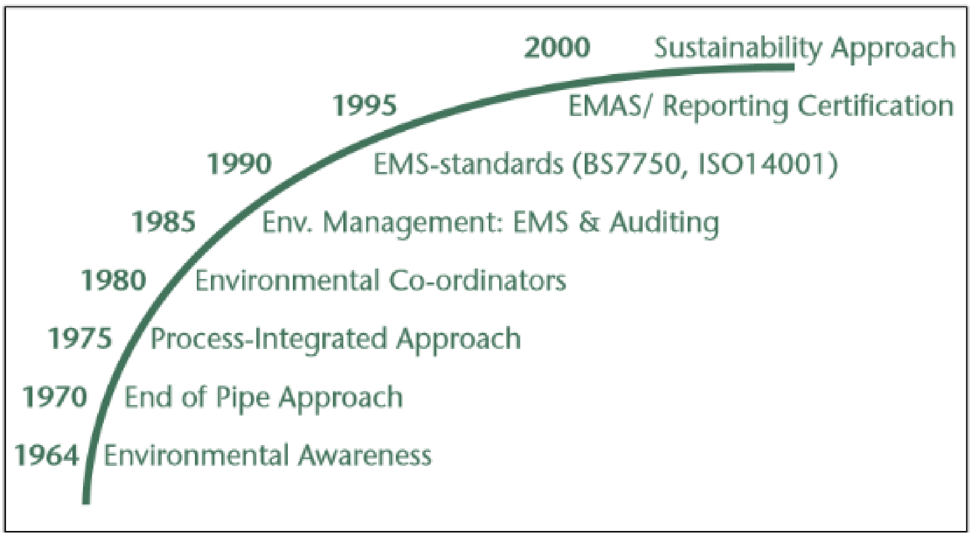

Figure 4: Development of the idea of environmental management (UNEP/ICC/FIDIC, 1996, p.4 - modified by Weiß and Bentlage, 2006)

In the early 1990s, work was initiated by the British Standards Institution (BSI) to develop an EMS specification, which was first published as BS 7750. National EMS standards were also published in Spain and Ireland (Brady, 2006).

At around the same time, the European Commission (EC) was developing the Eco-management and Audit Scheme (EMAS), which was similar to BS 7750, but included some additional requirements. The requirements of EMAS were published as Council Regulation 1836/93 in 1993 (EC, 1993). After the publication of BS 7750, the International Organisation for Standardization (ISO) developed ISO 14001 - Environmental Management Systems - Specification and Guidance for Use (ISO, 2004) (Figure 5).

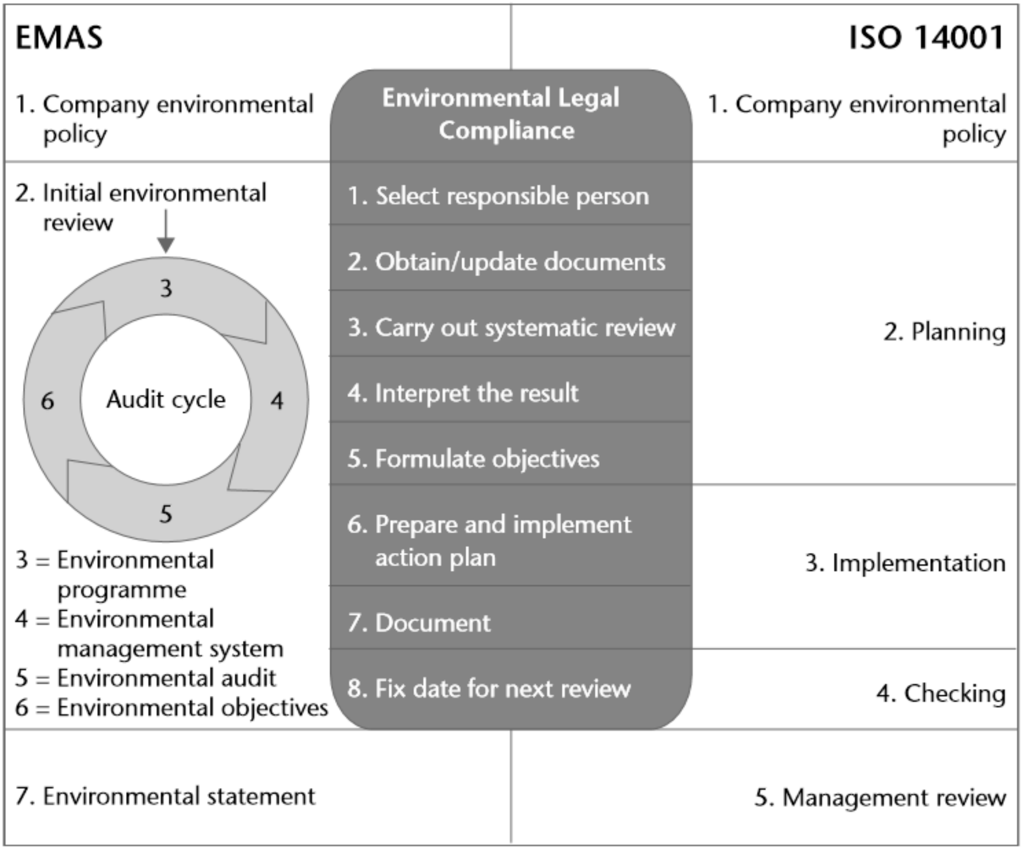

Figure 5: The linkage between ISO 14001 and EMAS (INEM, 1998, p. 73 cited in Weiß and Bentlage, 2006)

Its adoption as a European Standard by the European Committee for Standardization meant that in Europe, all similar national standards were required to be withdrawn. Afterwards, a new British Standard, BS 8555 - for the phased implementation of Environmental Management Systems - has been published (BSI, 2003).

Although the development of different standards at the national, European and then international level, was potentially confusing, all of the EMS standards followed the Deming Cycle (Figure

6) of: **PLAN** what you're going to do, **DO** what you planned to do, **CHECK** to ensure that you did what you planned to do, and **ACT** to make improvements.

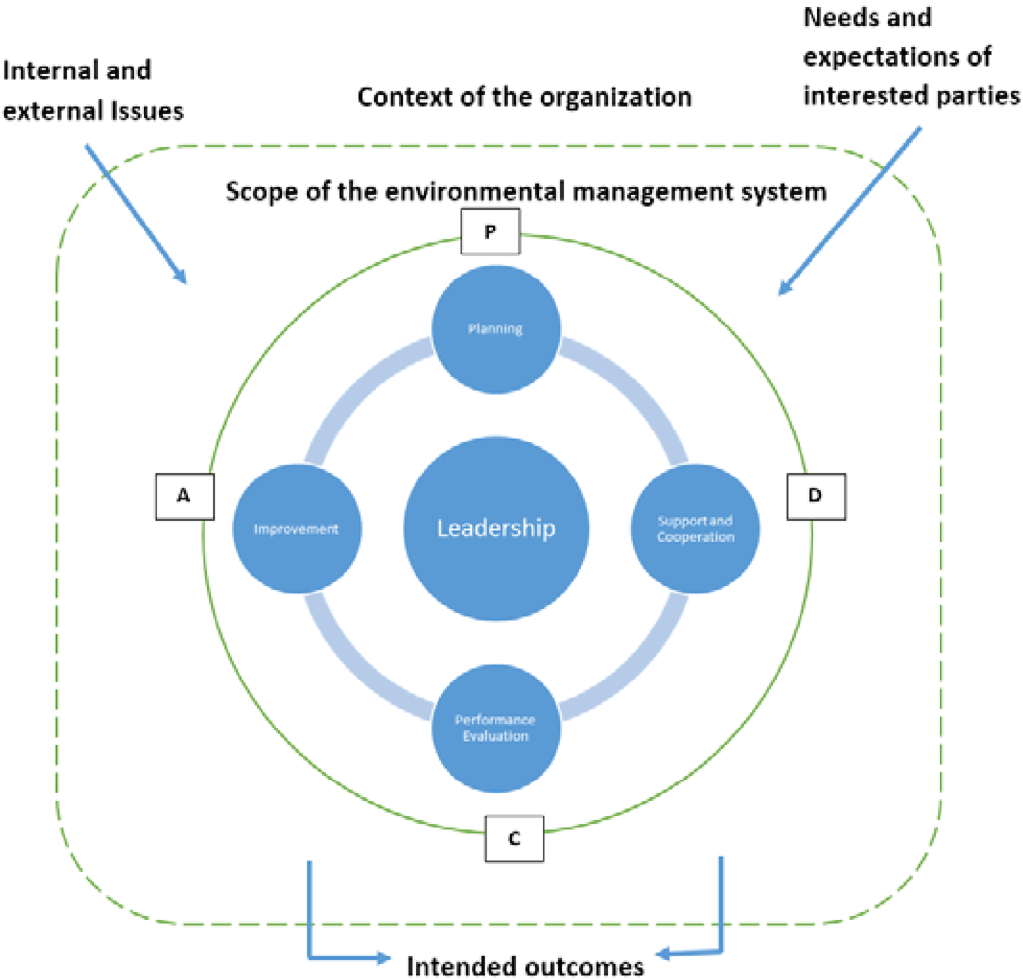

Figure 6: ISO14001:2015 Plan-Do-Check-Act Model (ISO, 2015c) - based on Deming's cycle

An EMS is, therefore, a framework that help companies achieve their environmental targets through regular control of its activities. It is assumed that increased control will improve the environmental performance of any company. EMS can be tailed based on company's business and environmental goals.

6. Benefits of ISO 14001

There are many reasons why an organisation applies ISO 14001 in order to improve environmental performance. According to ISO, based on the reports from its users, the key benefits of applying this standard are (ISO, 2015d):

- Demonstrate compliance with current and future statutory and regulatory requirements
- Increase leadership involvement and engagement of employees
- Improve company reputation and the confidence of stakeholders through strategic communication
- Achieve strategic business aims by incorporating environmental issues into business management
- Provide a competitive and financial advantage through improved efficiencies and reduced costs
- Encourage better environmental performance of suppliers by integrating them into the organisation's business systems

Box 4: Benefits from effective EMS programmes

- Improved environmental performance (e.g., reduced emissions and natural resource use)
- Cost savings through reduced chemical, raw material, and utility use; lower emission and disposal fees; reduced medical and biological monitoring; and lower administrative costs
- Increased knowledge and control of environmental, health, and safety issues by everyone in the facility
- Encouraged holistic, multi-media approach to environmental management
- Increased awareness and better management
- Better ability to prioritize environmental issues (i.e., what the company should focus on)
- Improved ability to provide project justification based on costs and benefits
- Increased employee awareness and pride.
- Reduced liability
- Improved customer relations
- Increased green and niche marketing opportunities
- Increased innovation
- Increased profitability

Source: The National Environmental Education and Training Foundation, 2001

7. Stages of an EMS

The five main stages of an EMS, as defined by the ISO 14001 standard, are described below (EPA, 2017):

i. Commitment and Policy

Company's top management is responsible to develop its environmental policy. The management's commitment in a form of policy is the foundation of the EMS.

ii. Planning

Firstly, the environmental issues related to activities of the company are identified such as air pollutants or hazardous waste that can have negative impacts on people and/or the environment. Secondly, the company needs to determine which issues are significant based on their magnitude and extent of impacts. Appropriate prediction techniques have to be applied.

For example, a company then can choose to reduce air pollutants that are released during manufacturing process. Based on this, the company sets its environmental objectives and targets.

iii. Implementation

A company implements its action plan mobilizing its human, financial and material resources. In order to execute the plans, trained employees aware of environmental issues is a must. Other steps in the implementation stage include documentation, following operating procedures, and setting up internal and external communication lines.

iv. Evaluation

A company monitors its operations to evaluate whether targets are being met. If not, the company takes corrective action.

v. Review

Top management reviews the results of the evaluation to see if the EMS is working. Management determines whether the original environmental policy is consistent with company values. The plan is then revised to optimize the effectiveness of the EMS. The review stage creates a loop of continuous improvement for a company.

8. Example of Success with ISO 14001

Organisations using ISO 14001 have found success across a range of areas, including reduced energy and water consumption, a more systematic approach to legal compliance and an improved overall environmental performance.

Box 5: Understanding an object and a target

An environmental objective is defined as an: 'overall environmental goal, arising from the environmental policy, that an organisation sets itself to achieve, and which is quantified wherever possible'.

An environmental target is a: 'detailed performance requirement, quantified where practicable that arises from the environmental objectives and that needs to be set and met in order to achieve those objectives'.

According to ISO 14004, objectives can include commitment to:

- Reduce waste and the depletion of resources
- Reduce or eliminate the release of pollutants into the environment
- Design products to minimize their environmental impact in production, use and disposal
- Control the environmental impact of raw material sourcing
- Minimize any significant adverse environmental impact of new developments
- Promote environmental awareness among employees and the community

Progress towards an objective can generally be measured using environmental indicators such as:

- Quantity of raw material or energy used
- Quantity of emissions such as CO_2
- Waste produced per quantity of finished product
- Efficiency of material and energy use
- Number of environmental incidents/accidents
- % waste recycled
- % recycled material used in packaging
- Number of vehicle kilometres per unit of production
- Specific pollutant quantities e.g. NOx, SO_2, CO, HC, Pb, CFCs;
- Investment in environmental protection
- Number of prosecutions
- Land set aside for wildlife habitat

For example:

Objective: Reduce energy required in manufacturing process
Target: Achieve 10% reduction compared with previous year
Indicator: Quantity of fuels and electricity per unit of production

Source: NEC, 2011

Box 6: Premier foods

Enhancing relationships with stakeholders and staff

"Since 2001, we have used ISO 14001 to make big improvements such as increasing our organisation's recycling rate. We have now been at "zero landfill" since March 2013 and are recycling and reusing 100 % of our site wastes. We have continued to improve our relationship with neighbours because we have the processes in place to respond quickly to any concerns. Among other benefits, our processes and the appointment of Green Matters Champions ensure that the staff are environmentally engaged and aware of the site's potential impact on the environment."

Richard Giles Premier Foods, UK

Source: ISO, 2015d

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Chapter 3

ENVIRONMENTAL ECONOMICS: CONCEPT AND APPLICATION TOOLS

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1. Concept, Scope and Origin of Environmental Economics

Ecology and economics - both comes from the same Greek word "oikos" which means "household". Ecology is derived from Greek word "oikos" and "logos" which means study of household. Economics is derived from Greek word "oikos" and "nomics" which means management of household (Odum and Barrett, 2006). Ecology deals with relationship or interdependence between living organisms and their environment while economics deals with the production, distribution and consumption of economic goods. Ecology focuses on harmony between nature and man while economy focuses on disharmony with nature (Karpagam, 2007). Economics deals with the allocation of scarce resources and its theories can be applied to any scarce resources (Besanko et al., 2011).

Environmental Economics

Environmental economics is the subset of economics which deals with the integration of economics and ecology (Brehmer et al., 2007; Karpagam, 2007). It is related to welfare economics and focuses on efficient allocation, optimal pricing, economic efficiency, consumer surplus and equity. It bridges the gap between two diverse fields of ecology and economics. It assesses the interrelationship between the economic agent and environmental components (Karpagam, 2007). It applies the principles of economics to solve environmental issues, uses supply and demand to minimize the impact of human economy on ecosystems. It focuses on impact of economy on environment and impact of environment on the economy (Dasgupta, 1996; Karpagam, 2007). It helps in regulating economic activity so that balance can be maintained among environmental, economic and social goods. It analyses various trade-offs of environmental issues and uses economic basis for addressing pollution problems and policy alternatives (Perman et al., 2003).

Resource Economics

Resource economics uses economic principles to manage naturally occurring resources for the need of population with efficiency as the primary goal (Dasgupta, 1996). Evaluation includes estimating costs and benefits of an economic activity to a particular person. It helps to manage natural resources, determine optimal rates of extraction, assess dynamic nature, help in resource allocation and understand resource markets. Natural resource economics is concerned with appropriate inter-temporal use of renewable and non-renewable natural resources (Dasgupta, 1996).

Environmental and natural resource economics helps to tackle pollution of air, water and soil, tropical deforestation, loss of biodiversity, contamination of drinking water, radioactive pollution, soil erosion, depletion of fisheries, oil crisis, energy crisis, nuclear pollution, desertification, loss of habitat of all types (including wetlands, grasslands, variety of aquatic habitat and forests), global warming and climate impacts, over-population, resource shortage and impacts on social and political institutions. It is the application of economics principle to study development and management of natural resources (Hussen, 2004). For more details, follow Perman et al. (2003).

2. Inter-linkages between Economy and Environment

From economics perspective, environment is a composite asset that provides life supporting services (Tietenberg, 2004). It provides us all the resources (renewable and non-renewable) and environmental services (recreation, research, scenic beauty, wildlife, etc) (Karpagam, 2007). Environment also provides fresh air for breathing, food and drink for nourishment and shelter and clothing for protection as a basic requirement for consumers. It also provides adventure from white water canoeing, trekking, natural beauty, scenery and mountaineering (Tietenberg, 2004).

Material Balance Model

Environment and economics interrelationship can be studied as a closed system as all the inputs (energy and matter) for household and industries and outputs for consumers and output as a waste occurs inside the environment. Material and energy are drawn from environment for the production and consumption activities in an economy. The used resources from industries and household are returned back to the environment in the form of waste (Hussen, 2004). It follows the First Law of Thermodynamics which states "Energy can neither be created nor be destroyed but can transform from one form to the other". No any transfer of energy, raw materials, final products and waste is completely efficient so it is an irreversible process. There is loss of some energy while transferring from one form to the other. While transferring raw materials and energy from environment to the industries, there is change of quality and energy. Production of waste by households and energy by the use of raw materials and energy also causes change of energy and quality. It follows the Second Law of Thermodynamics 'Entropy Law - Loss of energy while transferring from one form to the other' (Hussen, 2004; Tietenberg, 2004). For more details, follow Karpagam (2007).

Box 1: Production possibility curve

Production Possibility Curve shows different combinations of goods and services that can be produced with a given amount of resources. It is the locus of combination of two goods A and B produced by the firm with same level of inputs and technology. In Figure 1, PP_1 is the Production Possibility Curve formed by joining points A, B and C. In low economic growth (OB_1), environmental quality will be high (OA_3). In high economic growth (OB_3), environmental quality will be low (OA_1). By increasing production (enhancing economy) from B_1 to B_2, environmental quality will degrade by A_3A_2. Preserving environmental quality from A_1A_3 will have loss of economic benefit from B_1B_3 or Opportunity Cost will be from B_1B_3. There is no 'ideal' point on the curve. Any point inside the curve suggests resources are not being utilised efficiently. Any point outside the curve is not attainable with the current level of resources and technology. It is useful to demonstrate economic growth and opportunity cost (Karpagam, 2007).

Economic growth will help in technological advancement and help in improving environmental quality. It also shifts the production possibility frontier upwards and help in less use of resource to get more benefits. It is not only the economic growth which affects the environment but also the input and output combinations of the economy which affects the environment. Protecting the capacity of the environment to sustain the necessary inputs in the environment is the important aspect (Dasgupta, 1996)

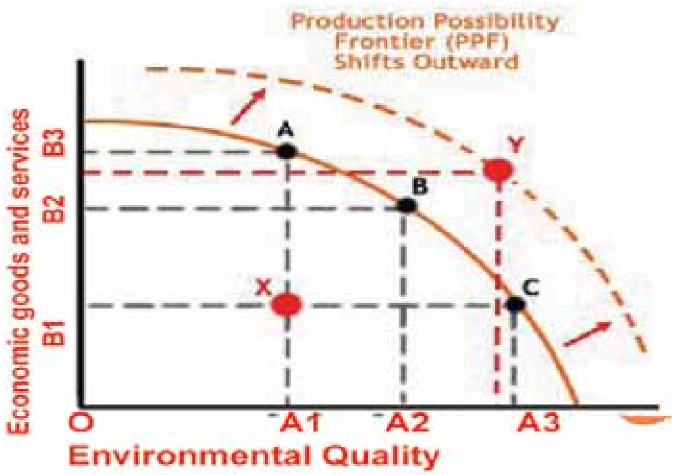

Figure 1: Production possibility curve

Box 2: Opportunity cost

The cost of foregone benefits is known as Opportunity cost (OC). Resources providing environmental services of one type cannot be used in their next most beneficial use. Sacrifice of some goods or services made of a decision to acquire some other goods or services is OC. It is the loss of benefit from not choosing the 2nd best alternative. Benefit will be from the chosen one. It occurs due to the choice made from limited resource.

i. A stretch of river can be used either for white water canoeing or to generate electric power. The opportunity cost of electric power generation is the foregone benefit from white water canoeing (Tietenberg, 2004).

ii. If the community wants to use its capital and resource to extract gold instead of crude oil, then the benefits from crude oil will be foregone (Hussen, 2004).

The Environmental Kuznets Curve (EKC) (positive case)

Living standard of people can change carrying capacity of a particular area. In the early developing stage of an economy, pollution increases but after it reaches certain economic growth, the trend reverses. Higher economic growth will ultimately lead to environmental improvement (Dasgupta, 1996; Brehmer et al., 2007). Environmental impact and economy relationship is an inverted U-shape or bell shape. When a country attains high standard of living, they will form appropriate legislative measure and new institutions for environmental protection and spend more money for environmental conservation (Dasgupta, 1996). A hypothesised relationship between various

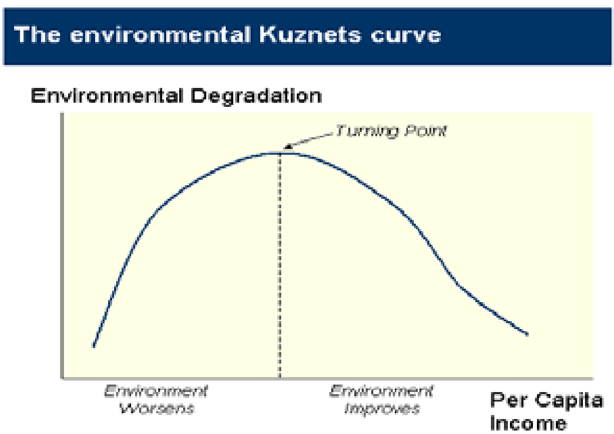

Figure 2: Environment Kuznets Curve

indicators of environmental degradation and income per capita is EKC (Figure 2). Also, economic growth is directly related to environmental improvement.

3. Market Economy

In a market economy, there are economic entities (consumers and producers), commodities, and market and non-market institutions. Consumers are the owners and final users of goods and services (labour, capital and natural resources) and it is necessary to fulfill their demands in market oriented economy. Producers are the firms or industries that manufacture goods and services for the consumers. Commodities are the goods and services which are the factor of production for producing final goods and services. These commodities can satisfy demand of consumer and are available in limited quantities.

Market is an institution which helps in exchange (buying and selling) between producers and consumers. There are basically two types of markets in basic economies: factor markets and product markets. In product market, there is buying and selling of final goods and services where demand provides information about consumer and supply provides information about producer. In factor market, there is exchange of basic resources or raw materials (labour, capital and natural resources) where demand provides information about producer while supply provides information about consumer. Information about price is determined by resource scarcity and technology. Non-market institutions help to operate market in efficient and effective manner through rules and regulations (Hussen, 2004).

Supply and demand are the important components of a market. Supply is the amount of goods and services available for use, and demand is the amount that people want for fulfilling their needs. Market has existed from historical past as people used barter system for exchange of food and other things. Market organises economic activity between buyers and sellers. Buyers determine the demand of a good at different price while sellers determine the supply of a good at different price. Interaction of buyers and sellers determine the market price and allocate scarce goods and services efficiently. To determine the amount of consumption and production, price is an important factor. It can be explained by law of demand and law of supply. Law of demand states that other things remaining constant if price of goods increases, demand decreases. Law of supply states that other things remaining constant, increase in price of goods will decrease its supply while decrease in price of a goods will increases its supply (Brehmer et al., 2007). In a market, resource scarcity and available technology identifies its price (Hussen, 2004). The market with equilibrium price occurs when supply and demand are in balance. At equilibrium price, supply is equal to the demand. It determines efficient allocation of the resources. It is explained clearly by Pareto efficiency (Erica Brehmer et al., 2007).

4. Perfectly Competitive Market

In an ideal capital market, consumers have a great role to play. The outputs are produced according to the consumer choices and preferences. To derive maximum output from the available labour, capital and natural resources is the important aspect as resources are limited but consumer choices are unlimited (Hussen, 2004). Market can be monopoly, perfectly competitive or imperfectly competitive. Monopoly of a producer or consumer will not use resources in an efficient manner. To be efficient in allocating resources, market should be perfectly competitive and should follow the following conditions (Hussen, 2004):

i. As buyers and sellers are knowledgeable, they act in their own self-interest. It is necessary to provide suitable environment for them to address scarcity of resources.

ii. Producers, consumers and other market agents should be provided full information about all the necessary market transactions at the present and the forecasting of future events.

iii. There are large numbers of price-takers (consumers and producers) in the market, so no single buyer or seller can affect the product and factor markets.

iv. Change in economy occurs from the combination of various inputs of economic system (consumer preferences, income, resource availability, and technology). For a dynamic economy, resources should be easily transferred from one sector to the other. It can occur due to removal of barriers to entry and exit in an industry.

v. There should be well defined property rights which can be protected from social rules and regulations. For more details, follow Hussen (2004).

5. Pareto Criterion of Efficiency

Functions and services of the environment have either no price or have non-optimal price that leads to overuse of resources and misallocation of resources. Environmental degradation is the basic problem of non-optimal pricing and misallocation of resources. Welfare economics assesses the optimal condition of an economy in terms of prices and quantities of inputs and outputs (Karpagam, 2007). Resource allocation is efficient if it is impossible to make few people better off without making few people worse off. An allocation is inefficient, if it is possible to make some people better off without affecting other individuals (Brehmer et al., 2007; Karpagam, 2007).

It is named after Italian born Swiss economist Vilfredo Pareto. Allocation are said to be Pareto optimal if no other feasible allocation could benefit some people without any deleterious effects on at least one other person. Efficient allocations are Pareto optimal. Net benefits are maximized by an efficient allocation. It is not possible to increase the net benefit by rearranging the allocation. Without an increase in the net benefit, there is no way the gainers could sufficiently compensate the losers. The gains to the gainers would be necessarily smaller than the losses of the losers. Allocation not satisfying this criterion is sub-optimal. Sub-optimal allocations can always be rearranged so that some people are better off and no one is hurt by the rearrangement. The gainers could use a portion of their gains to compensate the losers sufficiently to ensure they were at least as well off as they were prior to the reallocation. Inefficient allocations are judged inferior because they do not maximize the net benefit. By failing to maximize net benefit, they are forgoing an opportunity to make some people better off without harming others (Tietenberg, 2004).

Three conditions must be satisfied for any allocation to be Pareto efficient (Perman et al., 2003):

i. Efficiency in consumption

ii. Efficiency in production

iii. Efficiency in product mix

For more details follow, Karpagam (2007).

Perfect competition of market follows Pareto efficient condition. Hence, every competitive equilibrium is a Pareto efficient. The Pareto efficient condition is an ideal condition which is difficult to achieve in real world due to presence of imperfect competition, externalities and existence of public goods (Karpagam, 2007).

A socially optimal allocation of resources is one in which it is not possible to reallocate resources and improve the welfare of any one person without making at least one person worse off. Consumer surplus and producer surplus are monetary measures of people's utility and firm's profits which are often used as an approximation of social welfare.

6. Market Failure and Externalities

When market fails to produce the right amount of the product, it is called market failure. It occurs when resources are over-allocated or under-allocated. It can occur from demand side failures and supply side failures. It is impossible to charge consumers' willingness to pay for the product and some can enjoy benefits without paying which comes under demand side failures. When a firm does not pay the full cost of producing its output and external costs of producing the good are not reflected in the supply, it is supply side failures. The main causes of market failure are externalities, public goods, imperfect competition, imperfect information, asymmetrical information, coordination problems, etc (Perman et al., 2003). The main measures to correct market failure and manage environment are command and control measures, extension of property rights, taxation, subsidies, marketable emission permits, bargaining, etc.

Externalities

Externalities affect the people who are not directly involved in the activities (Brehmer et al., 2007). It is caused when industries and households do not evaluate the full cost or benefit of production and consumption activities. It is the incidental cost or benefit imposed by the consumption and production activities of the society. It can be adverse or beneficial due to production and consumption activities (Hussen, 2004; Karpagam, 2007).

Negative externality causes unfavorable side effects to the people and the environment. Industry pollutes the water and air during the process of its production and causes health risks to the people. They do not pay any money for health impacts of the people and polluting water and air. Affected people claim money for the damage by using legal measures (Brehmer et al., 2007). Adverse environmental problems and pollution comes under negative externalities. They are the costs of production and consumption activities which are not included in the cost category by the respective agents. Deposition of waste of organic and inorganic nature into a river by an industry will decrease the quality of water. It reduces dissolved oxygen and makes water unfit for fishing and drinking purpose. For determining the price of products, industry will only use wages, rent and material inputs but not the compensation to the local people for decreasing the water quality (Karpagam, 2007).

Positive externality is the unintentional benefit to the people from any activity in the environment. Aesthetic benefit of a private garden and community park build by the neighbour to other families is an example of positive externality. Free rider takes the benefit without paying any money (Brehmer et al., 2007). Vaccination to prevent a disease is positive consumption externality while pollination of flower by bee farming is positive production externality. Noise pollution while listening music in loud voice is a negative consumption externality while air pollution and water pollution from industries is a negative production externality (Karpagam, 2007).

Measures to Correct Market Failure and Manage Environment

There are different ways to address market failure and manage environmental problems. Command and control measure is the mandatory restrictions to an individual and industry by a state agency. It is the dominant method of reducing pollution in many countries. It can be forced in different stage of output production, location of emission sources, input controls, technology controls, setting quotas and emission licences (Perman et al., 2003). Industry will receive economic benefit by polluting the river while it would be cheaper to pollute the river than to treat the waste before transferring into the river. A rational industry will pollute the river and will not treat the waste until strict legal measures are enforced. Similar situation also occurs in the case of other types of environmental pollution (Karpagam, 2007).

Emission standard is a maximum legally allowable rate of effluent that can be discharged by an industry in the environment. It can be in different forms depending upon quality and quantity but the important one is quantity of waste material that can be released into the environment in unit time. Emission standards normally take ambient standard for allowable concentration of pollution (Hussen, 2004). For more details on command and control measure, follow Perman et al. (2003) and for more details on emission standards, follow Hussen (2004).

Economic measures create incentives to voluntarily change the behaviour of individual and industry. It can be done by taxes, subsidies and marketable emission permits. Polluter pays principle helps in making polluter responsible for bearing the costs of pollution. Its policies should protect the environment without disturbing free market economic system. It can be done by making payment of all the costs from a polluter (Perman et al., 2003). As explained by A.C. Pigou, taxes minimize adverse impacts while subsidies enhance beneficial impacts of any activities. Sometimes, Pigovian tax can be an effective way for reducing pollution as a negative externality than governmental regulatory measures. Industry will pay a tax if it is cheaper to continue its production process and increase profit (Brehmer et al., 2007).

External cost of industries for treating the waste and reducing environmental pollution should be internalized and kept under cost category of industries for determining the actual price of the product. It is done by taxation and is called internalizing the external cost which can be found in details in Karpagam (2007). Taxation is the economic instrument for demotivation of environmental pollution while subsidies provide economic motivation for reducing environmental pollution. The sum of private cost and external cost is equal to social cost (Field and Field, 2006). This external cost can be addressed by taxation and helps to solve adverse environmental problems. Industries will reduce pollution if it is expensive to pay tax than to abate emission. Pollution taxes have double benefits as it helps to improve environmental quality and also generates revenue from pollution tax and income tax. Subsidies can also contribute to pollution by encouraging production and use of inputs. But pollution subsidies pay directly to polluters for minimizing level of emissions (Grafton et al., 2004). For more details on taxes and subsidies, follow Grafton et al. (2004).

Negative externalities can also be internalized by assigning property rights (Dasgupta, 1996; Brehmer et al., 2007). Allocation of property rights such as right of an industry to pollute and right of a general people to get compensation from pollution can help to reduce negative externalities (Dasgupta, 1996). Property right is said to be well defined if quantity, quality and boundary is fixed; all the benefits and costs due to an action goes directly to the owner, property can be transferred according to the want of owner and property is legally defined (Hussen, 2004). Ronald Coase explained that voluntary bargain between polluters and general people to assign property right can be more efficient and effective than the taxes and subsidies. Coase theorem explains that free trade is possible when there is a well-defined property right (Hussen, 2004; Brehmer et al., 2007). If there is no emissions tax, industries will not work hard to combat pollution. For more details on bargaining, follow Perman et al. (2003) and for Coase theorem, follow Hussen (2004).

Cap and trade mechanism or marketable emission permits can help in minimizing negative externalities and manage environmental problems. It defines maximum limit of emissions for a particular source in a particular time period. Emission allowances set in cap and trade mechanism can be traded, bought, sold and banked for use in future. If emission level crosses the cap, further emission should be bought and if emission level does not reaches the cap, emission up to the cap can be sold (Brehmer et al., 2007). For more details, follow Perman et al. (2003).

Moral suasion helps to change behaviour of individuals and industries without forcing any rules and economic measures. It is a qualitative and direct instrument for pressurizing different economic agents. It can be done by conducting meetings and inspections and preparing guidelines (Perman et al., 2003). Sometimes, combined application of bargaining, taxation and subsidies and governmental regulatory standards can help in reducing market failure and help in reducing negative externalities (Dasgupta, 1996).

7. Type of Goods

Goods can be classified as non-excludable, when people who do not pay cannot be prevented from using a good, for example, national defence (Figure 3). It means any one can use this resource without paying for it. A good is non-rival when one person's use of a good does not reduce the ability of another person to use the same good, for example, digital music. It means utility of one good does not decrease with the presence of multiple users. A good is excludable when people who do not pay can be easily prevented from using a good, for example, cell phone. A good is rival when one person's use of a good reduces the ability of another person to use the same good, for example, food. It means utility of one person will decrease if others uses it (Perman et al., 2003; Karpagam, 2007).

A private good is both excludable and rival. Such goods are excluded for all users as only people who own it can use it and if one uses it others will be prohibited from using it. The things that we own such as cell phones, foods and our personal properties are private goods. There is less chance of free rider problem in private goods (Perman, et al., 2003; Karpagam, 2007). Club goods are a type of good which are excludable but non rival. Examples of club goods are cinema hall, cable television, services provided by social or religious clubs to their members, etc. These goods are also called natural monopolies. These are the type of public goods which can be used by a specific group (Karpagam, 2007).

Public goods are non-excludable and non-rival. These goods can be used by all people and utility of one person does not affect utility of others. These goods are also regarded as a basic need

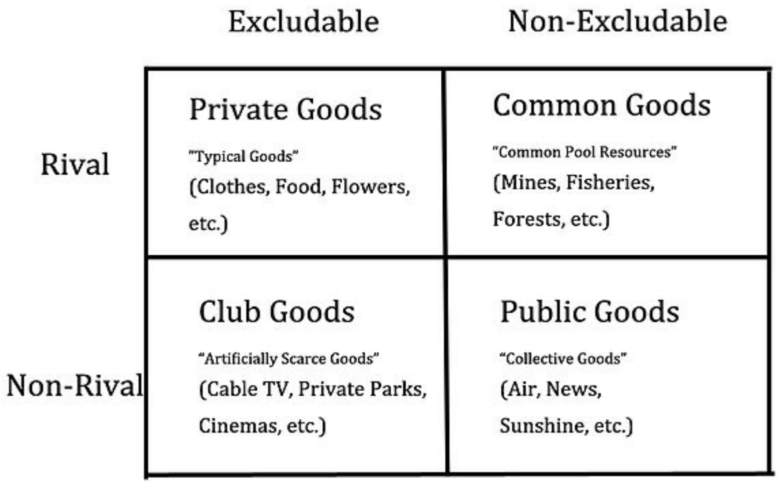

Figure 3: Types of goods

required for day to day use. The examples are national securities, street lights, light house, fresh air, official records, early warning system, etc. (Karpagam, 2007). Common property resources are goods that are non-excludable but rival. Consumers cannot be excluded from consuming these goods but utility of others will decrease when one uses it. There is a strong incentive to consume these resources before others (Karpagam, 2007). The examples of common property resources are forests, pasture land, rivers, local ponds, etc. (Dasgupta, 1996).

Public goods and common property resources may be subjected to excessive use resulting in negative externalities such as pollution and adverse environmental impacts. It is mainly due to free rider problem in which people use it without paying for it. These goods may be under produced, under maintained, overused or degraded causing market failure. For example: fish. Since fishes are not owned, it is difficult to prevent anyone from fishing. When one person catches a fish, there are fewer fish available to everyone else. Each person has the incentive to fish before others (Karpagam, 2007). Environmental quality is public goods which should be used equally by all people. There is no private property right of exclusion and rivalry in nature. Due to the property of non-excludability and non-rivalry, these goods cannot be sustained for long term in market under same quality. It will lead to market failure.

Box 3: Tragedy of commons

There is a chance of tragedy of the commons in common property resources as described by Garret Hardin in 1968. The grazing land in England which was free to all farmers was overgrazed and destroyed after the passage of time. The overuse of resources caused its destruction when it was open to all is tragedy of commons.

8. Alternative Measures of Economic Welfare

After World War II, countries have assessed economic growth through Gross National Product (GNP) as the production and consumption of goods and services. GNP does not analyse environmental benefits and costs and keep it together under economic activity. Increase in GNP is necessary for well-being but increase in productive activities had affected health and happiness. There are different alternative measures for assessing welfare.

i. United Nations Development Programme (UNDP) has brought concept of Human Development Index (HDI. by assessing three components: longevity, education and living standard. The economic growth component-GNP is addressed by its third component.

ii. Herman Daly and John Cobb have introduced Genuine Progress Indicator (GPI) as an advanced form of Index of Sustainable Economic Welfare (ISEW). It uses consumption component of GNP, income distribution and also addresses household and volunteer work and the costs of crime and pollution.

iii. Ecological footprint assesses the amount of land and water area necessary for human population for production and consumption activities and absorption of waste.

iv. Happy Planet Index (HPI. analyses human welfare through ecological efficiency and assesses satisfaction of life, longevity and ecological footprint (CASSE, 2010).

System of National Accounts (SNA) is the international measure of performance of a country based on economic principles. The economic information is used in economic analysis, decision-taking and policy making. They keep information of economic activities in any country in a comprehensive, consistent and integrated manner. It collects details about economic systems, assets, liabilities and wealth of its inhabitants at a particular time. SNA includes international account with link of country and the world, account of production, consumption and accumulation of assets and account of exchange (WB, 2009). For more details on SNA, follow WB (2009). Conventional system of national accounting (CSNA) accounts for man made capital and ignores the natural capital. In CSNA, Net national product (NNP) = Gross national product (GNP)-Depreciation (Karpagam, 2007)

NNP = Consumption + Investment – Depreciation + Exports - Imports

Box 4: Gross national product is the market value of all products produced during a given period of time in a country (Karpagam, 2007). It is the basis of ranking country into rich and poor.

9. Green Accounting

Environmental resources and economic components need to be integrated to address economic functions of the environment. Environment provides natural resources for production and consumption action, sink of waste, environmental services, life support and other human activities (UN, 2000). CSNA has focused on market components and indicators of welfare but do not address actual welfare. CSNA does not focus on pollution cost, environmental degradation cost and cost of sinking of waste arising from economic activities. Different aspects of natural resource depletion and scarcity of environmental resources which affects economic production and consumption are being ignored by CSNA. In CSNA, environmental costs and benefits are not addressed fully and kept in general overhead accounts and not analysed during the process of decision making (UN, 2000; Karpagam, 2007). From environmental perspective, it can be seen that environmental costs looks like an iceberg with very small part of the cost visible and much part left hidden (Karpagam, 2007). To address the impact of economic activities on environment, there should be adjustment in depletion of natural capital, environmental degradation and defensive expenditure (UN, 2000; Karpagam, 2007).

Environmentally adjusted GNP (ENP) = GNP - Depreciation of
manmade capital - Depletion of natural capital

(Dasgupta, 1996; Karpagam, 2007)

In green accounting system or integrated environmental and economic accounting, manmade capital, natural resources and technology are accounted. UN has proposed System of Environmental and Economic Accounting (SEEA) as a part of green accounting. The SEEA is an international standard developed by the United Nations Statistical Commission (UNSC) at its forty-third session in 2012. SEEA provides information about environmental and economic issues. It assesses trends and availability of natural resources, extent of emissions and discharges to the environment and the amount of economic activity undertaken for environmental purposes. It provides guidance on the valuation of renewable and non-renewable natural resources and land. It provides guidance of environmental regulations on economic growth, productivity, inflation and jobs (WB, 2012). For details, follow UN (2000) and WB (2012). It extends CSNA by focusing on all elements of CSNA, addressing future scarcity and depreciation of natural resources and including non-market valuations of environmental assets and flows. ENP can increase if the environmental resources and technology improves but decrease if sustainable growth of environmental function fails. Expenditure made on pollution clean-up increases NNP while loss in welfare due to pollution decreases NNP. Green accounting links monetary and physical information and enables national accounts for addressing environmental degradation (Karpagam, 2007).

Importance of Green Accounting

It focuses on environmental services, ecosystem life support functions and sink of waste in landscape approach. It addresses environmental damages, pollution, defensive expenditures and resource depletion. Environmental cost can be significantly reduced or eliminated as a result of business decisions in green accounting system (UN, 2000; Karpagam, 2007). Proper evaluation of environmental costs and benefits helps in estimating actual price and enhance advantage to customers and producers (Karpagam, 2007). Green accounting has benefits to industries, government and general people. For industries, it accurately tracks and manages the energy, materials, pollution and waste. Industries can accurately estimate and manage costs, performance and improve company image with customers, local communities, employees, government and financial providers. For government, there will be low financial, political and other environmental protection burdens. It increases effectiveness of existing government policies and regulations towards true environmental costs and benefits of regulations (Karpagam, 2007).

10. Renewable and Non-renewable Natural Resources

In economic sense, natural resources are the wide range of resources provided by nature and are used directly or indirectly in consumption and production process. Natural resources are of two types: stock or fund or non-renewable resources and flow or renewable resources (Karpagam, 2007). Renewal rate in an economic time scale separate two types of resources (Conrad, 1999). In non-renewable resource, maximum stock is fixed while in the case of renewable resource, available stock changes at a bio-chemical rate. Land area, metal ores, mineral resources, fossil fuels, etc. are the non-renewable resources while forest, fish stocks, natural flora, fauna, fresh air, water supply, etc. are renewable resources. Renewable resources can be used without depletion and available stock changes with biological rate. These flow resources can be perpetual as solar energy which can be used without depletion. Other type of flow resource is renewed at a biological rate whose harvest is constant without depletion. If harvest rate of such resource is higher than the biological renewal rate, then they will be depleted.

Non-renewable resources will deplete in future as their stock is limited. They have option value which can be used for current time or which can be preserved for future generation. Perpetual type of resources are not susceptible to human modifications, renewable type of resources can be renewed at a biological rate and non-renewable resources can be more or less recycled in nature. Most of the natural resources in the earth are in limited quantity as earth is closed system and is finite. There is urgent need of management and conservation of natural resources for future use (Karpagam, 2007).

Natural resources provide raw material for production and consumption activities in an economy. Land, labour and capital were the three type of resources focused in classical economics in which land falls under natural resource category. Economists discussed on absolute and relative scarcity of natural resources which can affect the long term economic growth. Price of natural resources will rise due to the scarcity of resources. Investment need to be increased for recycling of used objects, selection of alternate resources and exploration of new reserves of the particular resources. Scarcity of natural resources had increased concern on various theories and models of natural resource use (Karpagam, 2007).

Theories of Renewable Natural Resources

Renewable resources are those resources which can be renewed or regenerated at a particular bio-chemical rate. The stock of such resources changes with respect to amount of initial stock and rate of utilization. They can be expressed by a logistic function as shown in Figureure below and follow density dependent characteristics as follows:

$$G=G\ (S)$$

Where,

S = Stock size at a given time

It has a maximum carrying capacity for any species with respect to stock level S_{Max} shown in Figure 4. S_{Max} is the maximum size at which resource can grow under given environmental factors. At a particular stock size MSY, growth rate will be highest as shown in Figure 4. Maximum sustainable yield (MSY) is the highest yield obtained from a particular resource with the given environmental factors. S_{MSY} is the stock size at maximum sustainable yield. S_{Min} is the minimum level of stock which is essential for the survival of a species. If the stock falls below S_{Min}, mortality rate will be higher than reproductive rate and the species will be extinct from the environment. Use of natural resource equal to MSY will lead to sustainable yield of any resource but it does not show optimum rate of utilization. Discounting is important in determining renewable natural resource use rate. To determine the optimum rate of

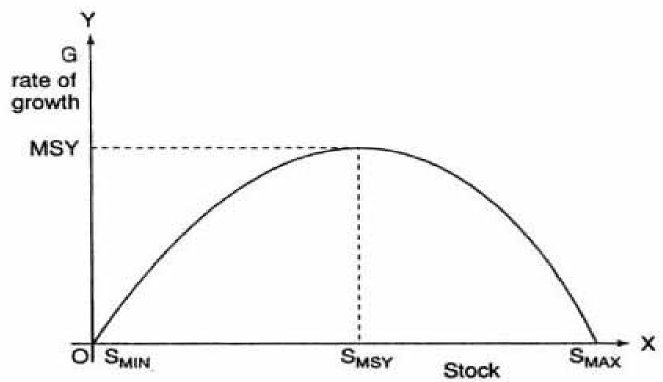

Figure 4: Logistic growth curve of renewable resource

utilization, rate of utilization and income and expenditure from utilization need to be determined. For more details, follow Karpagam (2007).

Box 5: Discounting

Discounting is important in environmental economics to adjust costs and benefits at a common point in time (Brehmer et al., 2007). It is used to measure present value of future benefit or cost (Karpagam, 2007). Discount rates are positive as people like to utilise things at present than saving for future (Brehmer et al., 2007). Benefit of NPR 100 is more at present than future. There is less benefit if you keep Rs. 100 simply for future as it can buy more goods and services at present. An investor would agree to pay more than NPR 100 in future for the present goods and services. Higher the discount rate, faster will be the depletion of natural resource. Discounting is important as policies and projects last for a long time and costs and benefits need to be assessed for present and future values. For renewable resource: Biological growth rate (b) + growth in capital value (c) = discount rate (d). If "d" is greater than "b+c", resource will be harvested now (Karpagam, 2007).

Theories of Non-renewable Natural Resource

Non-renewable resource had fixed quantity and if we extract more at present, there will be less available for future generation. For non-renewable resource, there will be no biological growth. As total quantity of resource is fixed, use of resource at present time will reduce the future benefits (opportunity cost) (Karpagam, 2007). Use of non-renewable natural resource for making tools of copper, bronze, and iron has played an important role in human civilization. Conflict on the access to these resources has helped in development of human history. Metals and fossil fuels are the backbone of modern economic development. In a geological time scale, they are the fixed asset and remain constant over a time without increment. Higher the extraction rate, faster will be the decline of these reserves.

Optimal rate of harvest of resource depend upon the change in price over time and the discount rate. If the price of resource is constant, it is optimal to harvest all the remaining reserves of the mineral as early as possible. Delay in harvest makes present value of benefit from resource lower than the rent paid for mining. In case of increase in present value of resource, it is optimal to wait for the last possible time so that the mineral can be sold in higher price. If there is increase in price over time making the present value of the resource same at any time, industry has option to use it faster or wait for the future and the rate of increase in the mineral price will be equal to the discount rate. This transversality conditions hadsa great role in obtaining optimal rate of harvest of non-renewable natural resource. As there is always some cost of harvest, it is profitable to harvest it faster. Economics of non-renewable natural resources indicate a strong relationship of extraction costs, price of resource, net price of non-renewable resources and the amount of reserves (Grafton et al., 2004).

Commercial Forestry Economics

Economics of managing private and public forests focus on maximizing the benefits of forests without sacrificing wide range of outputs over the long term. Management of private forests is important to maximize profits and enhance ecological services. Forest management is important as benefits increases by the passage of time. Value of timber increases with age as taller trees has higher value than shorter trees. Few investors may not like current market price and wait for higher profits from taller tree in the future. Non-market values of a forest are conservation of nature, management of water, purification of air, reduction of erosion, preservation of flora and fauna, mitigation of climate change, sequestration of carbon and control of flood. Non-market values are prioritized by the government and public sector.

Tropical rainforests provide benefits to both man and nature and supply 20 percent of the global oxygen and store carbon dioxide, methane, nitrous oxide and greenhouse gases. Deforestation is a major problem in tropical rainforest which has affected the forest economics of the region due to commercial harvest of wood for pulp or timber, converting forest into agricultural land, animal rearing, shifting cultivation and settlement. Economic efficiency and sustainable practices would increase productivity, maintain the amount of timber in the rainforest, reduce demand of timber and firewood, increase taxes, prohibit trade of timber, implement timber certification and receive foreign aid (Brehmer et al., 2008).

Forestry economics focus on the production of timber and forest products and important environmental resources. It plays a greater role in conserving ecosystems and enhancing rural communities. The important issue in forestry is to identify the best time of harvesting of forest products (Grafton et al., 2004). Non-exploitable forests are included in assets category in SEEA. In cultivated economic forest land or planted forest, growth and regeneration of timber and biological resources is under direct control and owner has management and responsibility to produce economic benefits. In uncultivated economic forest land, there is no direct control over natural growth and regeneration of timber and other biological assets. If it is used for recreation, education, medicinal herbs, animal rearing and other environmental services, it has direct benefits to the people. Biological assets such as flora and fauna can also be produced in the forest which may be accessible or non-accessible.

There can be forest roads, physical structures, non-residential buildings, equipment of forest industries and lodging for visitors which provides direct economical values (UN, 2000). Community forest management of Nepal is the successful story of green economy helping in controlling forest degradation and sustaining livelihood through local level participation (Sukhdev et al., 2010; Bhandari et al., 2013). Community forest user group (CFUG) set rules, harvest the forest products and fulfill the demand of forest products (Koirala and Adhikari, 2015; K.C., 2017). It was successful in generating local employment, maintaining social unity, increasing forest cover and carbon, helping in capacity building and improving leadership skills (K.C. et al., 2014; K.C., 2016). Local people are using timber, firewood, fodder, fruits, flower and dry leaf from forest. For more details on community forest management, follow K.C. (2016).

11. Ecosystem Services and Payments for Ecosystem Services

Ecosystem services are the ecosystem functions which are beneficial to individuals, social groups, economic sectors, and society. They are the direct and indirect contributions of ecosystems to human well-being (Braat, 2014). They include raw materials provided by nature which are essential inputs into all economic production. Raw materials basically used for production are timber, non-timber forest products, firewood, fodder, medicines, food, dyes, fisheries, construction materials, agricultural products, natural chemicals, ores, genetic resources, etc. (Hussen, 2004). They include market goods, ecosystem functions of value to humans and includes life support functions. Types of ecosystem services are regulatory, provisioning, information and supporting services. Regulatory services are air quality management, water regulation, erosion control, natural hazard regulation, soil creation, pollination, climate regulation, nutrient cycling, biological control and waste absorption (Hussen, 2004). Information services are cultural heritage, recreation, tourism, aesthetic values, unknown benefits, cultural attachments, scenery and emotional attachments. Cultural services are use values related to recreation and education and nonuse values related to bequest values and existence values (Liekens et al., 2014). Provisioning services includes production of food, biochemical, natural medicines, fuel, pharmaceuticals, fresh water supply and fibre while supporting services includes habitat (Hussen, 2004).

Payments for ecosystem services are important because nature provides services free of charge. Many ecosystems and the services are at risk due to the lack of proper markets and policy. They are not fully accounted in commercial markets from present strategies (Liekens et al., 2014). Consumption of ecosystem goods (such as timber or oil) is favoured over the conservation of ecosystem services. Market forces must be realigned to invest in the production of both ecosystem goods and services. If market forces reward investments in ecosystem services, a positive feedback loop will start in which increased investments in ecosystem services leads to increased production of ecosystem goods. It helps in sustainable economic growth and ecological restoration.

For private goods, prices reflect relative scarcity and people's willingness to pay. But for environmental goods, price does not exist or do not reflect the full value of resource. Environmental goods and services do not have well-defined ecological functions and they differ in value and composition. They have intangible benefits, multiple uses, unclear property rights and are often regarded as public goods. Economic valuation is the process of assigning accurate values to natural resources and use discounting to determine present and future values of environmental goods and services. It helps to express the full value of environmental resources in monetary terms (Brehmer et al., 2007). Monetary valuation brings environmental goods and services into decision-making process. For more details, follow DEFRA (2007).

12. Cost Benefit Analysis

Cost benefit analysis (CBA) is a tool used by governments and policy makers in making their social and economic decisions. It compares costs and benefits of any activity to the community. It is mostly used in education, health care, transportation, irrigation, electric power and environment sector (Brehmer et al., 2007; Karpagam, 2007). Public policy formulation is formalized and quantitative which can be evaluated by assessing benefits against costs. To choose among many alternatives by policymakers, they require a tool to select one option among different options (Brehmer et al., 2007). It is a decision making device for evaluating activities that are not priced by the market. It attempts to estimate cost and benefits to the client as well as to the rest of community (Karpagam, 2007). Benefit increases human well-being while cost decreases it (Brehmer et al., 2007).

CBA is the social appraisal of marginal investment projects, and policies, which have consequences over time. It helps to achieve economic efficiency in the allocation of resources (Perman et al., 2003). It uses criteria derived from welfare economics rather than commercial criteria to attain efficiency (Perman, et al., 2003; Hussen, 2004). CBA seeks to correct project appraisal for market failure and attach monetary values to external effects (Karpagam, 2007). Benefit-cost criterion is carried out on the basis that benefits always exceeds the cost or advantages are more than the disadvantages (Karpagam, 2007). It can be done in the form of highest ratio or the highest net benefits (Brehmer et al., 2007).

The main steps of CBA are as follows:

Step 1: Determine a social values of concern: The first step of CBA is to decide values and perspectives of decision-makers. It includes main elements of the project, location, timing, groups involved and connections with other programmes.

Step 2: Analyse the physical and biological changes to be measured: It includes assessing the changes of input and output flows (Hussen, 2004).

Step 3: Determine the costs and benefits of changes from a particular programme. Economic values is given to input and output flows and to measure social costs and benefits (Hussen, 2004; Brehmer et al., 2007).

Step 4: Compare the costs and benefits and determine cost benefit ratio: Total costs and benefits are compared in this final step. If future benefits are assessed, they should be converted to the present value. Net benefit is calculated by subtracting present value of costs by present value of benefits (Hussen, 2004).

Benefits include all the private and social advantages of a programme. Benefit is measured by the sum of WTP value of the demand curve for a product or a service under consideration. Estimation of benefit from a public project includes the cash flows plus consumers and producers (Hussen, 2004). Costs include private cost, production cost, transaction cost, opportunity cost and the social cost. Private cost is the cost for a person taking a particular decision while social cost is the cost occurring to the decision making person as well as the whole community who are not associated with the decisions. The sum of private cost and external cost is equal to social cost (Field and Field, 2006).

Net present value (NPV) helps to determine net benefit or cost in a lifetime of a long-term investment or a project. It helps to compare different alternatives in a similar time scale by converting all options to current price for decision makers. Most of the goods lose value or depreciates with the passage of time. This depreciation can also be addressed by NPV (Brehmer et al., 2007). NPV approach of a project takes account of the future benefits of the positive elements in the net cash flow (Perman et al., 2003). NPV is the difference between total discounted benefits and total discounted costs.

$$NPV = \text{Present value of benefits } (PV_B) - \text{t value of costs } (PV_c)$$

A single project with positive NPV in life time of a project can be accepted while for multiple projects, the project with highest NPV in a lifetime of a project should be accepted (Hussen, 2004; Brehmer et al., 2007).

Benefit cost ratio (BCR) is the ratio of total present benefits to the total present costs.

$$BCR=B/C = (PV_B / PV_C)$$

Box 6: PV of past benefits and costs using compounding method (K. C. et al., 2015)

$$\text{Present Value Benefits}=\sum_{n=0}^{N} Bn(1+r)n$$

$$\text{Present Value Costs}=\sum_{n=0}^{N} Cn(1+r)n$$

PV of future benefits and costs using discounting method (K. C. et al., 2015).

$$\text{Present Value Benefits}=\sum_{n=0}^{N} \frac{Bn}{(1+r)n}$$

$$\text{Present Value Costs}=\sum_{n=0}^{N} \frac{Cn}{(1+r)n}$$

Where,

B = Total Benefit in year 'n' expressed in constant dollars

n = Evaluation period in years

C = Total Cost in year 'n' expressed in constant dollars

N = Total number of years, 10 years;
r = Real discount rate

A single project with BCR greater than 1 can be accepted while for multiple projects, the project with highest BCR should be accepted (Perman, et al., 2003). Internal rate of return (IRR) is the discount rate at which the present value of benefits is equal to the present value of costs. A single project with IRR greater than discount rate can be accepted while for multiple projects, the project with highest IRR should be accepted (Perman et al., 2003). For more details on Cost Benefit Analysis, follow K.C. (2012) and K.C. et al., (2015).

13. Economic Valuation Methods

There are different market and non-market valuation methods, direct and indirect methods and stated and revealed preference methods. For stated preference method, amount of money a person is willing to pay for a good is determined. A person's behaviour is determined through revealed preference method when it is not possible to use market valuation method (Brehmer et al., 2007). Types of revealed preference methods are market price method, production function approach, hedonic pricing, travel cost methods and random utility models (DEFRA, 2007).

There are use values and non-use values of environmental resources. In use values, there are direct use values, indirect use values and option values. It is due to the use of a resource. Direct use values can be utilised from timber and other forest products. It can be consumed from the ecosystem such as food, timber and services (DEFRA, 2007). Indirect use values can be utilised in the form of ecological functions of forest. Benefit is taken from ecosystem services without directly using the resources (DEFRA, 2007). Option values are the insurance premium paid for the conservation of a resource for future use. It can be utilised in the form of WTP to conserve for future use (Hussen, 2004). In non-use values, there are option values, existence values and bequest values. Existence value is the satisfaction to a person due to the existence of a resource which may not be used directly. It can be utilised in the form of WTP to know an asset exists. For existence value, people would pay to preserve the natural environment or a species above any use benefits.

Bequest value can be utilised in the form of WTP to pass resource to next generation as it is intergenerational component. It is the desire to preserve environmental assets for the enjoyment of other people of both the present generation and the future generations. There are aesthetic values due to the beauty and emotion, scientific values from a scientific research, educational values due to teaching and learning activities (Hussen, 2004).

For assessing both use and non-use values, contingent valuation is used (Hussen, 2004; Brehmer et al., 2007). It is easier to determine the price a consumer is willing to pay if the environmental resources or services are used. Market price method can be used when there are tangible products while replacement cost method can be used to reverse environmental damage (Brehmer et al., 2007). Market price method helps to trade goods and services in market price (DEFRA, 2007). Market price method is used when there is change in real inputs and outputs of environmental resources. It can be used to assess benefit from forest products, extraction of minerals, benefit of fishing, use of new water pollution control technology, increase in crop yield, etc. (Grafton et al., 2004; Hussen, 2004).

Indirect Methods of Economic Valuation

Indirect methods use people's actual behaviour to determine the economic value of the product. Types of indirect methods are as follows:

i. **Hedonic Approach**: Utility function takes a particular form in this approach. Ex. travel cost approach, household production function, preventive expenditure approach, surrogate market approach, etc. (Karpagam, 2007).

ii. **Conventional Market Approach:** Use of actual market price of the product. Ex. productivity approach, foregone earning approach, dose response method, etc. (Karpagam, 2007).

iii. **Cost-based Methods:** It consider the expenditure value. Eg. replacement cost approach, relocation cost approach, opportunity cost method, etc. (Karpagam, 2007).

Direct Methods of Economic Valuation

Direct methods are based on surveys and are useful in valuing benefit of improvement of environmental quality when indirect methods are inadequate. It uses survey and experiment. Types of direct methods are contingent valuation method, trade-off game method, willingness to pay, Delphi technique, etc. (Karpagam, 2007).

The market based methods are production function approach, cost of illness approach, cost-based approaches, travel cost method, hedonic pricing approach, etc. (Karpagam, 2007).

Travel Cost Method

Travel cost method can be used to measure the value of environmental services from recreational sites from indirect process (Perman et al., 2003). It assesses the value of national parks, nature reserves and open space by calculating value of recreational activities such as hiking, camping, fishing, boating, swimming and wildlife watching (Shechter, 1999). This technique measures benefit (willingness to pay) from a recreational activity by using households' expenditures on the cost of travel. The entry fee of a recreational area is very low which cannot address all the value of environmental services. For this, basic information about characteristics of individuals, the number of visits they made and their travel costs is assessed (Grafton et al., 2004; Hussen, 2004). Travel cost method uses expenditures (transport costs and time) to reach a site to estimate willingness to pay. It assesses value of time spent in recreation activities, cost of travel, entrance fees and other site fees (Shechter, 1999). It is applied in recreational areas, national parks, historic/cultural sites. The steps of travel cost method (Perman et al., 2003) are as follows:

i. Define the zone, collect data of visitors from each zone and calculate the average round-trip travel distance and travel time to the site for each zone

ii. Estimate the regression equation between Visit/1000 and total travel cost

iii. Estimate the Demand Function using the above regression equation and calculate consumer surplus.

The advantage of using this method is that it is a well-developed technique and is based on actual observed behaviour. The disadvantages are that it can only be used in recreational sites, difficult to assess benefit of travel and multipurpose trips and it is resource intensive and statistically complex for analysis (Liekens et al., 2014). The limitations of this method are it is limited to the valuation of recreational sites and this method is incomplete as it cannot totally assess its existence value. It measures value of wilderness only from narrow perspective of its recreational value to identifiable current users. It measures use value but does not measure non-use values (Hussen, 2004). It requires survey skills and measures only use value. For more details, follow Perman et al. (2003)

Hedonic Methods

Hedonic method is based on the idea that value of physical properties depend upon environmental goods and services (Liekens et al., 2014). It uses market price of a good to estimate the value of an environmental attribute which is embedded in the price of the marketed good. The effect of negative environmental qualities on the price of goods is measured by hedonic price method (Brehmer et al., 2007). Land and house values are affected by its attractiveness, sensation of odour, noise, debris, health risks, proximity to landfill site, environmental quality, neighbourhood amenities, clean air, clean water, nearby residential areas, urban residential development, agricultural value, etc. (Grafton et al., 2004).

It uses statistical technique to estimate price of an environmental components with the help of functional relationship between dependent and independent attributes (Hussen, 2004). This method can also be used for assessing response of wage rate to change in human health conditions from different occupations. Pollution is an environmental factor causing health risk which can be assessed through willingness to pay from medical expenditures, income or wages (Grafton et al., 2004). In this case, statistical techniques can be used to construct a functional relationship between compensation to the workers and environmental risk. The dependent variables will be wage rates for occupation and the independent variables will be risk of environmental hazards (Hussen, 2004). For more details on Hedonic method, follow Grafton et al,, (2004).

The value of a house is affected by its structure (area of plot, size of house, number of rooms, size of room, floor space, age, quality of materials used, design, finishing, etc.) and environmental components (location, scenery, air quality, distance of development infrastructures, market, access to open space, etc.) (Hussen, 2004). The steps of hedonic methods for assessing price of house (Grafton, et al., 2004) are as follows:

Step 1: Collect data on residential property sales for a specific time period (usually one year).

Step 2: Statistically estimate a function that relates property values to the property characteristics and calculate environmental value of a house.

The limitations are it depends on human behaviour and requires survey, lots of data, economic theory and labour market (Hussen, 2004).

Contingent Valuation Method (CVM)

The recreational benefit (use value) can be assessed but there is real challenge to assess willingness to pay for non-use values. CVM measures both the use and the nonuse values of an environmental resource with the help of willingness to pay by conducting a survey. In CVM, the design of the questionnaire is important as it requires in-depth knowledge of statistics, environment, economics, creativity and imagination (Grafton et al., 2004; Hussen, 2004). CVM is commonly used to measure stated preference for an environmental good and measure economic welfare from environmental good or service. It is hypothetical method in which respondents accept an environmental improvement and make tax payments (Perman et al., 2003; Grafton et al., 2004). It involves a single good and individuals are asked to state their maximum willingness to pay (WTP) or minimum willingness to accept (WTA) for a change in the good. If individuals answer truthfully, their answers will exactly correspond to the utility change (Perman et al., 2003). It is survey-based method to assess the value of non-use resources (Brehmer et al., 2007).

Individuals are asked to state directly their WTP to obtain an environmental benefit or their WTA to tolerate an environmental cost. It is dependent on a hypothetical scenario put to respondents. There are two major phases in CVM: scenario analysis and valuation questions. In scenario analysis, it is necessary to define a good and explain its values and services with the help of photographs, videos and by stating similar example. Scenario analysis is important to give respondents necessary information about the relevant effects of the proposed actions. In valuation question, question is asked to the respondents for assessing the values. Two issues are involved in this part: context of the payment mechanism which assesses the mechanism of tax or fees and type of valuation question which provide value option (Hussen, 2004).

The steps of CVM (Grafton et al., 2004) are as follows:

i. Issue identification as a warm-up for respondents

ii. Describe the importance of a good and the change in the environmental quality from a particular good with the help of focus group discussion

iii. Define the payment process such as tax or government provision to identify real institution

iv. Find the WTP or choice decision

v. Administer the questionnaire to a random sample of individuals within the defined market

vi. Test for the reliability and validity of results: Analyse whether responses were consistent with demand theory. For more details, follow K.C. (2012).

Potential biases in CVM studies are as follows (Hussen, 2004):

i. **Information Bias:** WTP value for environmental assets depends on the quantity and quality of the information provided to them. There may be difference between willingness to pay (WTP) and willingness to accept (WTA).

ii. **Hypothetical Bias:** It occurs when respondents ignore real costs and benefits of a good. Respondents became sensitive to the payment of entrance fee, sales tax, payroll tax, income tax, etc.

iii. **Strategic Bias:** Respondents can refuse to respond and does not state actual WTP due to strategic cause. They may take it as a free rider situation and may refuse to give monetary value on the particular services as it is priceless.

iv. **Operational Bias:** Knowledge and understanding of respondents might affect the WTP value. It differs among different researchers.

v. **Design Bias:** Design of a questionnaire and a survey method can provide different results of WTP.

vi. **Vehicle Bias:** Choice of payment vehicle such as entrance fee and taxes inside a park might affect stated WTP

14. Conclusion

This chapter focuses on addressing information on Unit 1, 2 and 3 of Environmental Economics and Management (ENV 552) related to the latest course content of Semester II of Master in Environmental Science 2017. The chapter is prepared through extensive literature review of journals, books and electronic materials related to environmental economics. It will provide readers the basic concepts on the concerned topics. The information is shown in boxes to give additional information on the topic. Further reading materials is also recommended in chapters for getting detail information.

This chapter is the basic guiding document for the students of environmental science, it is recommended to follow the books and other literatures given in reference section for detail information. Few topics of course content which are included in other chapters are not explained in this part, so readers are recommended to follow the respective chapters for detail information.

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Chapter 4

Gender and Social Inclusion in Environmental Discourse

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1. Introduction

The Global Goals for Sustainable Development has committed to achieve by 2030, among others, a society without poverty and hunger, with good health and well-being, and with higher gender equality and reduced inequalities through partnerships, promoting peace and justice. Gender, social inclusion, equity, and justice are the core of current development discourses. The current development goals focus on governance and institutions for sustainability of resource management to achieve shared well-being, equity, and equality (UNDP, 2015; UNDP, 2016; WB, 2017).

The MSc course on Environmental Science aims to prepare responsible environmental scientists, leaders, managers, and practitioners to promote sustainable and equitable environmental development. This chapter on Gender, Environment and Social Inclusion is an introductory chapter to orient students about the concepts of gender, social inclusion, and equity as integral to natural resources use, environmental problems, management, and solutions[1].

Why Gender and Social Inclusion in Environmental Science?

Environmental science integrates all natural sciences - physical, biological, chemical- and earth science to understand natural systems and processes and environmental problems and solutions. Environmental science as an academic discipline emerged with the problem of environmental degradation, often induced by human actions and natural disasters.

The environment faces multiple challenges due to climatic and socio-economic changes. At the same time, the impact of environmental degradation is different for people belonging to different gender-based and other social groups. In turn, people belonging to these various social groups play differential roles and possess differential knowledge on the management, conservation, and use of environmental resources. These facts make gender and social inclusion integral to environmental science.

1 This chapter is reference material for Unit 6 on Environment and Social Responsibility of Course Env 511 Ecology and Environmental Philosophy. The other courses on Climate Change and Adaptation, Mountains and Plains, Biodiversity Conservation and Management, Urban Environment, Energy and Environmental Interdisciplinery, Research Methodology and Blostanstics, Water Resource Management, Environmental Hazards and Disaster Risk Reduction and Environmental Policies and Sustainability will benefit from this chapter, for it provides a gender and social inclusion perspective in environmental governance, vulnerability and poverty assessment, and policy discussions.

What is Gender and Social Inclusion?

Gender and social inclusion are interlinked concepts. Social and gender-based exclusions, and associated disparities and deprivations in a society are the context within which development activities are situated. The deprivations and exclusions are an outcome of unequal power relations among members of a society, which is a result of social and gender structures. The degree of deprivations and exclusions differs from society to society in specific space and time depending on the level of enlightenment of a society and associated structures.

Gender is a social construct organised around biological differences, i.e. sex differences. Individuals are predominantly born as heterosexual male or female, with minor cases of being homosexual. Over time, individuals ascribed, or acquired qualities or characteristics society considers typical to women and men.

There is a common misconception between the term 'gender' and 'sex'; it is mainly due to the use of a singular noun conferred to both the terms in Nepali vernacular (Bhadra, 2013). Sex refers to the biological characterictics. Gender identities are shaped by societal perceptions of what roles girls and women or boys and men are to play and what responsibilities to carry in day to day life. Harding (1986) argued that gender is both an organising principle of social life, creating and ordering relations between people in a hierarchical manner, as well as a process of giving meaning to and legitimization of social power relations (Zwarteveen, 2008). She explained three distinct processes through which gender-based social life is organized: 1) Symbolism - Gender-based social life is the result of assigning dualistic *gender metaphors* to various, perceived dichotomies that rarely have anything to do with sex differences; 2) Structure - Gender-based social life is the consequence of appealing to these gender dualisms to organise *social activity, of dividing* necessary social activities between different gender groups; 3) Identities - Gender-based social life is a form of socially constructed *individual identity* only imperfectly correlated with either 'the reality' or the perceptions of sex differences.

> Significant indicators for the differential well-being of men and women due to gender differences are differences in working hours, leisure time, longevity, and maternal and girl child mortality rates (Boserup, 1970; Acharya and Bennet, 1981; Sen 1992).
>
> In the event of disaster, women's mortality rates are higher than men's. For instance, during the earthquake 2015 in Nepal, 55% of the total dead were women. In some areas, the rate is higher. For instance in Nuwakot district, 16% more women died than men (GON, 2015).

Perceptions of gender are deeply rooted, and vary widely both within and between cultures, and change over time. But in all cultures, gender is associated with power and control over resources (including natural resources and economic gains) that are different for women and men. This gender-based, differential access to and control over resources and capabilities to make choices in life and access opportunities ultimately determine the level of their well-being. These differences prevail in the access to and benefit from natural resources, the management of resources as well as the impact of environmental degradation and disaster. So, understanding gender is crucial for people working on environmental issues and for environmental development.

Linked to the concept of gender is social exclusion and inclusion. The concept of social exclusion addresses deprivations of sections of society under various social structures in the form of class, caste, ethnicity, race, age, etc. For example, in the feudal structure the working class experienced deprivation. In the centralized development model, remote villages failed to participate in mainstream development. The capitalist mode of development based on the more work, more pay perspective has been blind to the differential capabilities and capacities of an individual, thereby marginalizing and excluding people with different abilities from mainstream economic growth. In the caste hierarchy, lower castes are excluded from opportunities and resources.

In short, in addition to gender, people belonging to a different location, class, caste, or race face multiple layers of exclusion. By extension, people who have been excluded because of different social structures are subject to multiple vulnerabilities when faced with environmental degradation.

Why should Gender and Social Inclusion be a Concern in Environmental Science and Development?

First, to design and implement environmental programmes in such a way as to not further widen the existing gender inequality and aggravate exclusions.

Second, to bridge the existing gender gap and eliminate exclusions so as to promote gender equality and inclusiveness in environmental sector development.

The core of gender and social inclusion concerns in environmental science is that the initiatives and investments made in environment should be responsive to the needs of the most vulnerable and deprived individuals and groups, coupled with gender sensitivity, to contribute to creating an equitable society in the long run.

Box 1: Gender equality and equity

Gender equality epitomizes the idea that all human beings, men and women, are free to develop their personal abilities and make choices without the limitations set by stereotypes, rigid gender roles, or prejudices. It means that the different behaviours, aspirations, and needs of women and men are considered, valued, and favoured equally. It does not mean that women and men have to become the same, but that their rights, responsibilities, and opportunities will not depend on whether they are born female or male.

Gender equity means fairness of treatment for women and men, according to their respective needs. This may include equal treatment or treatment that is different but considered equivalent in terms of rights, benefits, obligations, and opportunities. In the development context, a gender equity goal often requires built-in measures to compensate for the historical and social disadvantages of women and girls.

Source: UNINSTRAW (2007)

2. Gender Inequality and Social Exclusion in South Asia

Patriarchy is the predominant social outlook in South-Asian societies. It refers to a context in which men and masculinities are privileged over women and feminine issues. The patriarchal system bestows resource allocation and decision-making to men, both of which are important parameters for gaining power, confidence, and securities. In patriarchal social systems values, customs, norms, and practices subjugate women to the power of male heads of households, restrict their mobility, and limit or often disallow their decision-making rights, even regarding their own health and labour. All these are still very evident in most cultures and societies within the region (Agrawal, 1988; Tamang, 2000; Dwivedi, 2014).

During natural disasters and extreme events like earthquakes, tsunami, and floods women and girls are more prone to mortality than men and boys. Besides, although women are the first to suffer, they are the last to get disaster information, because the patriarchal social structure of most of these societies formally relegate women's dependency to male members with respect to receiving disaster information, or risk awareness, preparedness, and evacuation (Dhungel and Ojha, 2012; Shrestha et al., 2012).

Gender inequality also interacts with other social differences in South Asia like caste, class, and ethnicity. Based on these social stratifiers people belonging to these groups are included or excluded from various activities, resources, institutions, and decision-making processes. What this means is that women who belong to poor, low-caste, marginalized, ethnic, or other socially backward groups experience 'double marginalization'. Their sex not only means they are a sub-altern group already within their communities or groups, but they are also part of a larger community or group that is marginalized (Gilles and Debarbieux, 2012).

The UNDP Human Development Report's new Gender Inequality Index highlights that South Asia in particular trails behind on many of the critical measures of gender equality (UNDP, 2015). Gender issues in South Asia represent a complex scenario, manifesting in complex ways - emanating from, and interlinked with, other deeply embedded social hierarchies.

Box 2: Gender and social exclusion issues in Nepal

Nepal is a patriarchal country. Primarily, property is inherited through men. Though there have been some policy referendums nationally to address this, women's ownership of land and associated resources are still limited. The Census 2011 reports that only some 20% women have assets including land, and 64% are involved in unpaid domestic work, which includes managing water and forest resources, and care for children. A study reports that Nepali women are in high risk of water insecurity (Parker et al., 2016)[2]. Indeed, Nepali women carry a burden of water collection and management, both for domestic and farm use.

Nepal's demography in the last decade has drastically changed with increased long-term male absenteeism in almost all its districts (CBS, 2014). In this changing context, women's roles in managing natural resources, both inside the house and outside, have increased. In addition, there is a trend of leaving villages and going to cities. The rate of urban poor in cities has also increased and women face different problems there, particularly with respect to competing for water (UNDP, 2014).

In addition, Nepal faces natural disasters like landslides and floods caused by the changing climate. The delay of winter rain has been a key factor in forcing farming communities to migrate to other places for work. When a male member of the family migrates, the overall work burden comes down on the women.

In general, the women's workload in Nepalese society is more than that of the men. To illustrate, data on a daily time-use analysis of families living in Upper Rasuwa district in Himalayan region shows women sleep later than men and wake up early (Figure 1)

[2] The indicators to identify water insecurity used for this study are distribution by sex of agricultural holder, rural poverty headcount at national poverty level, employment in agriculture, agricultural irrigated land, information on floods, and a drought-exposure composite index.

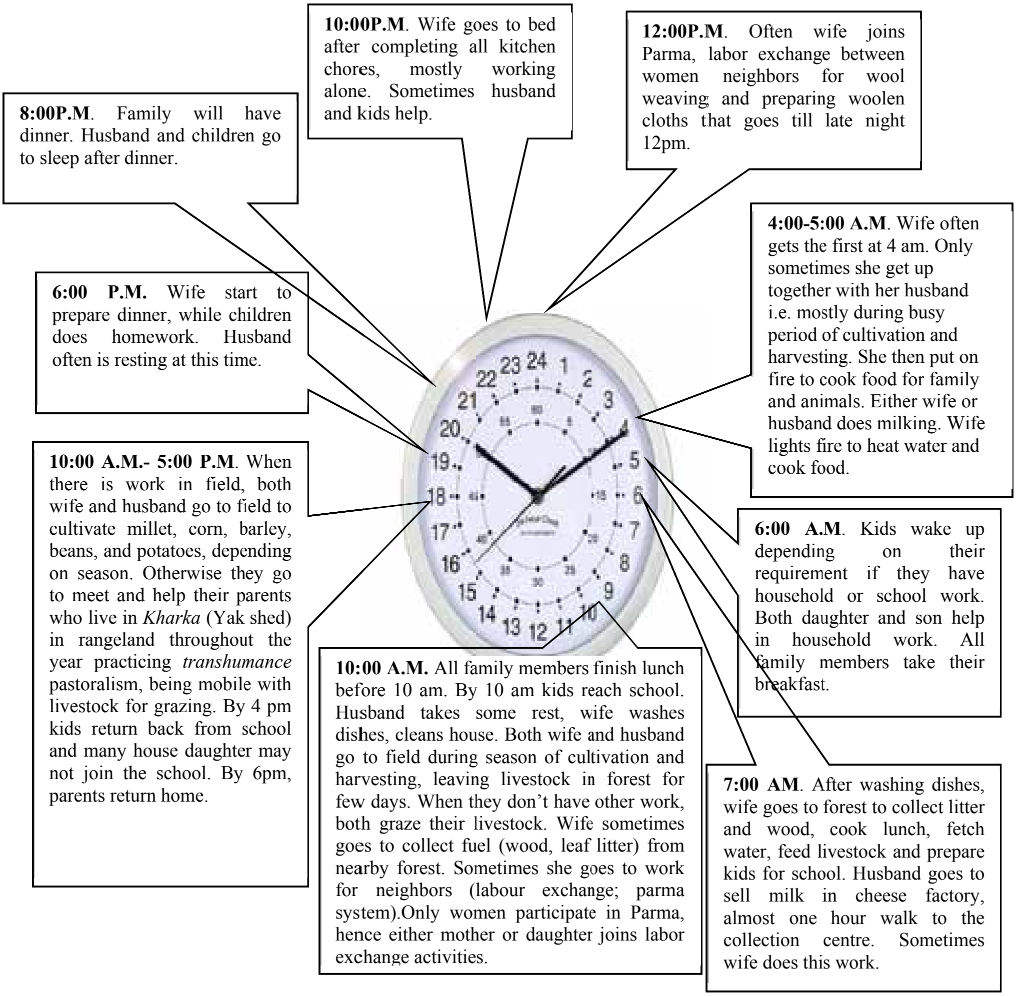

Figure 1: Daily time use analysis of families in Himalayan region of Nepal (Koirala and Deshar, 2016)

3. Theories and Discourses on Gender and Environment

Here we discuss some prominent theories and discourses that have guided gender perspectives, analysis, and integration into the field of environmental inquiry and problem solving.

Ecofeminism

Ecofeminism examines the connections between women and nature. Coined in the seventies at the time of the green revolution[3], this theory aims to address the problem of disconnect between science and natural system by linking it to women's engagement with nature and nurture, i.e. care for nature to regenerate and meet human need for future. Ecofeminism sees the deprivation and subjugation of women on one hand and the control and over-exploitation of nature on the

[3] Green revolution is the name given to science-based transformation of Third World Agriculture. It includes the scientific transformation of seeds and technology for agriculture aimed to increase agricultural productivity to meet human food security (Shiva, 2016).

other as an outcome of patriarchal and capitalist processes. It argues that women have a strong link and sense of sustainability with respect to natural resources by virtue of their nurturing and reproductive roles and responsibilities. Karen Warren, Rosemary Reuther, Vandana Shiva, and Maria Mies, among others, are prominent protagonists of ecofeminism (Shiva, 2016).

The first generation of environmentalists in our contemporary world, indeed, happens to be made up of women. For example, 'Silent Spring' (1962) was written by the female author Rachel Carson and'Our Common Future'was edited by Gro Harem Brundtland (1987), a visionary global leader, on how to manage natural resources from an environmental perspective.

Aligning with the ecofeminist perspective, Women, Environment, and Development (WED) approaches that emerged in the 1980s initially positioned women as victims/culprits/causative agents of environmental degradation. More focused studies in later years corrected this world view and placed more emphasis on women's importance in community-based environmental conservation and management, and environmentally related livelihood opportunities.

Feminist Environmentalism

Ecofeminism has been criticized for its essentialist perspective, considering all women as a homogenous group with similar relations with nature, and a similar sense of nurturing and conservation of nature. Departing from this perspective, feminist environmentalists argue that women's relation with natural resources varies with other social parameters such as class, caste, and location, and cannot be generalized. This theory adds structural inquiry as a factor that determines the relation between women and nature. Women's interests in particular resources and in the ecological process are shaped by the roles and responsibilities men and women are engaged in on a daily basis (Agarwal, 2016).

Feminist Political Ecology

Feminist political ecology, in turn, recognizes the close interlinkages of gender with other social categories as also differences in gender-environment relations. But it does not simply add gender to class, ethnicity, race, and other social variables as axes of power while investigating political resource access and control, and environmental decision-making. Instead, it points out that these resource-related relationships relate to 'women's particular circumstances' (Molyneux, 2007). These not only interact with class, caste, race, culture, and ethnicity to shape processes of ecological change, but also differ in different social, political, and economic settings dynamically shaping 'gender as a critical variable in shaping resource access and control' (Rocheleau et al., 1996).

In sum, it recognizes the importance of examining people's experiences of resource degradation, disasters, mobility, and displacements, as these connect with other scales of power and decision-making (Harding, 2008; Hanson, 2015).

How to Integrate a Gender Perspective into Environmental Concerns and an Environmental Agenda?

Gender Analysis

Gender analysis is the first step to integrating gender into any development effort including environmental development. It refers to a variety of methods used to understand the relationships between various gender-based groups, their access to resources, their activities, and the constraints, they face relative to each other. The collection of sex-disaggregated data is crucial for gender analysis, for it allows a pattern to see gender differences.

When patterns of gender difference and inequality are revealed, gender analysis is the process of examining why the disparities are there, whether they are a matter for concern, and how any related problems might be addressed.

Gender analysis also includes an examination of the multiple ways in which women and men, as social actors, engage in strategies to transform existing roles, relationships, and processes in their own interest and in the interest of others (UNINSTRAW, 2007).

Gender Mainstreaming

Gender mainstreaming is a strategy for making the concerns and experiences of various gender-based groups an integral dimension of the design, implementation, monitoring, and evaluation of policies and programmes in all political, economic, and social spheres, such that inequality between men and women is not perpetuated. It is also the process of assessing the implications for women and men in different social groups of any planned action, including legislation, policies, or programmes, in any area and at all levels (UNINSTRAW, 2007).

Gender-transformative Approach

Gender-transformative approach goes beyond identifying and exploring symptoms of gender equality. It aims to transform a persisting gender-based social structure that results into gender inequalities in access and prevents the sustainable management of resources (Verma, 2014). The approach identifies and explores the symptoms of gender inequality, with the aim to change existing gender barriers and gaps through structural changes. Thus, it addresses socially constructed norms, attitudes, and relations of power that underlie the inequalities.

This approach includes a rigorous gender analysis, organisational change, capacity and institutional strengthening, and ensuring a gender positive impact through meaningful engagement of deprived gender-based groups in leadership and policy and decision-making processes.

Gender in EIA and DRR

Environmental impact assessment (EIA) is a well institutionalized practice and can be seen as an outcome of long advocacy and activism on the conservation and protection of nature against development-led environmental degradation. Effective assessment can be achieved through the involvement of people living in a particular location and the knowledge they have about the environment (Stevenson, 1996). When we consider people in an environmental impact assessment, it is important to consider the different knowledge of women and men about different environmental resources and their uses and knowledge on regeneration.

Crisis such as natural disaster are experienced very differently by girls, women, boys and men. They face different risks, respond differently to stressful situations, and have different capacities for dealing with the effects of crisis (CDES-TU and UNESCO, 2015). The Hyogo Framework is a global blueprint for dealing with risk reduction efforts. On gender and disasters, the Framework states that ‘a gender perspective should be integrated into all disaster risk management policies, plans and decision making processes, including those related to risk assessment, early warning, information management, and education and training.

Long-term Environmental and Socio-ecological Monitoring

Long-term ecological monitoring (LTESM) is a complex of repeated, field-based, empirical measurements taken periodically for variables such as the income status of a local community, demographic change, the population size of a threatened species, a species richness and composition, habitat condition, forest cover, or the distribution of an invasive pest to assess the state of the system and draw inferences about changes over time like the last ten years (Yoccoz et al., 2001; Lindenmeyer and Likens 2010 cited in Chhetri et al., 2015).

Long-term observations of a comprehensive set of interacting physical, environmental, biological, and social variables allow for the assessment of relationships among components of socio-ecological systems.

Applying a gender perspective at the time of data collection and analysis during LTESM is crucial. This would include an understanding of relationships between men and women of different categories and how these are shifting in response to new vulnerabilities and opportunities, but also of shifting roles and preferences with response to changing environmental and socio-economic resources (Chhetri et al., 2015).

4. International and National Commitments on Gender and Environment

Key UN conventions and agreements have provided a global guideline for integrating gender and environmental initiatives. Here are some key gender-focused commitments integrated with environmental conventions and agreements.

The UN Convention on the Elimination of all forms of Discrimination against Women (CEDAW) adopted in 1979 is an important international treaty committed to reduce discrimination against women in all sectors including environment. A prominent feature of CEDAW is that under its provisions not only national authorities are held responsible, but also non-governmental parties are held accountable for non-discrimination, including in the areas of environmental finance and technological change (UNEP, 2015).

In 1992, the United Nations Conference on Environment and Development (UNCED) adopted Agenda 21 in Rio de Janeiro. Chapter 24, entitled Global Action for Women towards Sustainable Development, calls upon governments to make necessary constitutional, legal, administrative, cultural, social, and economic changes to eliminate all obstacles to women’s full involvement in sustainable development and in public life. Agenda 21 makes 145 references to establish linkages between women and environment and sustainable development, recognizes the importance of the knowledge and traditional practices of women, and underscores the contribution women have made to biodiversity conservation (UNEP, 2015).

In 1995, the United Nations Conference on Women (UN-Women): Equality, development, peace, and Platform for Action were held in Beijing. One goal was to review the progress made since CEDAW as well as Agenda 21 in the environmental sector. The Platform identified unsustainable patterns of production and consumption as an engine for poverty, inequality, and environmental destruction. It noted the consequences of widespread and worsening environmental degradation and disasters on all human beings, including exacerbated poverty and migration and displacement of peoples. It also highlighted that women and girls, particularly rural and indigenous, are disproportionately affected by illness, damaged livelihoods, increased unpaid work, and compromised well-being (UNEP, 2016).

The Millennium Development Goals has gender-specific goals for gender equality, including reduction in maternal mortality. However, no indicators for the goal regarding environmental sustainability had been integrated into the gender goals. This limitation has now been addressed in the Sustainable Development Goals (SDGs). The SDGs not only have a specific gender goal and targets, but gender targets are also integrated with other goals through explicit indicators or gender-disaggregated data collection and analysis (UNEP, 2016). The emphasis on gender has been integrated in all the 17 Sustainable Development Goals.

By now, other environment related conventions have recognized that gender is integral to any environmental agenda. The Convention on Biological Diversity (CBD, 2008) recognizes the vital role women play in the conservation and sustainability of biodiversity. The UN Convention to Combat Desertification (UNCCD, 1996) emphasizes the central role women play in regions affected by desertification and/or drought, particularly in rural areas of developing countries, and the importance of ensuring full participation of women and men at all levels in programmes to combat desertification and mitigate the effects of drought. The UN Framework Convention on Climate Change (UNFCCC) first addressed gender in 2001 at the Conference of the Parties (COP7), when it mandated that national adaptation programmes of action should be guided by gender equality. The UNFCCC Paris Agreement, 2015 recognizes the intersection of climate change and gender equality, empowerment of women, and realization of their rights. The Sendai Framework for Disaster Risk Reduction 2015-2030 recognizes the need to integrate gender, disability, and cultural perspective into disaster related legislations and programmes.

As the growth of urban areas is increasing, the Habitat Agenda on Global Plan of Action, 2003 is an important global commitment for the sustainability of cities. It recognizes gender equality as an important parameter in human settlement development. It commits to these important issues:

- Integrating gender into human-settlement related legislation and programmes
- Developing conceptual and methodological aspects of planning
- Collecting, analysing, and disseminating gender-disaggregated data and information
- Integrating a gender perspective into the design and implementation of environmentally sound and sustainable resource management mechanisms
- Producing techniques and infrastructure development in rural and urban areas
- Promoting full and equal participation of women in human settlement planning and decision-making

Integrating and implementing gender issues is a complex and context specific process. These international commitments are a positive development to integrating gender and addressing gender inequality issues in the environmental sector. However, their effectiveness depends on the translation of these global commitments into national and local policies and actions.

Nepal as a signatory of CEDAW has committed to global environmental agreements like the Paris Agreement, and has adopted the Sustainable Development Goals to be achieved by 2030. In the bargain, it has endorsed environmental and related policies to address some gender issues.

One of highly advocated and adopted policies is the one on the minimum participation of women in committees to manage natural resources. Policy and regulations have made mandatory the minimum participation of women in watershed, forest, drinking water, and irrigation committee agreements. In many sectors, social safeguard policies and guidelines have been prepared considering a possible negative impact of environment-related infrastructure development.

5. Gender Linkages

5.1 Gender and Disaster

Ikeda's 1995 study reports that female mortality rates were four to five times higher than male mortality in the 20-49 age group. Pradhan et al. (2007), based on a study on flood plains of Nepal, found that socially-constructed, gender-specific, female vulnerability was built into everyday socio-economic patterns, which led to the relatively higher female disaster mortality rates compared to men. A study of disaster events in 141 countries from 1981 to 2002 reported women's life expectancy was less than that of men,when they face a disaster (Neumayer&Plumper, 2007).

Studies from Bangladesh and Nepal show that women are more susceptible to injuries and death than men, because they do not get information in time during disaster (Khan et al., 2010). In Bangladesh early warning signals had not reached large numbers of women, because the information had been disseminated primarily in public places to which many women do not have easy access. Even when women did receive warnings, they were constrained by cultural norms that restrict women's freedom of movement in public. For example, since women were not allowed to leave the house without a male relative, many waited for their husbands to return to take the decision to evacuate. So they lost precious time that might have saved their life and that of their children (D'Cunha, 1997;UNEP, 1997; Parikh, 2007;Sharmin and Islam, 2013). In Sindh, Pakistan,at flood time the decision on when, where, and how to flee was entirely in the hands of male heads of household or male community elders (IDMC, 2011).

A post-disaster situation is even more hazardous for women and children (UNIFEM, 2010), because they face additional risks of intimidation, violence, sexual harassment, trafficking, and rape - largely due to gender inequalities. Disasters may disrupt local security safety nets, leaving women and children unaccompanied, separated, or orphaned due to the breakdown of normal social controls and protections, making them especially vulnerable to human trafficking.

Mainstreaming gender in Disaster Risk Reduction (DRR) is important, not only because ofthe gender-based impact of a disaster, but also because men and women of different social strata have different needs and knowledge of how to cope with disasters. So, DRR planning and programming in a gender-sensitive manner will ensure programme effectiveness.

5.2 Gender and Water Resources

Water is an important element of ecosystems as well as a human need for survival. Water fulfils also other needs such as energy, input for farming, and recreation. Since good water availability is limited, there is a competition for water. When water is a competitive commodity, its access is often governed by the ability to get to it. Ability and capability to access water depend on an ability to control, or purchase, water. Practices such as untouchability are structural barriers to access water as also sanitation services. More so, access to sanitation among the rich is about 80%, whereas among the poorest it is only 10% (ADB et al., 2012b).

Since women lack enough assets generally, the water goes mostly to the houses with more power and resources, that too, those headed by men. Besides, water related work is primary the job of women in a household. In most of the water chores such as irrigation and managing drinking water, women do the work, whereas representation in decision-making fora is mostly dominated by men. A review of the representation of women in the National Federation of Irrigation Users Associations in Nepal shows a remarkable number of high-caste, male members (ADB, 2012a).

These differences emerge from structural barriers and different gender-based roles and responsibilities that determines possibilities to effectively participate in decision making bodies. However, it becomes a problem, when these differences and barriers affect the wellbeing as well as efficiency of resource management at large. For instance, a study shows a drastic change in entitlement to drinking water taps in rural water supply projects in Nepal after 7 years of implementation, due to the informal privatization of community taps (Udas et al., 2014).

5.3 Gender and Climate Change

Two aspects of climate change -an increasing temperature trend and a shift in rainfall pattern -are virtually established facts now. Climate extremes have aggravated disasters such as floods, droughts, and landslides.

The effects of climate change are not homogenous, though, because people have different capacities and capabilities, thatwill have differential possibilities to cope with and adapt to the effects of climate change (Dankelman, 2002). Notably, though, women as primary caretakersof water and forest resource management face an increased work burden with the drying up of water sources and forest resources. They commonly are also confronted with higher risks from the impacts of climate change in situations of poverty. As it is, the majority of the world's poor are women. Their unequal participation in decision-making processes and labour markets compound inequalities and often prevent them from fully contributing to climate-related planning, policy-making, and implementation of coping strategies.

Yet, women can (and do) play a critical role in response to climate change thanks to their local knowledge and leadership in sustainable resource management and sustainable practices at household and community levels. At local level, women's inclusion as leaders has lead to improved outcomes of climate-related projects and policies. In contrast, when policies or projects are implemented without women's meaningful participation, it can increase existing inequalities and decrease effectiveness.

5.4 Gender and Mountain Issues

Women in the mountains have always played a central role in agriculture and natural resources management, but 'despite being the mainstay of the economy and the holders and practitioners of local knowledge, women have very little say in the decision-making processes relating to agriculture, water and forests and this remains a male domain' (Sogani, 2013: 266). Recent comparative research on the 'feminization' of agriculture and natural resource management, undertaken by ICIMOD and supported by IFAD, illustrates this trend, whereby in some mountain regions in India women undertake 5 to 6 times more agricultural work than men. In Nepal, the range is skewed even more with women carrying out over 6 times more agricultural work than men (Lama, 2010 and Jain, 2009).

In recent years, with the high rates of male out-migration, women's workloads in these domains of work have intensified without corresponding increases in access to resources, decision-making, and secure rights to land. Women continue to face differential access toand ownership and control of critical natural resources. They are further constrained by unequal power relations, gender-biased attitudes and norms, and sometimes even systematic exclusion and under-representation.

So, in mountain regions, gender inequalities in access to resources and decision-making processes that affect communities, cultures, and environments (U.N. General Assembly Resolution 64/205, 2010 cited in Karki et al., 2011) are key challenges that hinder women's and men's active participation in sustainable development processes. Moreover, different and new drivers of change also create new or exacerbate ongoing repressive dynamics. For instance, the high rates of male out-migration mean that women experience intensive workloads, responsibilities and burdens, which in turn often result in low enrolment and drop-out of girls from formal education as well as increases in gender-based violence and trafficking of girls and women.

5.5 Gender and Renewable Energy

Only about 24% of total households in Nepal use clean energy for cooking. This includes the use of LP Gas, bio-gas, and electricity (CBS, 2014). The rest still uses traditional sources of energy like natural firewood and processed firewood such as guidha, brickets. These energy sources are reported to cause smoke, which is a health hazard. Since women are responsible for cooking, they are the primary victims, together with the children they may have to take care of while carrying out their cooking responsibilities (PA, 2010).

Despite a huge potential in harnessing various renewable energy resources such as hydro-power, solar power, wind energy, and bio energy these resources have not yet been captured sustainably for geographical, technical, political, and economical reasons (Cecelski, 2000). Studies show that improved cook stoves and the use of solar energy and other forms of renewable energy have a positive impact on the health and well-being of women. In addition, women's involvement in management of such energy projects had positive outcome in resource management as well as equitable share on benefit from the projects.

5.6 Gender and Urban Development

The Global Report on Human Settlements 2009 (UN Habitat, 2009) estimated that the share of urban dwellers is expected to rise to 70% by 2050, and will mostly occur in developing countries. The trend as observed by the World Cities Report, 2016 (UNHabitat, 2016)is not much different. Human movements from rural to urban areas have been triggered by economic opportunities in cities as much as by forced displacement due to natural hazards and the adverse impact of the changing climate in agricultural areas.

While urbanization offers many benefits, its ugly face is urban poverty. This often has the most severe impact on women and girls.The World Cities Report 2016 noted that 75% of the world's cities in current period have higher levels of income inequalities than two decades ago. The spatial concentration of low-income unskilled workers in segregated residential quarters acts as a poverty trap for many with severe job restrictions, high rates of gender disparities, deteriorated living conditions, social exclusion and marginalization, and a high incidence of crime (UN Habitat, 2016).

Women often suffer disproportionately, not only because they are, on average, poorer than men (three-fifths of the world's one billion poorest people are women and girls[4]), but often also because they experience greater difficulty in accessing resources and services tailored to their needs, as well as decision-making opportunities.

6. Conclusion

A review, in terms of a gender perspective, of the conventional definition of Environmental Science based on a natural science perspective might well be the agenda of the day. The gender-based stewardship of natural resources has already been widely mentioned in recent literature from Asian and African countries.

The gender roles in decision-making in different societies and the importance of mainstreaming women's concerns and need have been identified as essential to the development of a just and equitable society. Gender is no more a subject of study of social science in isolation, for natural science is acknowledging its importance too. In this context, theories on gender and environment such as Ecofeminism, Feminist Environmentalism, and Feminist Political Ecology are core subjects.

Some issues should be incorporated into aspects of sustainability of the natural environment or of a development perspective. These would include gender analysis, gender mainstreaming, gender-transformative approach, and long-term environmental and socio-ecological monitoring.

In recent decades, international and national agencies have realized the importance of a gender perspective in the development agenda, and have agreed to set up institutional arrangements.

Nepal as signatory of and party to many of these agreements has either complied or is attempting to comply with them in full effort. It may be noted that the majority of students opting for Environmental Science at Nepalese universities are girls. This should not be seen as a coincidence only, rather as a growing realization to conserve the environment from a gender perspective.

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Chapter 5

Ecosystem Based Adaptation: Conceptual Background and Applications

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1. Theoretical Background

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (IPCC 2007). This change in climate system due to human cause is perhaps the greatest challenge of our time. For existence, we have to act quickly and adapt now. Ecosystem-based adaptation (EbA) is a science based approach, which is receiving growing attention for its great potential to reduce people's vulnerability to a range of climate change impacts. By definition ecosystem is a community of living organisms in conjunction with the nonliving components of their environment interacting as a system. Adaptation to climate change means modifying conventional practices and infrastructure to limit the risks posed by climatic changes.

Ecosystem is an abbreviation of ecological system. It was introduced by AG Tansley in 1935, when the ecological thinking was dominated by the concept of ecological community, that is, association of different organisms (species) or their populations. Tansley published "The use and abuse of vegetational terms and concepts" (Tansley, 1935) in which he introduced the ecosystem concept. He wrote: "Though the organisms may claim our prime interest, when we are trying to think fundamentally, we cannot separate them from their special environments, with which they form one physical system". An ecosystem, thus, is comprised of not only the structural components but it is also characterized by functional attributes.

From the structural standpoint, the ecosystem comprises of the following components (Figure 1):

i. Inorganic substances (carbon, nitrogen, carbon dioxide, water, etc.)

ii. Organic compounds (proteins, lipids, carbohydrates, etc.)

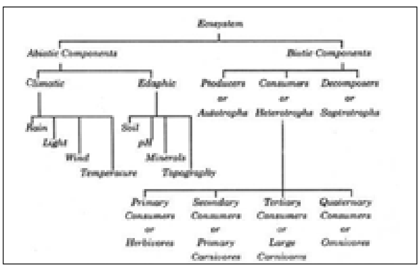

Figure 1: Schematic representation of structure of an ecosystem (Source: yourarticlelibrary.com)

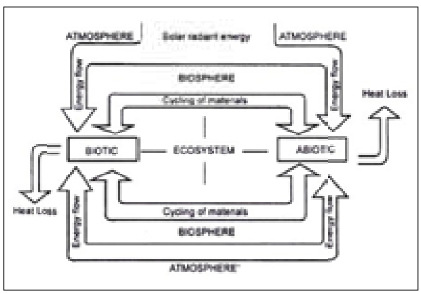

Figure 2: A hypothetical model of functional ecosystem (Source: yourarticle library.com)

iii. Climate regime (temperature, precipitation, etc.)
iv. Producers (autotrophic organisms, largely green plants)
v. Consumers (heterotrophic organisms, chiefly animals)
vi. Decomposers (heterotrophic organisms, chiefly bacteria and fungi.

From the functional standpoint, the ecosystem comprises of the following processes (Figure 2):

i. Energy circuits
ii. Food chains
iii. Diversity patterns in time and space
iv. Nutrient cycles
v. Development and evolution
vi. Control (cybernetics)

Ecosystem is normally an open system with a continuous, but variable influx and loss of materials and energy. It is an overall integration of the whole mosaic of interacting organisms and their environment. It is a basic, functional unit with no limits of boundaries. Different types of ecosystems are present in different geographic areas. An ecosystem may be conceived and studied in the habitats of various sizes, e.g., one square metre of grassland, a pool, a large lake, a large tract of forest, balanced aquarium, a certain area of river and ocean. In broader understanding, the biosphere is an ecosystem; yet a drop of water can also be viewed as an ecosystem entity.

Critical thinking: How can large as biosphere and tiny as a water-drop be defined as an ecosystem?

2. Ecosystem Goods and Services

Human beings live in and derive their needs from the ecosystem, whether a natural, semi-natural or non-natural; we understand it as our habitat. The three core needs of human beings: food (including water), shelter and clothing are but fulfilled by the structural components of an ecosystem, while their life cycle is a part of ecosystem's functional attributes. Any change in the ecosystem characteristics, by natural process or human intervention, is to bring impact squarely upon the human beings. In economics point of view, the structural components are the 'goods' (tangible items) and the functional components are the 'services' (activities) of an ecosystem. Thus, the characteristics of an ecosystem are the manifestation of a variety of goods and services upon which people depend. The ecosystem services are but human interpretation of natural product and processes.

Ecosystem goods include the "tangible, material products" of ecosystem processes-food, construction material, medicinal plants-in addition to less tangible items like tourism and recreation, and genes from wild plants and animals that can be used to improve domestic species. Ecosystem services, on the other hand, are generally "improvements in the condition or location of things of value". These include things like the maintenance of hydrological cycles, cleaning air and water, the maintenance of oxygen in the atmosphere, crop pollination and even things like beauty, inspiration and opportunities for research. The works of Costanza et al. (1997) and the Millennium Ecosystem Assessment (2005) lumped all of these together as ecosystem services.

Details in:

- Costanza, R, R D'arge, RD Groot, S Farber, M Grasso, B Hannon, K Limburg, S Naeem, RV O'neill, J Paruelo, RG Raskin, P Sutton & MV Den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387, 253 - 260
- Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

The ecosystem services are categorized into four groups - provisional, regulating, supporting and cultural services. These services provided by the ecosystem are essential for human well-being (Figure 3). According to Alcamo et al. (2003), provisioning services are the products obtained from ecosystems. Providing freshwater, food, fibre, fuel are some of the provisional services provided by the ecosystem. Regulating services are the benefits obtained from the regulation of ecosystem processes. The ecosystem helps regulate air quality, water quality, water flow, biodiversity, climate, etc which are its regulating services. Supporting services are those that are necessary for the production of all other ecosystem services. The supporting services include soil formation, nutrient cycling, water cycling, etc. Cultural services are the non-material benefits people obtained from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences. The cultural services include cultural diversity, aesthetic values, recreation, etc.

Figureure 3: Linkages between ecosystem services and human well-being

This Figureure depicts the strength of linkages between categories of ecosystem services and components of human well-being that are commonly encountered, and includes indications of the extent to which it is possible for socioeconomic factors to mediate the linkage. (For example, if it is possible to purchase a substitute for a degraded ecosystem service, then there is a high potential for mediation.) The strength of the linkages and the potential for mediation differ in different ecosystems and regions. In addition to the influence of ecosystem services on human well-being depicted here, other factors including other environmental factors as well as economic, social, technological, and cultural factors- influence human well being, and ecosystems are in turn affected by changes in human well-being.

A peer-reviewed study published in 1997 estimated the value of the world's ecosystem services and natural capital to be between US$16–54 trillion per year, with an average of US$33 trillion per year (Costanza et al., 1997). However, the scientists have indicated that 'The total value of biodiversity is infinite, so having debate about what is the total value of nature is actually pointless because we can't live without it'. The monetary pricing of the ecological goods and services is never to capitalize the invaluable natural entities and is done with respect to the valuation of ecosystem services. Often it is said that assigning the ecosystem services to economic valuation is to help inform decision-makers.

Ecosystem-based Adaptation or EbA is an emerging strategy for community development and environmental management that seeks to use an ecosystem services framework to help communities adapt to the effects of climate change.

3. Global Climate Change Impacts to Ecosystems

Climate is an important environmental influence on ecosystems. Changing climate affects ecosystems in a variety of ways. The adverse impacts of global climate change on the world's ecosystems and the people are escalating as temperature and precipitation patterns change and extreme weather events and related conditions increase in frequency and intensity. Climate change directly threatens the services ecosystems provide including food, clean water, coastal protection, fuel-wood, soil stability, and pollination as well as the people who depend directly on these ecosystem services.

For instance, warming may force species to migrate to higher latitudes or higher elevations where temperatures are more conducive to their survival. Similarly, as sea level rises, saltwater intrusion into a freshwater system may force some key species to relocate or die, thus removing predators or prey that are critical in the existing food chain.

Climate Impacts on Ecosystems
Key Points

- Climate change can alter where species live, how they interact, and the timing of biological events, which could fundamentally transform current ecosystems and food webs.
- Climate change can overwhelm the capacity of ecosystems to mitigate extreme events and disturbance, such as wildfires, floods, and drought.
- Mountain and arctic ecosystems and species are particularly sensitive to climate change.
- Projected warming could greatly increase the rate of species extinctions, especially in sensitive regions.

Source: EPA, 2017

Global climate change has significant impacts on biodiversity at different levels of organisation (CBD, 2009) that have caused significant changes in ecosystem and species distributions, principally due to increasing temperatures and altered precipitation regimes (Parmesan and Yohe, 2003). This change in climate is expected to cause shift in species distribution that leads to an increase in species extinction rates (Thomas et al., 2004), affect the species composition of many ecosystems that ultimately affects the continuity of ecosystem functioning, invasion of non-native species in numerous ecosystems. These impacts undoubtedly affect the provision of ecosystem services where visible impacts on fisheries, water flow regimes, and carbon sequestration processes have been observed in different parts of the world (McCarty, 2001 as cited in Andrade 2010).

There is high confidence that climate change will result in extinction of many species and reduction in the diversity of ecosystems (IPCC, 2007). Vulnerability of ecosystems and species is partly a function of the expected rapid rate of climate change relative to the resilience of many such systems. Human activities have substantially reduced the resilience of ecosystems and made many ecosystems and species more vulnerable to climate change through blocked migration routes, fragmented habitats, reduced populations, introduction of alien species and stresses related to pollution.

As put forward by IPCC (2007), there is very high confidence that regional temperature trends are already affecting species and ecosystems around the world and it is likely that at least part of the shifts in species observed to be exhibiting changes in the past several decades can be attributed to human-induced warming. Thus, additional climate changes are likely to adversely affect many more species and ecosystems as global mean temperatures continue to increase. For example, there is high confidence that the extent and diversity of polar and tundra ecosystems is in decline and that pests and diseases have spread to higher latitudes and altitudes.

Details in: Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability. IPCC Fourth Assessment Report: Climate Change 2007

4. Ecosystem Approach and EbA

The "Ecosystem" has been treated as a fundamental unit in Ecology to understand the inter-relationships of the living beings and their physical environment. For many years, the conservation organisations were much inclined to the protection of some specific species, specifically those endangered. The concept of land ethics (developed by Aldo Leopold in late 1940s) and publication of the Theory of Island Biogeography (by Robert MacArthur and Edward O. Wilson in 1967) opened a discourse of considering a whole system in conservation. In the following years, scientific research studies carried out on species and their habitats expanded our understanding of how the species are maintained in their natural systems, that is, their ecosystems. This improved understanding of system interdependencies and ecosystem processes led conservation organisations to take ecosystem approach. In more recent days, ecosystem has been a key component in understanding climate change impacts and planning adaptation models.

Ecosystem Approach: The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way (CBD, 2000). It is based on the application of appropriate scientific methodologies focused on levels of biological organisation which encompass the essential processes, functions and interactions among organisms and their environment, and recognizes that humans, with their cultural diversity, are an integral component of ecosystems. It is a conceptual framework for resolving ecosystem issues and manages the environment through the use of scientific reasoning. One key feature of the ecosystem approach is that it is a broader method to the traditional system of site protection. As described by the Conference of the Parties (COP) to CBD, the ecosystem approach is the primary framework for action.

The initial idea for an ecosystem approach was floated during the second meeting (1995) at the COP to the Convention on Biological Diversity (CBD). In the subsequent meetings, the COP-CBD further elaborated on the ecosystem approach and its fifth meeting recommended for application. With the development and application of the ecosystem approach, at least two more terminologies came into use: i. Ecosystem-based management (EBM), and ii. Ecosystem management. EBM is used for projects that incorporate interaction of different levels: organisms, the ecosystem, and the human component. It considers social and cultural aspects into the solution not just only scientific reasoning. EBM gained support after the Millennium Ecosystem Assessment (2005). With ecosystem management, the process is similar to EBM; however, factors such as socioeconomics and politics can impact the decision and solution.

Ecosystem-based Adaptation: Climate change is a serious environmental problem we are facing today. With the deleterious impacts of climate change on the ecosystems, various remedies have been proposed to save the ecosystems and build their resilience. The healthy and functioning ecosystems also help people to mitigate and/or adaptation to climate change. For instance, the plantation of giant cane Narkat (*Arundo donax*) is useful for wastewater treatment as well buffering rivers from flood during heavy rainfall. Similarly, in coastal regions, mangroves act as natural barriers against storms and floods. Because of such multiple benefits, the governments around the world are restoring the lost ecosystems, and supporting their communities for the same. These practices, in fact, are examples of Ecosystem-based Adaptation (EbA).

In the UK, more than 3.000 ha of farmland were converted back into moors and wetlands as a means of reducing flooding events. Read more in: <www.greatfen.org.uk>.

EbA is fastly being recognized as an effective approach to enhance human resilience to climate change through the use of biodiversity conservation and ecosystem services. The foundation of EbA being based on the management of ecosystems not only helps communities address climate adaptive deficits but also contributes towards enhancing local economies which may be based on natural resources. The EbA concept was introduced and the term coined at the UNFCCC COP 14 in Poznan in 2008 (Table 1, Figure 4). Since then, the concept has successfully been promoted into broader adaptation negotiations, policies, strategies and action plans, and the international organisations have been working together and sharing knowledge on EbA. The Parties at the various UNFCCC meetings are also promoting the definition of EbA reached under the CBD.

Table 1: Evolution of adaptation agenda in the Conference of Parties to Climate Change

Year	Event	Outcome
2001	CoP-7 Marrakesh	Political interest in adaptation increased to complement mitigation activities; Marrakesh Accord gives importance to adaptation
2005	CoP-11 Montreal	Develop "Program of Work" on technical and socio-economic impacts, vulnerability and adaptation
2007	CoP-13 Bali	• Bali Action Plan highlights the significance of adaptation; Recognizes linkages between climate change and disaster risk reduction • IPCC: climate change affects poor human communities disproportionately; Community based Adaptation (CbA) suggested
2008	CoP Poznan	EbA terminology coined and implementation promoted
2009	UNFCCC CC Talk Bangkok	IUCN Position Paper on Ecosystem based Adaptation (EbA) presented in the meeting
2010	CoP-16 Cancún	Ecological resilience prioritized
2012		The first EbA pilot project addressing the fragility of mountain ecosystem implemented Nepal, Peru, Uganda; Supported by BMZ Germany

Figure 4: Evolution of EbA concept (Raasakka, 2013)

5. EbA Definition and Conceptual Background

By definition "Ecosystem-based Adaptation is the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change" CBD (2009). Further, at the 10th Conference of the Parties (COP) in October 2010, the CBD stated that ecosystem-based approaches for adaptation (EbA): Recognizes that ecosystems can be managed to limit climate change impacts on biodiversity and to help people adapt to the adverse effects of climate change; implement where appropriate ecosystem based approaches for adaptation, that may include sustainable management, conservation and restoration of ecosystems as part of an overall adaptation strategy that takes into account the multiple social economic and cultural co-benefits for local communities. UNEP has elaborated EbA as harnessesing the natural climate resilience of ecosystems as part of an overall adaptation strategy to help people and communities minimize the negative impacts and benefit from the positive effects of climate variability and change.

In the central point to advocate EbA has been the CBD; its COP in 2007 noted that the Parties take measures to manage ecosystems so as to maintain their resilience extreme climate events and to help mitigate and adapt to climate change. Nevertheless, the concept of EbA has evolved into an important link between the three Rio Conventions: i. the United Nations Framework Convention on Climate Change (UNFCCC), ii. the Convention on Biological Diversity (CBD) and iii. the United Nations Convention to Combat Desertification (UNCCD). In progression, the International Union for Conservation of Nature (IUCN) presented a position paper on EbA in a UNFCCC meeting held in Bangkok in 2009. The advocacy and lobbying continued for EbA, and a pilot project of EbA in mountain ecosystem was implemented in three counties, namely Nepal, Peru and Uganda in 2012. In Nepal, the project was undertaken in Panchase protected forest by the Government of Nepal, the other implementing organisations were: UNEP, IUCN and UNDP. Earlier, the Government of Nepal produced National Adaptation Programmes of Action, which included ecosystem management for adaptation (Table 2).

CBD COP 7, 2004 Kuala Lumpur, Malaysia
The CBD, in decision VII/15 adopted in 2004, encourages the management of ecosystems for climate change adaptation and mitigation. The term ecosystem-based adaptation was coined later and an agreed definition for EbA is included in CBD X/33, based on the work of the Second *Ad-Hoc* Technical Expert Group on Biodiversity and Climate Change: "The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. It aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change. Ecosystem-based adaptation is most appropriately integrated into broader adaptation and development strategies."

In these days, a large number of actors have taken up EbA in their measures and approaches and their numbers are steadily growing as awareness for EbA is increasing. These range from donors, international, national and regional NGOs, to implementing agencies, research institutions and global networks. Among others, IUCN, Conservation International (CI., the Centre for International Forestry Research (CIFOR) and the Nature Conservancy (TNC) support various projects, research studies and mainstreaming of EbA. The other implementing partners are: UNEP, UNDP, WWF. The academia are involved in EbA knowledge generation. In Nepal, Tribhuvan University Central Department of Environmental Science and Central Department of Geography are involved in the EbA projects. The most important donors for EbA-related activities are the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Federal Ministry for Economic Cooperation and Development (BMZ) of Germany.

Table 2: Combined project profile of National Adaptation Programme of Action (NAPA), Government of Nepal, 2011 (NAPA, 2011)

SN	Combined Profile	Budget US$ Estimated
1	Promoting Community-based Adaptation through Integrated Management of Agriculture, Water, Forest and Biodiversity Sector	50 million
2	Building and Enhancing Adaptive Capacity of Vulnerable Communities Through Improved System and Access to Service Related to Agricultural Development	44 million
3	Community Based Disaster Management for Facilitating Climate Adaptation	60 million
4	GLOF Monitoring and Disaster Risk Reduction	55 million
5	Forest and Ecosystem Management for Supporting Climate Led Adaptation Innovations	25 million
6	Adapting to Climate Challenges in Public Health	15 million
7	Ecosystem Management for Climate Adaptation	31 million
8	Empowering Vulnerable Communities through Sustainable Management of Water Resource and Clean Energy Supply	40 million
9	Promoting Climate Smart Urban Settlement	30 million

Ecosystem-based adaptation has been interpreted as reducing the vulnerability to climate change of people through the sustainable use and conservation of ecosystems. In contrast to common natural resources and biodiversity management approaches, EbA purposefully assesses and selects measures in the context of an overall adaptation strategy. Although EbA measures use ecosystems to adapt to climate change, EbA still is an anthropogenic approach which particularly utilizes the ability of ecosystems to provide so called ecosystem services. They are also referred to as “Green Infrastructure” and can be seen as complementary to or substitutes of hard (“grey”) infrastructural measures. For example, ecosystems are able to generate direct services such as food and building material, as well as indirect services like water purification or pollination. An overview of ecosystem services has been described by The Economics of Ecosystems and Biodiversity, TEEB. <www.teebtest.org>.

Position Paper on EbA presented by IUCN
at UNFCCC Climate Change Talks, 28 Sep – 09 Oct 2009 Bangkok

- **EbA Definition**: The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change
- **EbA Approach**: The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way
- **EbA activities** should be part of a broader portfolio of adaptation measures.
- **EbA is a cost-effective** way to protect communities from climate change and extreme weather events.
- **EbA promotes** policy coherence

Apart from the intended outcomes, EbA measures tend to generate additional co-benefits such as carbon sequestration or biodiversity conservation, improved livelihood conditions and are generally considered no-regret options. To determine the specific requirements of maintaining or restoring an ecosystem and its services, EbA ideally draws on studies of climate change impacts or integrated climate analyses, which make use of climate scenarios and models. Worldwide surveys have shown that restoration and conservation of ecosystems are generally very cost effective and highly profitable for maintaining ecosystem services. In comparison to the economic loss caused by loss of ecosystem services, the cost-benefit ratio of return of investment of appropriate restoration of ecosystems may be as high as 3 to 75, depending on the ecosystem context and the measures taken (WOCATpedia, 2017).

For example, a study in Vietnam shows that planting or maintaining mangrove forests to act as breakwaters for coastal protection is significantly cheaper (costing 1.1 million USD for 12,000 hectares) than mechanical repair of wave-induced dike erosion (costing 3.7 million USD annually) (IFRC, 2002).

6. EbA Principles and Approaches

The UNFCCC has offered the following principles underlying ecosystem-based approaches to adaptation:

a. Understanding that maintenance of ecosystem services can be achieved by conserving ecosystem structure and function;

b. Recognizing that ecosystems are complex, have limits and are interconnected;

c. Understanding that ecosystems evolve and change over time and that, until recently, the major drivers of long-term ecosystem change was from climate shifts. As a result, ecosystems are naturally resilient and adaptable to some rates of change;

d. Ensuring participatory decision-making that is decentralized to the lowest accountable level, and is flexible and adaptive;
e. Managing ecosystems at the appropriate spatial and temporal scales;
f. Using information and knowledge from all sources, including traditional, local and contemporary scientific sources, and recognizing that such information needs to be gathered and validated.

Many countries have now undertaken EbA activities. From these countries, there are wide-ranging examples of ecosystem-based approaches for adaptation (Table 3). Some are summarized as follows:

a. Coastal defenses through the maintenance and/or restoration of mangroves and other coastal wetlands to reduce the impacts of coastal flooding and coastal erosion;
b. Sustainable management of upland wetlands, forests and flood plains for the maintenance of water flow and water quality;
c. Conservation and restoration of forests to stabilize land slopes and regulate water flows;
d. Establishment of diverse agroforestry systems to cope with increased risk from changes in climatic conditions;
e. Management of invasive alien species that are linked to land degradation and which threaten food security and water supplies;
f. Management of ecosystems so as to complement, protect and extend the longevity of investments in hard infrastructure;
g. Conservation of agrobiodiversity to provide important gene pools to facilitate crop and livestock adaptation to climate change;
h. Establishment and effective management of systems to ensure the continued delivery of ecosystem services to support resilience to climate change, for example through protected areas, diverse land use and agricultural systems.

Table 3: Examples of ecosystem-based approaches for adaptation and their potential benefits

Adaptation measure	Benefits	Co-benefits			
		Social and cultural	Economic	Biodiversity	Mitigation
Restoration of mangroves for protecting coastal settlements against storm surges in the United Republic of Tanzania	Protection against storm surges and coastal inundation	Provision of employment options Contribution to food security	Generation of income to local communities through marketing of mangrove products	Conservation of species that live or breed in mangroves	Conservation of carbon stocks, both above ground and below ground
Restoration of mangroves in Pakistan		Improved crab and shrimp catch Shoreline protection		Villages could be saved from wave surges	Provision of employment options
Making use of indigenous knowledge for forest management in Bolivia (Plurinational State)	Protection of forest Communities are empowered Indigenous knowledge recognized and protected	Potential sources of income for local people	Reduced emissions from deforestation and forest degradation		
Conservation of upstream forests to regulate water flow and control erosion for the benefit of vulnerable communities in the United Republic of Tanzania	Protection against erosion	Opportunities for recreational and cultural activities		Conservation of habitat for forest plants and animal species	Conservation of carbon stocks Reduction in emissions
Sustainable non-timber forest product management in the Lao People's Democratic Republic	Enhanced local livelihoods	Opportunities for recreational and cultural activities Protection of indigenous peoples and local communities		Conservation of habitat for forest plants and animal species	Conservation of carbon stocks Reduced emissions from deforestation and forest degradation
Protection of forests in Austria	Protecting settlement areas from avalanches	Raising awareness about forests and forestry	Strengthening the forest sector Increased livelihood generation and potential revenue from recreational activities	Protecting soil from erosion	Reduced emissions from deforestation and forest degradation

Adaptation measure	Benefits	Co-benefits			
		Social and cultural	Economic	Biodiversity	Mitigation
Sustainable forest management to safeguard livelihoods in the United Republic of Tanzania	Conserving land and biodiversity	Opportunities for recreational and cultural activities Protection of indigenous peoples and local communities		Conservation of habitat for forest plants and animal species	Conservation of carbon stocks Reduction in emissions from deforestation and forest degradation
Making use of traditional farming methods such as the Matengo pit system (the Ngoro system) in Mbinga District, southern United Republic of Tanzania	Conserving land and biodiversity	Enhanced food security Diversification of food products Conservation of traditional knowledge	Possibility of agricultural income in difficult environments	Conservation of genetic diversity of crop varieties and livestock breeds	
Restoration of the Shinyanga region of the United Republic of Tanzania through ngitilis (woodland enclosures)	Increase in production of fodder, fuelwood, and other products such as fish and non-timber products such as honey				
Slope stabilization through indigenous grass plantation in Nepal	Increased fodder and fuel availability Improved disaster risk reduction				

Adaptation measure	Benefits	Co-benefits			
		Social and cultural	Economic	Biodiversity	Mitigation
Restoration of wetlands in Thailand	Improved water availability and local biodiversity Enhanced grazing potential	Sustained provision of livelihoods, recreation and employment opportunities	Potential revenue from recreational activities	Conservation of wetland flora and fauna through maintenance of breeding grounds and stopover sites for migratory species	Reduced emissions from soil carbon mineralization
Using local traditional seeds in Rwanda and Kenya		Enhanced food security Diversification of food products	Possibility of new income in difficult environments	Conservation of genetic diversity of crop varieties and livestock breeds	
Maintaining water security in critical water catchments in Mongolia	Mean annual in-stream summer 30-day base flow maintained in two project sites Groundwater and surface water quality improved or maintained in two project sites Number of monitored wells increasing ground-water consumption efficiency in project sites		Water use efficiency improved to maintain ecosystem integrity as measured by the amount of surface water extracted for irrigation in project sites		

Adaptation measure	Benefits	Co-benefits			
		Social and cultural	Economic	Biodiversity	Mitigation
Protection of wetlands and ponds in the Czech Republic	Slow water run-off from the watershed Ensuring the protection and creation of habitats for aquatic and water-bound ecosystems Increasing self-cleaning water flow Interaction between groundwater and surface water Creation of space for recreation of local population	Good cooperation of local and national authorities Positive impacts on local population, fauna and flora	Increased livelihood generation and potential revenue from recreational activities	Positive impacts on local population, fauna and flora	Reduced emissions from soil carbon mineralization
Establishing climate ready estuaries in the United States of America	Sustained provision of livelihoods and recreation	Protecting people living in coastal areas	Reduction of long- term costs of climate impacts	Conservation of biodiversity along the estuaries	Reduced emissions from soil

Derived from examples presented and discussed during plenary, panel and breakout group meetings at the technical workshop on ecosystem-based approaches for adaptation to climate change and the framework taken from the Convention on Biological Diversity (*Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change.* Technical Series No. 41. Montreal: Convention on Biological Diversity).

7. Operationalizing EbA Framework

The overarching objective of EbA responses should be to arrive at the solutions that will help decrease vulnerability and increase the resilience of communities and ecosystems by effectively utilizing and managing natural resources such as forests, wetlands, and coastal ecosystems within a given area. The basic conceptual architecture of the framework is presented in Figure 5. It consists of:

i. The context of different components of the social-ecological system (SES), i.e. broader human (communities) and biophysical (ecosystem) conditions, including processes within the social and biophysical system;

ii. Existing and future key drivers of change such as development activities and climate change; and

iii. Current and future vulnerability depending on exposure, sensitivity and adaptive capacity of the social ecological system.

The EbA framework builds on other vulnerability assessment frameworks, which has basic four steps of:

Step 1: Vulnerability assessment of social-ecological systems

Step 2: Identification and prioritization of EbA responses

Step 3: Implementation of EbA responses

Step 4: Mainstreaming EbA in national and local climate change planning

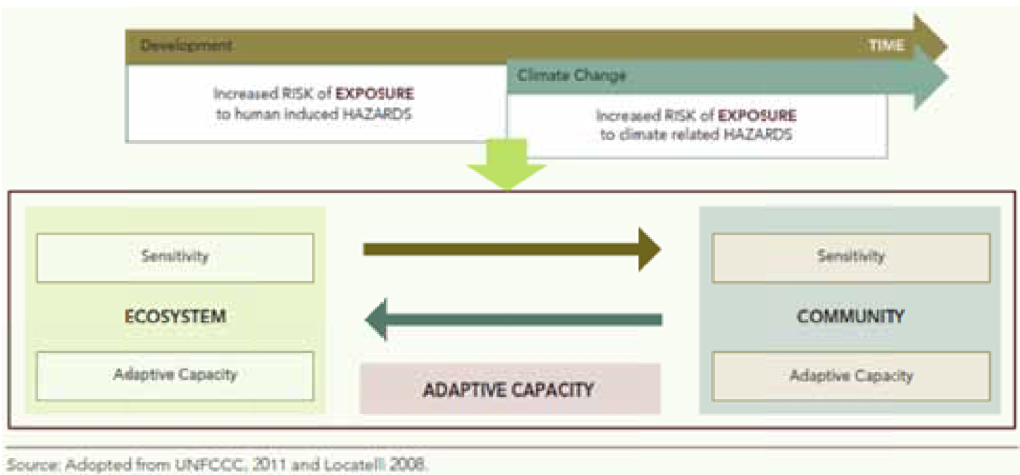

Figure 5: Conceptual architecture of the EbA framework

To develop an EbA plan, vulnerability impact assessment (VIA) is the first step. This assessment focuses on current vulnerability to both climate and non-climate related factors, sensitivity of the ecosystem and its adaptive capacity. It makes use of the model based impact assessment as well as the participatory methodology. The central of the tool is focus group discussion with the community dependent on the ecosystem. The experiences of the people in relation to climate variability or change over time, and observed impacts make basis of further analyses. Such information acquired from the community, however, is validated scientifically through data from the meteorological stations, field surveys and climate modeling. It then includes ranking of the individual component and evaluation of vulnerability to future climate related risks involving key stakeholders in the evaluation process. This eventually supports to the formulation of management plan and adaptation strategies.

The vulnerability, as defined by IPCC (2007) is the function of exposure, sensitivity and adaptive capacity. Each of the components contains elements/indicator, which is measured by using both field survey tools such as focus group discussion, and technical data. Exposure is the degree or magnitude of stress placed upon a species or a habitat due to changing climate conditions, or increased climate variability. Exposure includes two variables, temperature and precipitation, which are calculated by indicators, either direct or indirect or proxy. According to IPCC, sensitivity is defined as the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. It is measured at the level of forest, aquatic system, soil, grassland and human dimension. Adaptive capacity refers to the potential or capability of a system to adjust to climate change, including climatic variability and extremes, so as to moderate potential damages, to take advantages of opportunities, or to cope with consequences. Its indicators are grouped under three pillars of development: environment, social and economic.

Tribhuvan University Central Department of Environmental Science has developed a practical guideline on vulnerability impact assessment of climate change impact in mountain ecosystem (TU-CDES, 2015). Table 4, 5 and 6 presents a summary of the VIA components and data sources.

Table 4: Exposure

Exposure	Variables	Direct Indicator	Indirect Indicator	Proxy Indicator	Data Sources	
					Field Survey	Scientific Validation
Climate	1. Temperature	Meteorological database*	1. Hot days/Summer days 2. Cold days/ Winter days 3. Cold waves 4. Hot waves	1. Major cereal crops 2. Major vegetable crops 3. Fruit crops 4. Diseases (Human/Animal/Birds) 5. Insects (Human/Animal/Birds) 6. Water availability (Drinking/ Irrigation) 7. Phenology of plant species 8. Migration of birds 9. Climate induced hazards	Social tools	DHM Data; Worldclim
	2. Precipitation	Meteorological database	1. Pre-monsoon rainfall 2. Monsoon rainfall 3. Post monsoon Rainfall 4. Winter rainfall 5. Frost 6. Dew 7. Hailstone 8. Fogs 9. Thunderstorms 10. Snowfall		Social tools	DHM Data; Worldclim
Climatic Hazards	1. Forest fire 2. Drought 3. Landslide 4. Flash flood				Social tools	Disaster database; Disinventar data base

Table 5: Sensitivity

Sensitivity	Indicators	Source		Unit	Format
		Field Survey (Perception)	Scientific Validation		
Forest	1. Biomass 2. Crown cover 3. Species composition 4. Status (Categories) 5. Succession stage	Resource identification and mapping	Field measurement IUCN categories	Tons/hecatre Percentage Diversity index IVI	• Ecological Pyramid, • Open Modeller • Excel
Aquatic system	1. Runoff 2. Storage (surface and underground) 3. Water budget			Cusec/cumec Cubic metre	• SWAT • Excel
Soil	1. Moisture index 2. pH 3. Soil fauna 4. SOC		Field sampling and lab NDVI (Satellite image) DHM-GoN	Index value pH value No./unit area Diversity index Ton/hectare	• SWAT • Excel
Grassland	1. Biomass 2. Species composition 3. Status (Categories) 4. Succession stage		Field measurement IUCN categories		• Ecological Pyramid • Excel
Human Dimension	1. Agricultural production 2. Population density 3. Population flux	Crop calendar, FGD	CBS MoAD	Ton per unit area Number per unit area Number per unit area per time	• Excel

Table 6: Adaptive capacity

Adaptive Capacity	Indicators	Source	Unit	Format	Adaptive Capacity
		Field Survey (Perception)	Scientific Validation		
Environment	2. Succession stage 3. Resilient species 4. Drainage density	FGD	Field measurement	Diversity index IVI Index value	• Open Modeller • Excel
Development	1. Food availability 2. Drinking water 3. Water for irrigation 4. Communication 5. Energy consumption 6. Transportation 7. Household type 8. Local market	FGD	CBS GIS	Index value	• Excel • Raster
Social aspect	1. Education 2. Health and sanitation 3. GESI 4. Technical institution 5. Government services 6. I/NGOs 7. Indigenous technology and knowledge	FGD	CBS GIS	Index value	• Excel

8. EbA in Policy Framing

According to Vignola et al. (2009), EbA approach in supporting adaptation to climate change is a relatively new issue in the policy arena. It involves multiple stakeholders-national and regional governments, local communities, private companies and NGOs in addressing the pressures on ecosystem services and managing ecosystems to increase the resilience of people and economic sectors to climate change. For implementing EbA in policy, the adaptation policies and measures should take into account the role of ecosystem services in reducing the vulnerability of society to climate change, in a multi-sectoral and multi-scale approach. Its effective implementation inherently depends on co-ordination among three key stakeholders – policy makers, scientists and civil society (Table 7, Figure 5).

Table 7: Key players and role message in EbA (Vignola et al., 2009)

SN	National policy-makers	Communities, local actors and other members of civil society	Scientists
1	Mainstream adaptation and ecosystem services into national policies	Define and implement adaptation	Quantify and value ecosystem services
2	Develop innovative funding	Reward ecosystem service providers	Evaluate uncertainties
3	Influence international policies	Interact with policy makers	Work at local scales
4	Strengthen the links between adaptation and mitigation	Interact with scientists	Communicate results to non-scientists
5	Interact with local communities and scientists		Interact with local communities, private sector and policymakers

In 2008, an international workshop in “Adaptation to Climate Change: the role of Ecosystem Services” was held in Costa Rica. The 80 participants came gathered from 24 countries representing 56 institution to discuss the role of ecosystem services in adaptation to climate change.

9. EbA in Practice

In practice, the EbA measures use sustainable management, conservation and restoration of natural and agro-ecosystems – taking into account anticipated climate change impact trends – to reduce the vulnerability and improve the resilience of ecosystems and people to climate change impacts (UNDP, 2015). The main objectives of EbA are to promote community

Figure 6: Role of key stakeholders for framing EbA in policy

resilience through ensuring the maintenance of ecosystem services, support adaptation of different sectors, reduce disaster risks, among others (Coll et al., 2009), and prevent "mal-adaptation" which may be the result of a lack of information and high levels of uncertainty (Andrade et al., 2010). EbA is applicable to a range of ecosystems and geographical areas, in both developed and developing countries.

EbA in Nepal

Panchase is the pilot project site of 'Ecosystem-based Adaptation (EbA) in Mountain Ecosystems Programme' in Nepal. The Panchase area is situated in the center of the Gandaki River Basin and supports three major watersheds, i.e Modi Khola Watershed, Upper Seti Watershed, and Lower Mid-Kali Gandaki Watershed. Panchase covers an area of 279 km^2 and has a population of 62,000 (UNDP, 2015). The elevation of Panchase area varies from 500 to 2517 metres above the mean sea level (GoN/UNDP, 2016). Panchase has a climate varying from subtropical to cold temperate (UNDP, 2015). A total of 589 species of flora have been recorded in Panchase area, with 113 species of orchids including 2 endemic species. Likewise, 15 mammal species and 14 avian species have also been recorded in Panchase (GoN/UNDP, 2016). Panchase ecosystem is broadly classified into forest, agriculture, grassland, river, lake/ pond, and wetland ecosystems, with the forest ecosystem dominantly covering 61% followed by agriculture at 34% and grassland at merely 3% (GoN/UNDP, 2016).

The programme was implemented in the Panchase region in the districts of Kaski, Parbat and Syangja through 17 Village Development Committees (VDCs) of which 9 VDCs are within the Panchase Protected Forest (UNDP, 2015). The Panchase Protection Forest covering 5775.73 ha is classified as 'Core' and 'Fringe' while the forest area near vicinity of the settlements was designated as 'intensive use zone or impact area'. 79% of PPF area is managed by community as community forests (144) while the remaining 21% forest area is managed as the government forest (GoN/UNDP, 2016). The economy of Panchase is largely subsistence agriculture based on crops and livestock (UNDP, 2015).

According to Dixit et al. (2015) as cited by UNDP (2015), an increase in annual average temperature of 2°C to 5°C is projected for the Panchase area by 2100. Meteorological records for the Panchase area from 1977 to 2009 show some increase in annual rainfall, although with significant inter-annual variability, while Parbat and Syangja districts showed some reductions in winter rainfall and increases in summer rainfall. By the 2030s, rainfall is expected to be intense and its seasonality more pronounced, while the frequency of floods and landslides is likely to increase.

Several EbA interventions were made in different sites of Panchase area to build the resiliency of ecosystems and reduce the vulnerability of local communities (Table 8).

Table 8: EbA measure adopted in Panchase, Nepal (Compiled from GoN/UNDP, 2016)

THEME 1: Ecosystem Restoration	**THEME 2: Water Conservation**	**THEME 3: Land Rehabilitation**	**THEME 4: Livelihood Diversification**
More than 54,500 multiple-use trees and Non Timber Forest Products (NTFPs) planted in degraded and fallow lands in 65 Ha benefitting 2496 households	More than 31 traditional water sources conserved Construction of collection tanks for collection and distribution during dry seasons	Bio-engineering treatments (development of green belt and drain construction) for gully erosion control, stream bank protection, river bank conservation	Promotion of identified high value NTFPs: more than 1500 species of Amriso, 100 species of Timur and other fodder species planted in a 5 Ha degraded shrub land
Six nurseries with capacity to produce 60,000 seedlings of in-demand fodder trees established	More than 1542 households benefitted from water source conservation	72 vulnerable sites rehabilitated protecting 120 Ha	Ecotourism development: Home stays registered by local communities to support tourist flow
More than 26,000 seedlings of multiple-use trees distributed to support agro-forestry practice in fallow lands	Thirty-five conservation ponds renovated benefiting more than 1800 households and irrigating more than 150 Ha agriculture lands during dry seasons	Plantations to supplement and strengthen the engineered structures along the river banks	Farming and livestock Husbandry: 365 livestock farmers trained on livestock rearing practices and rangeland management to mitigate open grazing practices.
			
Photo 1: Nursery producing NTFP and fodder species seedling in Pumdi Bhumdi	Photo 2: Renovated water source/natural spring in Arukharka	Photo 3: Bio-engineering interventions in Saunepani, Ramja	Photo 4: Home stay operators greet guests in Chitre

10. Scope and Challenges

Ecosystem-based adaptation offers the potential for ecosystem services protection and resilience enhancement in a climate change world but face main challenges related to governance and long term sustainability (Ojea, 2015). There are three key challenges in implementation of EbA approaches and measures are:

a. Lack of information

b. Lack of financial resources

c. Institutional resistance (UNEP, 2012).

According to Ojea (2015), Raasakka (2013), and UNEP (2012), lack of information includes climate change and ecosystem science inherent uncertainties in future projections of climate impacts, ecological and societal vulnerability and economic growth. These forecast uncertainties are exacerbated by the relative paucity of information from monitoring and evaluation of the effectiveness of past and ongoing EbA interventions. The financial challenge includes lack of financial resources for project implementation as well as for capacity building. The institutional challenge arises because EbA requires cooperation across institutions, ministries, communities and the private sector. Often the benefits of EbA are spread across numerous sectors and most visible over the long-term while institutional decision-making tends to be focused sectorally and on shorter timescales.

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DEFINITION/DESCRIPTION

Name	Definition/Description	Source
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate	IPCC
Climate Change Adaptation (CCA)	The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate harm or exploit beneficial opportunities. In natural systems, human intervention may facilitate adjustment to expected climate and its effects	IPCC AR5
Community based Adaptation (CbA)	A community-led process, based on communities' priorities, needs, knowledge and capacities, which should empower people to plan for and cope with the impacts of climate change	IIED
Ecosystem based Adaptation (EbA)	EbA Incorporates biodiversity and ecosystem services into an overall adaptation strategy to help people to adapt to the adverse effects of climate change	CBD
	Uses biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities adapt to the negative effects of climate change at local, national, regional and global levels	UNEP
	Any initiative that reduces human vulnerabilities and enhances adaptive capacity in the context of existing or projected climate variability and changes through sustainable management, conservation and restoration of ecosystems	IUCN
Ecosystem Approach	Strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way	CBD
Ecosystem based Disaster Risk Reduction (Eco-DRR)	Sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim to achieve sustainable and resilient development	Estrella and Saalismaa 2013
	Decision-making activities that take into consideration current and future human livelihood needs and bio-physical requirements of ecosystems, and recognize the role of ecosystems in supporting communities to prepare for, cope with and recover from disaster situations. Sustainable ecosystem management for disaster risk reduction is based on equitable stakeholder involvement in land management decisions, land-use-trade-offs and long-term goal setting.	IUCN
Ecosystem Services	The benefits people obtain from ecosystems, which have been classified by the Millennium Ecosystem Assessment as: Supporting services, such as seed dispersal and soil formation; regulating services, such as carbon sequestration, climate regulation, water regulation and filtration, and pest control; provisioning services, such as supply of food, fibre, timber and water; and cultural services, such as recreational experiences, education and spiritual enrichment	MA 2005
	The ecosystem services are but human interpretation of natural products and processes	Bhuju et al., 2017

Chapter 6

Payment for Ecosystem Services: A Possible Instrument to Sustainable Ecosystem Management In Nepal

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1. Introduction

Ecosystems provide a wide range of critical goods and services for human wellbeing. However, climate change and other anthropogenic activities put ecosystem productivity at risk and negatively impact ecosystem's ability to supply consistent quality and quantity of ecosystem services. Millennium Ecosystem Assessment (MEA, 2005) indicates that considerable degradation of ecosystem services has already occurred, impacting on ecosystem dependent communities (ICIMOD, 2010). Ecosystem services such as clean drinking water were considered as free nature gift or free services. A common example, is how wetlands, one of the most productive ecosystems, were seen as wastelands and were often degraded (Barbier et al., 1997). Ramsar Convention on Wetlands of International Importance 1971 and studies on ecosystem services have, over the years, slowly transformed this perspective by demonstrating the value of ecosystem services generated by the wetlands. Wetlands store carbon, purify water, replenish groundwater apart from direct or consumable benefits such as timber (Mitsch and Gosselink, 2000). These indirect benefits are most valuable and are also often public goods, creating a challenge for maintaining these valuable ecosystem services in contrast to marketable good and services. Land use managers may have to decide between converting wetlands into a lucrative built up area and managing the wetlands for their ecosystem services. However, policy makers and land use managers may not consider the external factors impacting on supply of these services. As a result, anticipated conservation and development outcomes are not achieved. National and international policy targeted towards conserving high functioning and high value ecosystem, such as through the Ramsar sites and national parks, may not be adequate to sustain critical services at the local, regional and global scale (National Research Council, 2005). Number of scholars highlighted and emphasized the need of multifunctional ecosystem management, and possible interface of ecosystems (Wunder et al., 2005; Cubbage et al., 2007).

Ecosystem services illustrate societal dependence on ecological life support systems (Daily, 1997; de Groot et al., 2002) and concept of ecosystem services was used to increase public interest in biodiversity conservation (Westman, 1977; Ehrlich and Ehrlich, 1981; de Groot, 1987). Over the years, the mainstreaming of ecosystem services in the literature (Costanza and Daly, 1992; Perrings et al., 1992; Daily, 1997) has occurred rapidly, and different methods to estimate their economic value (Costanza et al., 1997) have been practiced. The Millennium Ecosystem Assessment (MA, 2003) contributed much to putting ecosystem services firmly on the policy agenda (Fisher et al., 2009). Ecosystem services are being used as one of the tools for economic decision-making through the widespread promotion of Market Based Instruments for conservation such as Markets for Ecosystem Services (Bayon, 2004) and Payments for Ecosystem Services schemes (Landell-Mills and Porras, 2002; Wunder, 2005; Pagiola and Platais, 2007; Engel et al., 2008; Pagiola, 2008). Mainstreaming of ecosystem services, however, has resulted in the application of the concept in directions that diverge significantly from the original purpose with which the concept was introduced. For example, Peterson et al. (2010) noticed a move from the original emphasis on ecosystem services as a pedagogical concept designed to raise public interest for biodiversity conservation, towards increased emphasis on how to cash ecosystem services as commodities on potential markets. Redford and Adams (2009) noted that such payment schemes are being adopted with great speed, and often without much critical discussion across the spectrum of conservation policy debate, developing a life of its own, independent of its promulgators. These observations add to a growing body of literature that has raised questions on how utilitarian framing of ecological concerns and market strategies can modify the way humans perceive and relate to nature in a way that may be counterproductive for conservation purposes in the long run (Rees, 1998; Martínez-Alier, 2002; Robertson, 2004; McCauley, 2006; Soma, 2006; Spash, 2008a; Kosoy and Corbera, 2010).

Despite these challenges, Payment for Ecosystem Services (PES) has emerged globally as an approach or instrument to sustainable ecosystem management, supporting rural livelihoods, and thus contributing to the global agenda of poverty reduction (Hubermann, 2009; Bhatta et al., 2014). PES, as described by Wunder (2005), is a voluntarily mechanism based on free market concept. A global example of this market based instrument is the Reduced Emission through avoided deforestation and forest degradation (REDD+) where international markets are providing monetary payments to community level forest management. However, in developing countries, a fully market based instrument may be difficult to practice, even with substantial investments in establishing institutions and governance mechanism (Fletcher et al., 2016).As a result, a context specific approach needs to be discussed and implemented. A successful case study of incentive based mechanism is New York City's drinking water supply, which has saved billions of dollars by incentivizing improved watershed management (Catskills watershed) in the upstream for clean drinking water to millions of residents downstream in the city of New York (Appleton 2016).The concept of incentive for ecosystem services or incentive based mechanism has been discussed in developing countries to ensure service providers are well supported through various development project or in kind contribution (Rai et al., 2016; Bhatta et al., 2017).

This chapter will briefly describe what the ecosystem services are and why they are important. It will discuss the current mechanism for PES, challenges and recommendations for enhanced implementation in a developing country like Nepal.

2. Ecosystem Services and their Importance

Nature and its ecosystems deliver a number of services beyond tangible goods. Ecosystem services, often underappreciated and undersupplied, are of increasing importance for society: climate regulation, water purification and regulation, protection against natural and man-made hazards, biodiversity, and more. The 2005 Millennium Ecosystem Assessment initiated by the United Nations found that while provisioning of food and fibers has steadily gone up over the last hundred years, the flow of almost all other ecosystem services has gone down. Across the range of biodiversity measures, current rates of change and loss exceed those of historical past by several orders of magnitude and show no indication of slowing. Human demand and persistent economic neglect have resulted in the alarming deterioration of the state and supply of many ecosystem services. A prime example is nature's regulation of the climate, which is now imperiled by man-made greenhouse gas emissions. Thus far, government regulations, public budgets, private charity, and community activism-important as they all are-have not been enough to stem this negative trend.

The change in land use and land management practices may result in both positive and negative impacts. For example, if upstream communities clear forests, there may be a considerable increase in soil erosion, which may have many consequences downstream, affecting irrigation infrastructure, flood risk, siltation, river navigability and fish reproduction and productivity. On the other hand, if upstream communities maintain vegetation, this may positively influence downstream water availability during the dry season (Ojha et al., 2009).

Unfortunately human activity is straining ecosystems to the point where some of these support services are beginning to falter. Watersheds scoured of vegetation by deforestation are losing their ability to filter water, wetlands destroyed for housing are no longer able to control floodwaters when heavy rains hit, and the loss of natural habitat is causing the decline of wild pollinators essential for agriculture. Perhaps most perilous of all, the global temperature is fluctuating (fueling extreme weather events) as forests and oceans lose their ability to absorb heat-trapping gases. There is a growing global awareness of the services that natural ecosystems provide. The value of these ecosystem services and the long term costs of their loss, however, are rarely taken into account in decisions about how natural resources are used. Because day-to-day management decisions often focus on short-term financial returns, the ecosystems that provide these services are often degraded, sometimes in ways that irreparably reduce ecosystem service provision (Herbert et al., 2010). The degradation of these ecosystems and the services that they provide creates greater hardship for the rural poor – at times being the principal factor causing rural poverty and social conflict. Therefore, improving the condition and management of ecosystem services is an essential component to reducing poverty (MEA, 2005).

From a functional point of view, the Millennium Ecosystem Assessment (2005) classifies ecosystem services into four broad categories: provisioning, such as the production of food and water; regulating, such as the control of climate and disease; supporting, such as nutrient cycles and crop pollination; and cultural, such as spiritual and recreational benefits. Ecosystem services can also be classified according to their geographical scale (local, regional, global), value to society (direct or indirect), or the type of natural ecosystem providing the service (forest, coral reef, wetlands, etc.) (WRI 2009). Various frameworks and perspectives for ecosystem services classification exists in the literature (Costanza et al. 1997; de Groot et al. 2002; Wallace 2007; Fisher et al. 2009). Costanza et al. (1997) discusses 17 ecosystem services from 16 different biomes. Here, we will only discuss a few ecosystem services that demonstrate the breath of ecosystem services that we benefit in our daily lives.

Climate Regulation: Ecosystem terrestrial and aquatic systems regulate climate through biogeochemical processes maintaining of atmospheric gases, including greenhouse gases. Physical process such as albedo and reflectance also regulate the energy, and ultimately temperature. Living organisms in forest, oceans or other ecosystems, absorb carbon lowering carbon dioxide concentration in the atmosphere. Climate regulation is critical as anthropogenic drivers is rapidly changing the climate, threatening communities living in the coastal areas, communities dependent on rainfed agriculture and many others. Forests in particular have a key role in "carbon storage." In total, the planet's tropical forests absorb approximately 1.8 billion metric tons of carbon per year, storing ¼ of the world's greenhouse gas emissions in their woods and soil. When tropical forests are cleared, however, the carbon that was stored in the trees is released into the atmosphere, adding to global emissions of greenhouse gases and contributing to climate change. Depending on how they are managed, therefore, forests can become either carbon sinks or carbon sources when they are cleared. It is noteworthy that forests are not the only carbon sinks. Carbon is also absorbed into the soil and oceans. Certain agricultural practices, such as using no-till agriculture and grazing land management lead to increased carbon dioxide storage in the soils.

Nutrient Cycling: Ecosystems also have an important function in the protection of soils and nutrient cycling. Soil nutrients relate directly to agricultural productivity. Appropriate levels of soil nutrients, with water, sun and other conditions, usually leads to greater crop production (Campos, 2009). Nutrient cycling increases the quality of the soil and is regarded as a service provided to the environment. The degradation of soils can, therefore, have a huge impact on the availability of food across the country.

Maintenance of Water Quality and Supply: Well-functioning ecosystems are commonly able to filter out pollutants such as metals, oils, excess nutrients, and sediment as water moves through wetland areas, forests, and riparian zones. This purification process provides clean drinking water and water suitable for industrial uses, recreation, and wildlife habitat. Water filtration provides humans and animals with health benefits such as clean drinking water. The provision of water filtration by well-functioning ecosystems also provides economic benefits as it is often easier and cheaper to maintain a natural ecosystem rather than build a filtration plant. Human activities that compact the soil or contaminate water – such as paving roads or removing forest cover beside rivers – can have a significant impact on the delivery of this service. Wetland ecosystems play an indispensable role in maintaining the water supply, filtering water, providing flood control, groundwater recharge and microclimate regulation.

Food, Fiber and Fuelwood Provision: Ecosystems provide humans with the means for growing (crops) and gathering (fish, game) the foods which provide the basis for our diets. Ecosystems also provide us with firewood and charcoal as well as other sources of fuel. In Nepal, traditional biomass fuels contribute directly to the energy supply. Almost all people in rural areas rely primarily on fuelwood for meeting their domestic cooking and heating energy needs. The challenge is that use of firewood is also source of deforestation and forest degradation and other ecosystem pressures, hence is the importance of continuing to explore alternative sources of fuel.

Pollination: Pollination is a very important process for agriculture as well as maintaining a diverse array of plants across the landscape. The process of pollination involves the pollen from a plant being moved from a stamen (the male part of a plant) to the stigma (the female part of the plant) in order to produce seeds. This process can be carried out by humans or natural causes such as the wind. Most often, however, bird and bee species play this role when they are searching for food like the pollen or sweet nectar in the flower. Bees play such an important role in the pollination of coffee plants that without bees, a farmer will likely produce less than 1% of his or her potential coffee yield. A diversity of birds is also important for agricultural production. Birds eat many different pest species which can negatively affect crops, while also being one of the most effective mosquito repellents.

Cultural Services: The importance of ecosystems goes far beyond its beauty and the products that it offers. Many people have a very strong cultural link with the ecosystem where they live. Many times they have developed myths, beliefs, and rituals that are associated with the environment, in addition to the traditional knowledge related to natural resources, such as the use of medicinal plants over thousands of years. The rhythm of life itself often reflects the natural environment, rainy and dry seasons and phases of the moon. The destruction of these ecosystems can affect the cultural richness of these local populations (Campos, 2009). Natural areas are often a draw for tourism or other recreation uses. When trees are cut down, watersheds are degraded or the landscape is modified, the opportunity for appreciating the scenic beauty of the environment is lost. This damage is not only detrimental to the biological organisms affected, but also to tourism and other economic benefits for the local populations and government in these regions.

Ecosystem Services and Human Well-being

According to Millennium Ecosystem Assessment, the strength of linkages between categories of ecosystem services and components of human well-being that are commonly encountered, and includes indications of the extent to which it is possible for socioeconomic factors to mediate the linkage. For example, if it is possible to purchase a substitute for a degraded ecosystem service, then there is a high potential for mediation. The strength of the linkages and the potential for mediation differ in different ecosystems and regions. In addition to the influence of ecosystem services on human well-being, other factors-including other environmental factors as well as economic, social, technological, and cultural factors-influence human well-being, and ecosystems are in turn affected by changes in human well-being.

3. Payment for Ecosystem Services (PES)

The definition of payment for ecosystem services (PES) varies widely, from narrow market-based definitions with direct transactions between providers and beneficiaries (including schemes where private buyers and sellers arrange voluntary and conditional transactions for the delivery of ecosystem services), to broader schemes in which those who benefit from the ecosystem services pay (usually indirectly) those who provide the services. In other words, changes in the livelihood practices of the uphill farmers, either reducing dependency on natural resources or improving management practices of upstream ecosystem, would make downstream residents better off. Many scholars (Merlo and Briales, 2000; Cubbage et al., 2007) have described the progress of environmental policies in order to achieve multifunctional objectives of ecosystem management. Payment for ecosystem services (PES) is one of those mechanisms that are increasingly and typically used to sustain ecosystem services. Many scholars have considered PES as an incentive for local communities to secure their efforts in conserving natural capital through redistribution of livelihood resources and transfer of financial support (Gutman, 2007; Kumar and Managi, 2009).

For a mechanism of payment for ecosystem services to occur, at least four conditions need to be met (Wunder, 2005):

i. Defined ecosystem service ("product"): there needs to be a very well defined ecosystem service where the maintenance and/or supply can be of interest for someone. This will be the "product" which will be marketed.

ii. Buyer: someone (one or more people, communities, companies, governments, etc.) able and willing to pay for this product. In this case, it is the conservation of the specific ecosystem service.

iii. Seller/Provider: someone (one or more people, communities, companies, governments, etc.) receiving a financial resource, who, in exchange, must promise to maintain that ecosystem service.

iv. Voluntary: the transaction of paying and receiving for an ecosystem service should be primarily voluntary. That is those involved in the transaction should participate because they want to and not because they are obligated to do so.

For more clarity, let's see some example of how this scheme can occur in practice through an example. Imagine a city that is located near a mountain. The inhabitants of the city depend on the water from the rivers that flows down the mountain for their basic necessities like drinking, bathing, washing clothes, and other activities. On the high part of the mountain live some producers who own forests and productive systems with trees (agroforestry systems such as shade-grown carbon). Keeping in mind that the maintenance and regulation of water quality is one of the ecosystem services, if the producers in the high regions cut the trees present upstream, this would affect the provision of high quality water for the inhabitants of the city. In this context, the people in the city may be willing to pay so that the producers who live in the high regions in the mountains can maintain, or even reforest, the region in order to maintain high water quality. In this case, the buyers are those who live in the city who are paying for the ecosystem service of the maintenance of water quantity and quality which is provided by the forests and agroforestry systems. The providers are those rural producers in the mountainous region who conserve and manage the forests to allow for delivery of the ecosystem service.

PES is a method of internalizing the positive externalities associated with a given ecosystem. PES operates according to the logic of the 'free market,' which says that if ecosystem services are given economic values and assigned property rights, the rational behaviour of buyers and sellers in the market environment will produce efficient ecosystem outcomes (Wunder, 2005; Engel et al., 2008). The provider, often a resource manager, of a service is paid to maintain or enhance that service. PES involves transfer of financial resources from beneficiaries of certain environmental services to those who provide these services or are fiduciaries of environmental resources (Mayrand and Paquin, 2004). The concept revolves around financial support schemes that aim to conserve ecosystem services, by providing an economic incentive to those who contribute to conservation of specific resources, which is done mainly by managing ecosystem services to adopt land use practices and by encouraging the protection and conservation of ecosystems (Khanal and Poudel, 2012). Guided by a different definition, the study defines PES in context of Nepal as "a mechanism of providing an economic incentive from benefit recipients to those who provide services to ensure sustained supply of services". PES is an innovative market-based mechanism, which stands on twin principles: those who benefit from environmental services should pay to those who provide environmental services (World Bank, 2007).

Use of PES schemes has gained popularity with focus on watersheds, biodiversity, carbon sequestration and aesthetic and landscape beauty. There are more than 300 programmes worldwide with the broad estimated global value of USD 8.2 billion (Blackman and Woodward, 2010). PES are estimated to channel over USD 6.53 billion annually by national programmes in China, Costa Rica, Mexico, the United Kingdom and the United States alone (OECD, 2010). The payment schemes are increasing at 10-20% per year (Karousakis, 2010).

Box 1: Dhankuta drinking water supply

In Dhankuta town, East Nepal, demand of drinking water is increased substantially while the supply from existing source is limited. In order to meet the demand, a new water supply project is completed with support from Asian Development Bank, taking water from Tankhuwa and Nibuwa Khola. A tripartite agreement among Dhankuta municipality, Dhankuta town water user management committee, and upstream communities of Tankhuwa and Nibuwa watersheds has been endorsed. The agreement provisions that each household using the drinking water pay additional NPR 15 per month to upstream communities for watershed management. This generates about NPR 564,000 annually. Additionally, government line agencies will provide support to water source communities in terms of development projects such as income and enterprise based training and support, soil retention and erosion control.

Box 2: Incentivizing communities for carbon sequestration under REDD+ schemes

REDD+ is a global scheme under the UNFCCC to provide benefits to developing countries for reducing deforestation and degradation of forests. Under this scheme, Ministry of Forests and Soil Conservation in collaboration with ICIMOD piloted a project in 3 watersheds (Gorkha, Dolakha and Chitwan districts) in Nepal. From 2011-2013, carbon increment was estimated in all three watershed with additional carbon stock of 63,192 ton. Based on forest carbon trust funds, an amount of USD 285,000 was paid to local forest users of these watershed.

Box 3: Buffer zone development programme: PES like instrument ensured by the National Park Act

The Buffer Zone Management Regulation 1996 under the National Park and Wildlife Conservation Act of Nepal, 1973, encourages local participation in biodiversity conservation. The Act and regulation mandated to provide 30-50% of total revenue generated by a protected area to plough back to buffer zone. Some scholars (Bhatta and Kotru, 2012) argue that buffer zone incentive is merely a development approach rather than PES. However, incentivizing local communities for their efforts in conservation definitely support ecosystem management while ensuring flow of ecosystem services.

Box 4: Dhulikhel drinking water supply: An ideal case on community based PES

Drinking water of inhabitants of Dhulikhel municipality, Nepal is managed by local water user committee. A 14-km long pipeline to upstream water source in Kharkhola, Lalitpur district supplies water to local residents. In 2010, the water user management committee signed a formal agreement with upstream communities, in which they agree to pay NPR one million per year to upstream communities in cash. Besides this, Kathmandu University, the largest consumer of water, provides scholarship to needy student from the upstream. Additionally, a subsidized health facility is available for upstream communities at the local Dhulikhel hospital. In return, upstream communities maintain and protect water source, control grazing and open defecation near the water source.

3.1 Payment Mechanism for Ecosystem Services

In all of the schemes, the rationale is to provide incentives and benefits to people to utilize ecosystem services for the benefit of the wider population (Karky and Joshi, 2009). Hence, those who provide ecosystem services should be directly compensated by those who receive the services. Table 1 below highlights ecosystem services and payment mechanisms which are being practiced internationally.

Table 1: Major ecosystem services and payment mechanism practices (Modified from Mayrand and Paquin, 2004)

Major ecosystem services	Scheme type	Focus	Market	Payment mechanism
Watershed protection (Irrigation, drinking water, hydropower, flood and sedimentation control)	Area based, water-shed level	Financing land use that generates watershed services	Mostly local cooperative relationship between sellers and buyers	Use fee Additional charge
Carbon sequestration	Area bases, Forests	Financing based on carbon credits, sequestration, Reductions and carbon off-sets	Mostly global market, and International buyers Highly competitive and developed	International market price
Biodiversity Conservation	Area based, Product based	Land uses that protect species, ecosystems or genetic diversity	Local, national and international scale Pharmaceutical companies, conservation agencies Markets are nascent and Experimental	Conservation grants and concessions Conservation finance Incentives Premium pricing License fee
Recreational use and contribution to scenic beauty	Area based, Product based	Promoting tourism on protected areas or natural or cultural heritage	Local, national and international scale Immature and less willingness to pay	Use fee Entrance fee Service taxes

3.2 Payment for Ecosystem Services in Nepal

Policy, Legislative and Institutional Arrangements

Laws and policies are important drivers influencing the success of PES schemes. There is no specific policy or legislation in Nepal, which support or facilitate the institutionalization of PES. Nevertheless, recent policy reforms specifically national development periodic plan identified PES as one of the potential market based instruments for generating conservation finance. The Three Year Plan (2010/11-2012/13) and the Thirteenth Plan Approach Paper (2012/13-2013/14) have accorded high priority for generating sustainable conservation finance through the selling of ecosystem services such as tourism, carbon and water resources. Apart from this, Ministry of Forests and Soil Conservation (MoFSC) formulated the guidelines to compel hydropower companies operating inside protected areas to deposit 10 percent of their royalty fees towards environment conservation and community development. Likewise, MoFSC also established a Forest Sector Development Fund from the commercial sale of forest products from national and private forests. Regardless of the debate on whether these mechanisms can truly be considered PES or not, most of these mechanisms were not fully operational. Contradictions and confusions with the existing legislation and less interest from the government on timely amendment or formulation of new policies are the main reasons for poor implementation of these innovative financing practices. There are few environmental related legislation such as the Forest Act (1993), Water Resources Act (1992), National Parks and Wildlife Conservation Act (1973), Environment Protection Act (1996) and Soil and Watershed Conservation Act (1982). All these acts are regulatory instruments directing the implementation of specific activities and delegate power to stop activities that have adverse effects on the environment. These acts follow the polluter pays principle rather than PES approach.

Despite this, the Forest Act and the National Park and Wildlife Conservation Act provide ample opportunities for the institutionalization of PES. The Forest Act recognized Forest Users Group as autonomous institutions and delegated management responsibility including sustainable use.

Likewise, tourism entry fees, hunting/gaming license fee are being charged from National Parks and Wildlife Conservation Act. These act support for institutionalizing PES in Nepal, and specific laws may not be needed until and unless the communities have use rights. This has been quite evident from local level piloting in Nepal such as Kulekhani hydropower. However, institutional mechanism are yet to be developed and established. Establishment of REDD cell within the MpFSC can be seen as one step ahead. Supportive policy and institutional environment is crucial for the success of PES. Hence, PES policy and operational guideline with appropriate institutional mechanism should be developed and strengthened.

Table 2: Major Legal and Policy instruments supporting PES in Nepal (Adopted from Bhatta, et.al, 2014)

Year	Policy/Strategy	Related provisions
1973	National Parks and Wildlife Conservation Act, 2029	It provides power to declare Buffer Zone (BZ) around the national parks and wildlife reserves. The Act allows funneling back 30-50% of park and reserve revenue for the community development activities in the BZ.
1982	National Trust for Nature Conservation Act, 2039	It is an autonomous body set up to conserve, promote and manage wildlife and other natural heritages. The Annapurna Conservation Area management (ACAP) regulation provides authority to NTNC that 100% revenue generated by the ACAP will be shared to conservation area committees for conservation and development.
1982	Soil and Watershed Conservation Act, 2039	It provides legislative measures concerning soil and watershed conservation
1993	Electricity Act, 2049	It has stated that during the construction and operation of hydropower station, environment and watershed areas should be protected. This Act provisions that 10% of the total revenue generated by hydropower needs to plough back to concerned district development.
1993	Forest Act, 2049	The Forest Act, 1993 accounts for all forest values, including environmental services and biodiversity, as well as production of timber and other products. The Act empowers local people for their participation in decision making and sharing of benefits in terms of forest resources.
1993	Water Resources Act, 2049	It provides provision to form a water users association (autonomous and corporate body) from persons willing to make use of water resources for collective benefits on an institutional basis.
1996	Buffer Zone Management Regulation, 2052	It facilitates public participation in the conservation, design and management of buffer zones and provides guidelines to manage 30 to 50 per cent of park generated revenue with the communities in the buffer zone.
1996	Environment Protection Act, 2052	It provisions a fund named environment protection fund for the protection of environment, prevention and control of pollution and protection of the national heritage.

Year	Policy/Strategy	Related provisions
1999	Local Self Governance Act, 2055	It provides immense autonomy to the District Development Committees (DDCs), municipalities and Village Development Committees (VDCs). Section 55 empowers VDC to levy taxes on utilization of natural resources. Similarly, Section 189 sanctions the DDC for formulation of and implementation of plans for conservation and utilization of forest, vegetation, biological diversity and soil.
2000	Revised Forestry Sector Policy	It introduced a new concept in managing the forests of the Tarai, Churia and Inner Tarai named collaborative forest management (CFM). Fifty percent of the income from CFM will be provided to local communities and local governments.
2002	Water Resource Strategy Nepal (2007-2027)	It envisions protection of watershed and aquatic ecosystem and emphasizes on implementation of watershed protection to improve downstream surface and ground water quality.
2007	Interim Constitution of Nepal	Article 35 (4) and (5) committed to the protection of forests and environment. It states that except for the revenues of religious endowments (Guthi., all revenues received by the Government of Nepal under the authority of any Act and any other moneys received by the Government of Nepal shall be credited to a Government Fund to be known as the Consolidated Fund.
2007	National Water Plan (2007-2027)	This supports Churia conservation programme for ecological services down to Tarai irrigation.
2008	Forest Development Fund (Establishment and Conduction) Guideline, 2064	It provides operative guidelines to manage funds received through sale of timber. NPR five rupees from the sale of per cubic feet timber from entrepreneurs and equal amount from concerned institutions be deposited in forest development fund (FDF) which will be invested to conservation activities at the district level. 25% of the district forest development fund will be utilized by the central government.
2008	Kanchenjungha Conservation Area Management Regulation, 2064	75% of the income of sale and transportation of Non timber forest products will be received by the concerned user committee and remaining 25% will be collected by Kanchenjungha Conservation Area.
2009	Tourism Policy	It states that certain proportion of income from village tourism will be utilized in tourism infrastructure development and environmental conservation.
2009	Working Policy on Construction and Operation of Development Projects in Protected Areas	It highlights that ten percent of the government royalty earned from electricity generated thereof shall be deposited by the hydropower owner to the concerned protected area for environmental conservation and community development.
2010	Three Years Interim Plan's Approach Paper (2010-2012)	It provisions that thirty-five percent of the income of community based resource management models will be returned back to local communities for their livelihood. It states that a trust fund will be created from private contribution to be used for the development of forest based enterprises.

3.3 PES Practices

Some form of payment mechanism for use of ecosystem services, especially on drinking water, irrigation and tourism already exists in Nepal. Local communities are making payments in the form of cash or kind for the salaries of watchers/operators, repair and maintenances. However, it lacks the key elements of PES, especially in case of service providers not receiving payment for management of services. Most of the payments are made because of mandatory requirements, but not for sustained supply of services. Hence, PES differs from community based conservation approaches in three respects: their focus on ecosystem services (the benefits provided by ecosystems), their use of positive financial incentives to achieve the production of additional services, and the conditionality of those incentives on some measure of performance (Arriagada and Perrings, 2009). Sharing of protected area income between park owner and local communities is one of the examples of PES like mechanism. Income received from protected area in terms of entry free and its utilization for conservation and management of protected area or hunting and license fee obtained from game hunting are some form of PES practices, which are operational in protected area of Nepal. However, it again does not comply with the fundamental principles of PES. Nepal has a very recent history of PES implementation. PES piloting first started nearly a decade ago (2006) by International Union for Conservation of Nature (IUCN) Nepal at Shivapuri National Park focusing on investigating delivery of ecosystem economic benefits for upland livelihoods and downstream water resources. Afterwards, it started gaining momentum in Nepal with an effort of conservation partners and international agencies. Most popular PES scheme is at Kulekhani watershed area, which focused on promoting sustainable natural resource management and alleviating poverty among poor upland communities through transfer payment on use of environment services. Nearly a dozen of PES schemes are being piloted or implemented in Nepal, focusing on watershed services, especially in drinking water. Apart from above, a few schemes are at preparatory stage or in process of implementation, focusing on watershed services at Shivapuri National Park and Sardu watershed with support from International Center for Integrated Mountain Development (ICIMOD). World Wildlife Fund (WWF) is working in Phewa watershed for establishing PES mechanism. Likewise, Multi-Stakeholder Forestry Programme (MSFP) of government intends to bring management of 100% of community managed forests, 50% of government managed forests and 50% of private managed forests under the PES mechanism (MSFP, 2011). MSFP is also supporting for implementing PES at the local level. This shows high growth prospects of PES in Nepal.

3.4 Opportunities and Challenges

PES is at an evolutionary stage in Nepal. The efforts have been largely confined on piloting and development of appropriate policy tools. Many of these schemes often lack key elements of the PES. Nevertheless, growing environmental awareness and high economic use value of ecosystem services provide opportunity for institutionalization. However, poor compliance of contractual obligations, limited number of buyers of services and less willingness to pay, free availability of services, poor conservation awareness, poor economic conditions of buyers and sellers are the main challenges. The fund concept has been widely used, however, limited funds have been generated. Most have been utilized for the management or regulation of services. Absence of true economic valuation and poor cost and benefit analysis on designing and implementing schemes often possess challenge for making investments on conservation. Table 2 below presents opportunities and challenges for institutionalizing PES based on lessons learned from several PES schemes which are being implemented in Nepal.

Table 3: Opportunities and challenges of PES

Opportunities	Challenges
• Growing environmental awareness among private sectors and civil society • Management responsibility delegated to community institutions • Favourable policy environment, recent policies have prioritized securing sustainable conservation finance through market based instruments such as PES • Piloting already started on localized scale, knowledge and lessons learnt from existing practices and knowledge • High economic use value of ecosystem services such as water and carbon • Fund concept had already been institionalized at local level, hence provide institutional framework • Increasingly used as a tool to promote the twin goals of conservation and development	• Payment based on increment or additionality of services or sustained supply • Poor compliance of contractual obligations • Limited number of buyers of services • Less willingness to pay and fund even not adequate for maintenance or management of services • Minimizing or avoiding leakages within and nearby area • Payment based on true economic value of services or willingness to pay • High dependency on ecosystem services, especially on forest products • Equitable sharing of conservation benefits among different community institutions • Sustainability of schemes, including establishment of appropriate institutional structure

4. Lessons and Way Forward

Global and national practices on PES or PES-like mechanism show the promising potential to establish and implement PES schemes, integrating conservation and development together both at watershed or larger scale. However, institutional arrangement and conducive policy are essential to upscale such small scale PES schemes at the wider level. The conditionality, land tenure rights, contracting provisions supported by legislative instruments, equitable benefit sharing mechanism, and monitoring framework are key and essential elements to make a PES schemes successful.

Valuation of targeted ecosystem service(s) or bundle of services can be a basis for such payment. However, various researches indicate that understanding economic value of particular service or bundle of services may need concrete and agreeable methodology. In most cases, such as in Dharan and Dhankuta town in Nepal, actual payment is less than the willingness to pay of users. In this context, a wider methodology and tools can be beneficial.

Payment for ecosystem service schemes are contextual and sometimes very specific to site or location. A generic framework can guide such schemes, but mechanism for incentives need to be adopted at local context. In particular to the Himalayas, incentive for ecosystem services should not be limited to providing cash.

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Chapter 7

Waste Management and Wastewater Treatment in Nepal

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1. Introduction

Nepal is a rapidly urbanizing country, which has seen marked shift in living standards, social habits and people's aspiration in last few decades. Increased population but poor infrastructures development and waste management is exerting environmental and social challenges to most of the urban areas (including capital) which if left unchecked might bring health havoc in urban population in future. Unsegregated waste generation, low efficiency waste collection, unregulated waste collectors, unprocessed waste disposal, river side or open space dumping, unsanitary landfills are some of the key issues with solid waste management. Similarly, inadequate wastewater infrastructures, mixed sewer, septic and storm-water lines, lack of or non-functioning wastewater treatment system, mixed industrial, and residential lines are key issues with wastewater management.

Government of Nepal came up with many waste management policies since 1987. Objective of solid waste management policies introduced time and again was to mobilize waste as resources and make solid waste management simple and effective. But concerned authorities are still treating waste as problem and spending tens of millions to solve this problem. Most of the Waste is being dumped without any treatment leading to environmental degradation and public health issues.

Most of municipalities in Nepal are underequipped and underfunded to be able to deal with the issue effectively. Despite spending major chunk of its revenue in waste management, Kathmandu Metropolitan City's waste management is not satisfactory. For most of other towns, waste management has not yet emerged as top priority. Thus, street side dumping, river dumping and open burning of waste is common sight in most of the urban area. Those municipalities which are trying to manage their waste are also not fully successful. As sanitary waste collection, transportation and sanitary landfill's construction is expensive affair, municipalities have started to use innovative approach to manage their waste. Many smaller municipalities have achieved success by partnering with private sector and reducing waste volume by waste segregation, recycling, and using composting technologies. Despite all efforts, municipalities have not yet utilized modern technological advancement to manage waste. Waste management technologies like mechanical waste segregators, modern composting plants, waste to energy technologies like biogas plants have not been used by any municipalities in significant manner. The only sanitary landfill in Sisdole has also outlived its useful life and has become unsanitary.

Similarly, sewer lines built in Nepal serves both as sewer line and storm-water lines. Additionally, many urban households have connected their toilet line directly to sewer line without building any septic tank. Due to lack of restriction of opening industries nearby residential regions, their wastewater are also thrown in the same sewer line. Most of the towns don't have any wastewater treatment system while those which have built have also not properly used them. Except few, use of modern technologies to manage wastewater is almost non-existent.

2. Municipal Solid Waste Management in Nepal

Solid waste management (SWM) is one of the major environmental issues in cities of many developing countries, including Nepal. Rapid and uncontrolled urbanization, lack of public awareness, and poor management by municipalities have intensified environmental problems in towns of Nepal, including unsanitary waste management and disposal. The use of products that generate hazardous waste is another concern. Unmanaged disposal of medical wastes from hospitals and clinics also contribute to pollution and public health hazards in the localities. Therefore, SWM has become a major concern for the municipalities of Nepal.(ADB, 2013)

Based on the survey conducted by ADB in 2012, it is estimated that waste from households in general contributes about 50–75% of the total MSW generated and average MSW generation was found to be 317 g/capita/day. In 2011, the total MSW generation of the 58 municipalities was estimated at about 1,435 tons/day and 524,000 tons/year (ADB, 2013).

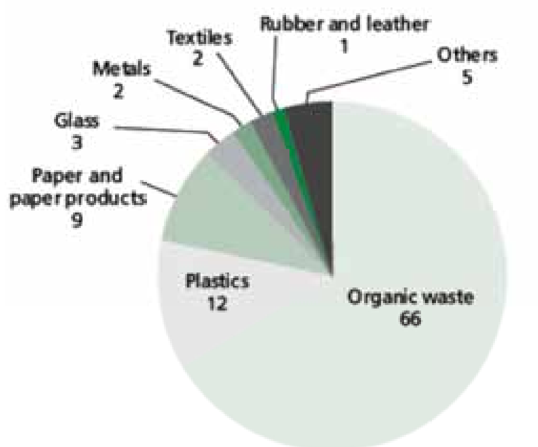

Figure1: Composition of household waste in 58 municipalities (ADB, 2013)

The characteristics of MSW collected from any area depend on various factors such as consumer patterns, food habits, the cultural traditions of inhabitants, lifestyles, climate, and economic status. The composition of MSW is changing with increasing use of packaging materials and plastics. The average composition of household waste of the 58 municipalities in the eight major waste categories is shown in Figure 1.

The household waste composition analysis indicates that the highest waste fraction is organic matter (66%), followed by plastics (12%), paper and paper products (9%), others (5%), and glass (3%). Metal, textiles, and rubber and leather each accounted for 2% or less. The high organic content indicates a need for frequent collection and removal, as well as good prospects for organic waste resource recovery. The content of major reusable and recyclable materials (i.e., plastic, paper and paper products, metal, glass, rubber and leather, and textiles) comprised 29% on average. The organic fraction was higher in the Tarai municipalities than in the mountain and hill regions (ADB, 2013).

Overall Municipal Solid Waste Composition

The average composition of MSW is as follows: organic waste 56%, plastics 16%, paper and paper products 16%, glass 3%, metals 2%, textiles 2%, rubber and leather 1%, and others 4%.

Waste generated from offices, schools, and colleges were categorized as institutional waste. The composition analysis revealed 45% paper and paper products, 22%

organic wastes, 21% plastics, and 8% others. Glass, textiles, metals, and rubber and leather each made up 2% or less. The average composition of waste from commercial establishments such as shops, hotels, and restaurants comprises 43% organic wastes, 23% paper and paper products, 22% plastics, 4% glass, and 4% others, with the rest accounting for 2% or less each.

2.1 Waste Management

Generally, MSW management consists of three stages: waste collection, transfer and disposal (Figure 2). Private and municipal sectors collect waste from the streets, from door-to-door or by a container system. In the streets, scavengers collect useful plastic, paper and metals. When the wastes reach the transfer station, the dumping site scavengers again sort out some portion of paper, plastic and metals.

Managing solid waste has been accorded low priority by municipalities because of high demand for other public services and low budget. It is essential to know the quantity and composition of MSW when designing and implementing proper waste management plans including resource recovery through appropriate methods but lack of SWM baseline information and data related to the functional elements of SWM has made it difficult.

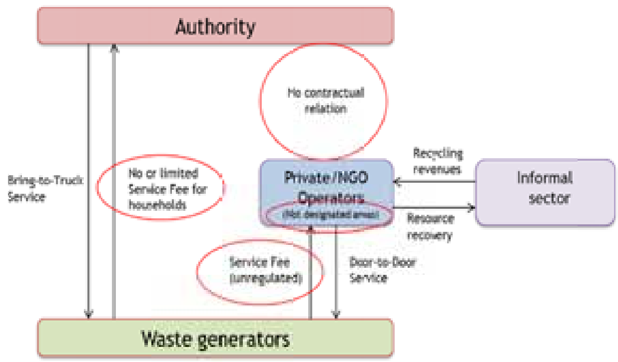

Figure 2: Typical municipal waste management system in urban Nepal

2.2 Collection and Segregation

Only 30% of households in the municipalities practice segregation of waste at source. Many households in some of the municipalities, especially from the rural wards, were found to segregate kitchen waste for their own use, such as feeding cattle. In recent years, 21 municipalities have promoted waste segregation at source but effective and large-scale segregation programmes are yet to be implemented.

The present waste collection efficiency ranges between 70% and 90% in major towns and is below 50% in several smaller municipalities. Many people dispose their waste within their compound (unscientific composting or open burning) or throw it in the open surrounding space. Collection, city cleaning, and sweeping is not regular in most of the places. Many areas are served only twice a week or twice a month, or are not served at all.

Container service, door-to-door collection, and roadside pickup from open piles or containers are the types of collection service generally practiced in municipalities. While door-to-door collection is practiced by 24 municipalities, roadside pickup from open piles is still a prevailing practice, with 49 municipalities continuing this collection method.


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2.3 Transport and Final Disposal

In Kathmandu, around 30% of the waste is collected by Kathmandu Metropolitan Municipality (KMC) and 70% by private operators and NGOs. The waste collected by KMC is taken to teku transfer station where it is unloaded on to a concrete platform and transferred to Sisdole landfill site, located at around 25 km from Kathmandu centre along a difficult accessible road, using bigger trippers. The waste collected by POs is directly transported to Sisdole landfill site because they don't have access to Teku transfer station, primarily because of social opposition (ADB, 2013). Lalitpur sub-metropolitan city also uses the Sisdole landfill for dumping. Sisdole doesn't have any tipping fee yet but KMC is planning to introduce it. When waste arrives at Sisdole landfill, this is deposited on the site and covered with soil.

Private and municipal sectors collect waste from the streets from door-to-door or by a container system. Domestic waste is either collected from streets, or in waste containers or by door-to-door collection. The municipal sweepers clean the streets and collect the waste, usually by handcarts, after which it is loaded on either tractors or trucks. In the streets, scavengers collect useful plastic, paper and metals. When the waste reach the transfer station the dumping site scavengers again sort out another percentage of the paper, plastic and metals.

The vehicles and equipment available for waste collection and transport in each municipality varies widely. In Kathmandu, the waste collected is first taken to either Teku transfer station, where it is unloaded on to a concrete platform, or directly to the landfill at Sisdole. At the transfer station, the waste is loaded on to bigger vehicles before it is taken to the dumping site.

Vehicles commonly used include rickshaws and carts for primary collection, tractors for secondary collection or transport, and dump trucks for transport to the disposal sites but smaller municipalities generally do not have all types of vehicles. Transfer sites are not available in major municipalities except few. Sites for treatment facilities and sanitary landfill are yet to be identified by many municipalities and waste is currently being disposed of without treatment in crude dumping sites, creating public health risks and environmental problems. Open dumping, including riverside and roadside dumping, is practiced by as many as 45 of the 58 municipalities. Only six municipalities - KMC, Lalitpur, Pokhara, Ghorahi, Dhankuta, and Tansen-have constructed sanitary landfill sites (ADB, 2013).

Three largest generators of MSW-KMC, Pokhara, and Lalitpur-all have sanitary landfills. However, KMC and Lalitpur are facing the problems including frequent local protests, lack of proper management and unavailability of necessary equipment, leading to unsanitary methods of disposal. Many municipalities have started to plan a designated landfill site (whether sanitary or not), but many municipalities have no such plan (ADB, 2013).

2.4 Waste Management Cost

Except the municipalities within Kathmandu valley and Biratnagar other municipalities have rural settings (ADB, 2013) affecting solid waste generation, composition and disposal cost. Average solid waste disposal cost for a municipality was estimated of NPR 168000 per day or US $ 1680 per day (Environment statistics, 2013; CBS and PDNA, 2015).

SWM sector uses most resources of the municipalities (Figure 3). Municipalities spend an average of 10% for SWM, of which 60%–70% is used for street sweeping and collection, 20%–30% on transport, and any remaining small amount for final disposal. On average, municipalities spend about NPR 2,840 ($30) per ton of waste for collection, transport, and disposal. In terms of revenue collection, some municipalities collect a SWM service fee, a door-to-door collection service fee, a surcharge on property or business tax, and a service fee from major waste generators but they appear pale compared to expense of municipalities.

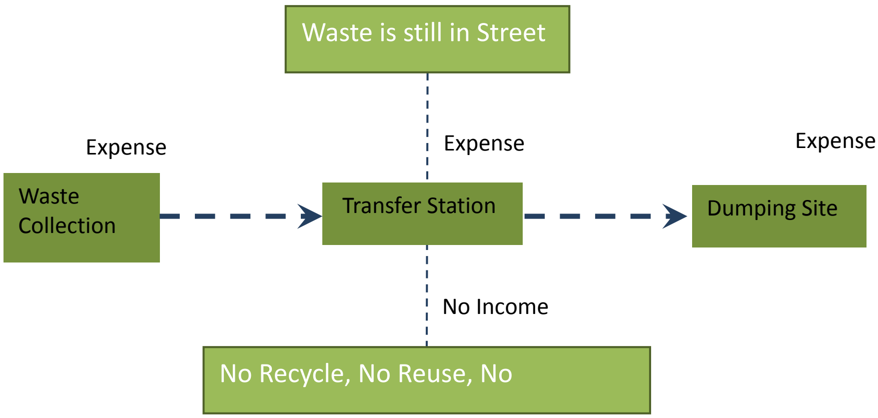


Figure 3: Economics of waste management in Nepal

2.5 Recycling

Municipal solid waste in Kathmandu contains more than 60% of organic waste and more than 25% of recyclables such as plastics, metals, textiles and paper. Most of the waste is managed by disposal. Municipalities in Kathmandu don't have formal waste recycling schemes but sorting of recyclables at household is taking place since long. Primary collectors employed by Private Operators (POs) sort out the valuable recyclables quickly during collection at household level.

Similarly, on the streets, recyclables such as plastic, paper and metals are collected by the informal sector and at the dumping site scavengers sort out another percentage. From here it enters a long chain of buyers/middle-men until the recyclables are eventually sold/exported to processing industries in- and outside Nepal. Recycling is affected by several factors such as proximity to the markets, scaleof economy, quality of recyclables, demand of the recyclables, etc. Kathmandu valley has limited recyclable processing units and often the final destination is beyond the country border.

2.6 Organic Treatment

> **Healthcare waste**
>
> Few of the bigger hospitals practice incineration of Health Care Waste (HCW), although this basically involves burning the waste in a chamber or open burning in the hospital's compound. In some cases, medical waste is mixed with municipal waste and in some cases it is burned or dumped. There is no proper system for the management of medical waste and the staff, including medical personnel, are mostly unaware of the health impacts. In terms of sorting and primary treatment, few of the bigger hospitals in Kathmandu valley have taken steps.

Composting has been traditionally promoted in Kathmandu valley where more than 60% of the waste is of organic nature. With urbanization, the volume of waste increased quickly and new composting technologies started to evolve. Household level bin composting is being practiced by various municipalities under a subsidizing scheme. Windrow composting, chamber composting and vermi composting has been piloted in different municipalities in Kathmandu valley but they were not operationally successful. KMC has several examples of bigger scale composting initiatives since 1986 but none of them succeeded. The quality of compost (C:N Ratio, NPK Value, presence of other residual waste in compost), marketability, rate of return, environmental nuisance and behaviour-related socio-economic factors have been major hindrances in composting.

Kathmandu has a biomethanation project of 3 TPD under European Union (EU) funding. Lalitpur has a similar kind of project, which is still under construction and results will be available only after operation commenced.

2.7 Disposal

Whatever technologies and equipment are used, they should be appropriate for and adapted to the local conditions. Apart from conventional waste disposal system like dumping site, most cities are trying to bring innovation in their waste management system by investing resource in material recovery facilities, ecofriendly disposal sites, etc. The small and relatively remote municipalities like Dhankuta in eastern part and Gorahi in western part in Nepal shows what can be achieved with limited local resources: their well-sited and managed facility includes waste sorting and recycling, sanitary landfilling, leachate collection and treatment, and a buffer zone with forests, gardens that shields the site from the surrounding area. Taking example of these municipalities as pioneer having best practices in solid waste management, other municipalities have already started working to adopt appropriate model in their municipalities also. Now, Waling and Ilam are also considered cities with good solid waste management practice.

> **Slaughter waste**
>
> Slaughter waste management is another crucial issue in waste management. Slaughter waste nowadays is being used for composting to some extent and dumped improperly in other cases. Dead animals are buried or dumped. The burying is done near riverbanks, in jungle areas and at dump sites.

When started 10 years ago Sisdole was a reasonably well-engineered landfill but today operational practices can be characterized as unsanitary dumping. The site has been extended several times and right now the "3rd valley" is in use. The leachate collection and recirculation system only functioned in the 1st valley. A system of perforated pipes has been installed to vent out the gas below the landfill to avoid any kind of potential explosion.

Besides the environmental threats Sisdole faces various problems including presence of scavengers, local protests, lack of proper management and unavailability of necessary equipment. Employee's strikes and community blockades to the site, as well as to Teku transfer station, are common. Above all, the landfill has developed beyond its original foreseen capacity and extensions are required to keep operating at the current location.

Dhankuta Municipality

Dhankuta municipality has adopted daily, twice a week and weekly door to door waste collection system in main market area, semi urban area and residential area respectively, whereas in fringe area waste collection service is provided as per request. It has extended the collection services in residential and fringe areas including newly included area, and number of wards receiving SWM services has reached 9 out of 15 (1, 2, 3, 4, 5, 6, 7, 14 and 15 against baseline 1, 4, 5 and 7). About 5500 households are receiving waste collection services from the municipality.

Dhankuta municipality has distributed 1216 sets of segregation bins and 70-75% households are practicing source segregation as per municipal progress report. Similarly 167 compost bins including 100 vermi-composting kits have been distributed to households and about 40-45% households are practicing household composting. Source segregation and composting of biodegradable waste at household level contributed to the minimization of waste at source and reduction of waste collection and transportation cost.

In Dhankuta municipality, most of the biodegradable waste is consumed for animal feeding. Out of total collected waste of 8 tons/day, 10% is sorted out by private operator under contractual arrangement. The sorting takes place at tipping area near designated landfill cell. About 850 kg of recyclables is collected each day and record of collected recyclables is maintained. Private operator sell recyclables to the scrap dealers for further recycling. Dhankuta collects NPR 25,000 annually from private operator for collecting recyclables from landfill.

Municipality is operating landfill site as per landfill operational manual as far as possible. Necessary staffs for waste recording and site supervision is deputed. Waste is covered regularly. During operation of site, erecting of landfill gas vents, cleaning of drain, etc. are carried out regularly. Because of lack of landfill equipment, municipality hires Back-Hoe loader for waste compaction and covering.

Ghorahi Municipality

In Ghorahi municipality, municipality collects mixed waste. Collected waste is unloaded to the tipping area where recyclables are sorted and stored in ware house, remaining waste is disposed in landfill. Record of such recyclables is maintained at landfill. Collected recyclables are then sold to the private scrap dealers for further recycling. This is also a source of revenue for the municipality. In 2016, municipality collected over NPR 2,022,232.00 from SWM sector.

Ghorahi municipality has adopted door-to-door as well as curbside waste collection system in main market areas, semi urban areas and residential areas of 3 wards 6, 10 and 11 mainly in urban areas of the municipality. Urban wards are ward 10 and 11 where mixed waste is collected whereas in ward 6, municipality collects two types of segregated waste biodegradable and others which includes recyclables and inert. To minimize waste, Municipality has distributed 1000 segregation bins in ward 10 and 11 which is mainly the main market area. Currently, about 15% households are practicing composting (Figure 4).

Figure 4: Compost pit of Ghorahi municipality

Ghorahi landfill accepts about 14 tons of collected waste every day from where recyclables are sorted and stored and rest is disposed at landfill. At present, waste is disposed at recently constructed landfill cell. Necessary mitigation measures have been applied for the management of leachate and landfill gas. Landfill gas vents are erected at different locations for safe release of landfill gas. Waste record is maintained each day and record of recyclables collected is also maintained. Municipality employed 8 collectors at landfill for sorting and collection of recyclables.

3. Wastewater Treatment System

Water is the most valuable natural resource in Nepal. The annual renewable surface water available in the country is estimated to be 225 billion m^3 (WECS, 2003) and renewable groundwater 12 billion m^3 but only about 23.70 billion m^3 of water is estimated to be in use at present and much of this use is limited in agriculture, drinking water and sanitary uses (UNEP, 2001).

The demand of water in the social and economic sectors, however, has increased significantly due to increase in population and expansion in the economic and commercial activities especially in the urban areas. The per capita availability of water resources in Nepal is estimated to be 8,900 m^3/capital/per annum, is at least 5 times higher than the threshold of 1,700 m^3/capital per annum to meet all water needs in agriculture, water supply and sanitation, energy and environment (UNDP, 2006).

Piped water supply system in the country started as early as in 1895 in Kathmandu, essentially to serve the ruling elites at that time which was later expanded to serve common people. Prior to this, water needs of the people were met from traditional water systems which continue to meet significant part of the water needs of the people even to this date. The development of sewer system in the country started in 1920s with the development of 55 km long brick channel to collect and dispose combined sewer and rainwater runoff in Kathmandu and Patan (Nyachhyon, 2006).

Table 1: Assessment of water resources availability and use in Nepal (1991-2011)

Particulars	1991	2001	2011	Remarks
Annual Renewable Surface Water (billion m^3)	225	225	225	Including the catchments outside Nepal
Annual Renewable Groundwater (billion m^3)	12	12	12	
Total Population	**18,491,097**	**23,151,423**	**26,620,809**	**CBS (2011)**
Per Capits Renewable Surface and Groundwater (1000 m^3 years)	12.81	10.23	8.90	
Total Annual Withdrawal (billion m^3 year)	12.95	16.70	23.70*	
Per Capita Annual Withdrawal (.000 m^3 year)	0.69	0.72	0.89	
Sectoral Withdrawal as % of Total Withdrawal*:				
Domestic	3.97	3.68	3.43	
Industrial	0.34	0.41	0.41	
Agricultural	95.69	95.91	96.16	

Government institution with the responsibility of operation and management of water supply infrastructure and services, named Pani Goshwara, was created in 1929. It was the beginning of organised efforts in the development and management of water supply and wastewater system in the country. The modernization of water supply and sanitation infrastructure in the country began only after 1972 with the support of the World Bank, focusing essentially in improvement of the urban water supply and wastewater services in Kathmandu valley. This effort led to the formation of Water Supply and Sanitation Board in 1974 which was reorganised in 1989 and named Nepal Water Supply Corporation (NWSC), which was entrusted with the responsibility of organising, maintaining and managing water supply and wastewater services in the country. In 2008, the responsibility of operation and management of water supply and wastewater services in Kathmandu valley was transferred to Kathmandu Upatyaka Khanepani Limited under public private partnership (ADB, 2010).

Rivers in Kathmandu valley and in other parts of the country have been the main repository of untreated sewage, solid wastes and industrial effluents. Investment in the development of infrastructures and services for wastewater treatment in the country began only after 1970. During 1970s and 1980s centralized wastewater treatment plants were developed in many parts of Kathmandu valley though planned development of infrastructures and services for wastewater management in other urban areas of the country started much later in time.

The production of wastewater in Kathmandu and other urban areas in the country are through domestic, commercial and industrial sectors. The sewer systems in Kathmandu and in other parts of the country are essentially combined sewerage and storm water drains. Direct disposal of solid and liquid wastes along the river course and rainwater runoff originating from the urban areas and agricultural lands have also been responsible for significant degradation in the water quality of the rivers and other surface water bodies. Wastewater produced from the domestic routes includes grey water and black water produced in washing, cleaning, bathing and sanitary uses. Only small numbers of houses are connected to sanitary wastewater system and therefore most houses end up disposing the wastewater directly into the rivers and other water bodies. With 232 km long sewer system developed in Kathmandu valley, only 40% of the population has access to sewer facility (ICIMOD, 2007).

Wastewater generated from the industries has been another source of wastewater. The industries producing significant amount of wastewater in the country include brewery and distillery, cement, cigarette and tobacco, animal feed, iron and steel, rosin and turpentine, soap and chemical solvent, oil and vegetable ghee, jute, paper and pulp, sugar and leather tanning. Total of 4,500 industrial units of different sizes are estimated to be operating in different parts of the country. The concentration of industries are large in Kathmandu valley and some urban centres (Birgung, Biratnagar, Bharatpur, Butwal and Bhairahawa) in Tarai, adjoining Indian borders. Nearly 40% of the industries in the country are estimated to be producing significant amount of wastewater and nearly 50.9% of the total industries in the country are located within Kathmanedu valley (UNEP, 2001). The combined wastewater production in three industrial estates in Kathmandu Valley- Balaju, Patan and Bhaktapur which house nearly 200 industrial units in the valley is estimated to be 800 m^3/day.

Beside the industries located in the industrial estates where more organised facilities are developed for the management of solid and liquid wastes, there is are large number of small and medium scale industries scattered throughout the valley. The wastewater generated in most industries is mixed with the municipal sewerage system while the solid industrial waste is collected and dumped into pits or in open spaces. Since the waste water generated in the industries contain high loads of oxygen demanding wastes, synthetic organic compounds, inorganic chemicals and minerals, these lead to significant degradation in the water quality at the local level.

In addition to wastewater and sewage from domestic and industrial sources, the rivers also receive inputs of storm water directly from the roads and streets in the urban areas and the runoff originating from the agricultural lands. The streets in the urban areas contain different kinds of solid wastes in different volumes which get emptied directly into the river after every rain storm and become important part of wastewater and contributor of river pollution. Though the present level of use of inorganic fertilizers and other agricultural chemicals in Nepal is much lower than other countries in the region, the use of agricultural chemicals and fertilizers has increased in some areas, especially in Kathmandu valley and agriculturally prosperous districts in central and eastern Tarai (Basnyat, 1999). Altogether 250 different types of pesticides are known to be in use in Nepal with the average use of pesticides to be 0.142 in the country (Palikhe, 1999). All the pesticides in use are organochlorides and organophosphates which are persistent in the environment and pass through the food chain through the processes of bioaccumulation and biomagnification, and thus are hazardous to human health. Organochlorides have been detected in samples of fish and plankton in three lakes, Begnas, Phewa, and Rupa in the Pokhara valley in the western mid hills of the country (Palikhe, 1999).

Wastewater Treatment Plant in Hetauda Industrial Center

Hetauda lies in Makawanpur district, Narayani zone of Central Development Region of Nepal at 390 m from the sea level. The city is enclosed by three rivers, the Rapti to the west, the Samari to the north and the Karra to the south. The Karra River is perennial flow and originates from North-eastern Siwalik hill and flows towards west to join with the Rapti River near Hetauda city. Hetauda city is covered by forest, agricultural land, residential area, and industrial area. The Hetauda Industrial District (HID) is the largest industrial zone in Nepal with an area 145ha. The natural waste stabilization treatment plant at HID (Figure 5) was built in 2002-03 under financial and technical assistance of the Government of Denmark. The plant was constructed with an investment of NPR 380 million from the Danish government and NPR 120 million from the Nepal government.

The treatment plant is located on the lowland in the northern part of HID and occupies seven bigha and 15 kattha of land. Among 45 operating industries, the waste generated out of

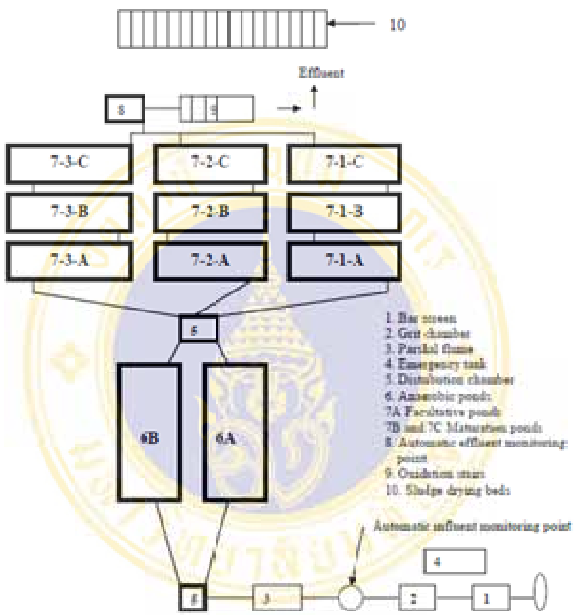


Figure 5: Central wastewater treatment plant in Hetauda Industrial Centre, Nepal

22 industries is being treated in the treatment plant, whereas other industries discharge their waste directly into the Karra River. The plant was established with the motive of purifying polluted water from Hetauda Textile Industry, which used to be let out into the Rapti River directly and was a major pollutant. But since the textile industry has been shut down, the production of wastewater has decreased (THT, 2004).

The technology used for water treatment is completely natural with screening of floating objects. There is an emergency tank, nine aerobic and two anaerobic ponds along with the other necessary machineries. A 6.8-km long underground sewer and a 10-km long surface sewer have been constructed to transfer the polluted water from industries to the treatment plant. Wastewater is allowed to pass through grit chamber. Sand grit settle by the force of gravity, followed by sedimentation tank where silt, clay and organic matter settle down and various algae and microorganisms help treat water. It treats wastewater of HID for 18 days in different phases. It has the capacity to treat 1.1 million litres of wastewater in a day.

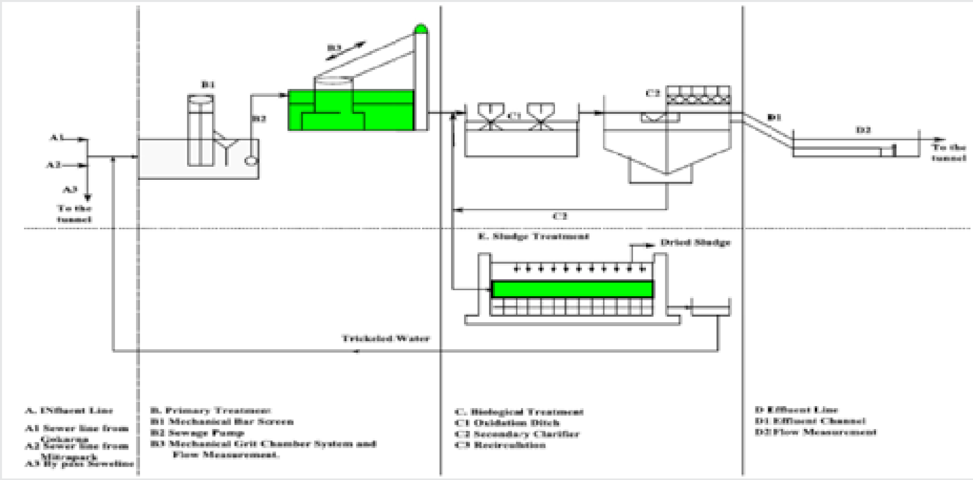
Guheswori Wastewater Treatment Plant (Shahi, 2012)

Kathmandu valley currently has five municipal wastewater treatment plants, among which Ghuheswori Wastewater Treatment Plant (GWWTP) is the only wastewater treatment plant in operation (Figure 6). The treatment system involve is the activated sludge system at Guheshwori (Green, 2003). Guheshwori wastewater treatment plant is located at the bank of Bagmati River in the northeastern part of Kathmandu City. It was constructed at the initiative of the government to clean up the Bagmati River. The treatment plant site covers an area of 5 hectares. A chain of interceptor drains along the river corridor to check haphazard disposal of the raw sewage was installed (Khatiwada). The plant treats the untreated wastewater generated by the household, industries and other institutions of Gokarna, Chabahil, Bouddha and Jorpati. It serves an estimated population of around 198,000. It has a design capacity of 0.19 m^3/s.

Figure 6: Guheswori Wastewater Treatment Plant

The activated sludge wastewater treatment process is identified by three major characteristics: a biological reactor for the decomposition of degradable organic chemicals, a settling tank for the removal of solids and biomass from the water, and a recycle stream from the settling tank to the reactor to ensure sufficient levels of microorganisms. This facility provides pre-treatment of wastewater with a mechanical bar rack and a grit chamber.

The Guheshwori WWTP lacks primary clarification tanks. The major components of the treatment plant include the primary and secondary units. The bar rack eliminates large objects from the influent, and inorganic particles like sand are removed in the grit chamber. The wastewater at Guheshwori WWTP is biologically treated in two carrousel 15 type oxidation ditches, each with three aerators. From the oxidation ditches, wastewater flows into two secondary clarifiers for the settling of solids. Up to 2,500 MLSS sludge is pumped from the clarifiers back to the



oxidation ditches to be metabolized by microorganisms, and any excess sludge is wasted to one of fourteen drying beds (Green, 2003). Figure 7 displays design and operational parameters of Guheswori WWTP.

Figure 7: Schematic diagram of Guheswori Wastewater Treatment Plant

Operational Challenges

The river systems in the valley serve as important resource in keeping the overall environment and the micro-climate in good condition. The rivers are virtually now serving as open sewers, the water pollution is causing tremendous environmental and health impacts to the inhabitants.

The treatment plant does not have a separate collection system for storm water and sewage, so, during monsoon, the wastewater overflows and mixes directly with the river. The design location of a grid chamber seems inappropriate as the influent water has to flow from lower level to the higher level with the help of pump. The system also lacks primary sedimentation tank. Nitrogen and phosphorous removable is not possible because it lacks tertiary treatment unit. Routine maintenance of the units including the pumps and other accessories was missing and some of the equipment were also observed in critical condition. The frequent power cut has also added a big burden in the operation and maintenance of the plant.

4. Conclusion

Nepal is facing challenges to manage the ever increasing waste (both wastewater and municipal solid waste) as a result of changing demography, urbanization and lifestyle. There are many technologies being deployed to treat solid wastes and wastewater in Nepal. But most of the efforts to manage waste has not been completely successful owing to the fact that they were not suited for local condition (local management, weather, manpower, availability local expertise etc). So, it is important that decision-makers have the information they need to make informed choices taking lesson from past experience. Unfortunately, experience shows that there are no magic solutions: technologies developed for relatively dry wastes with high calorific value in one region may not work when confronted with wet and mainly organic wastes with low calorific value in other regions.

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Chapter 8

Fresh Water Resources of Nepal: Perspectives and Issues

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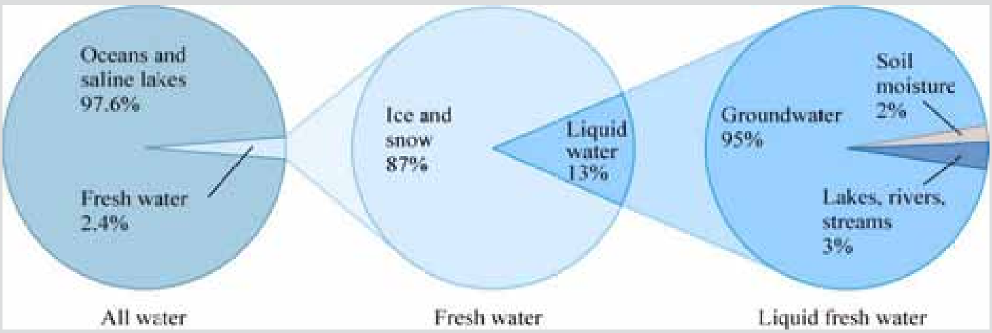
1. Introduction

Water is a fundamental resource for survival of live and maintenance of socio-ecological system. Water exists as freshwater or as salty (marine) water. Freshwater represents the naturally occurring water having a low salt concentration (<1%). These waters occur on the surface of earth (ice sheets, ice caps, lakes, rivers, stream) and underground in aquifers, usually in the solid (snow and ice) and liquid forms. Freshwater covers about 2.6% of the earth's water resources and over two thirds of this is in the frozen form in glaciers and polar ice caps (Box 1).

Box 1: Overview of the world's freshwater resources

Water is one of the main natural resource of the earth, covering 70% of the earth surface area. World freshwater is 36 million km^3, about 2.6% of total water volume. About 11 million km^3 (0.77% of total or 30% of freshwater) pass through water cycle, rest remain as polar ice sheets and glaciers on the ground.



The global distribution of fresh water on earth crust, including ground water and water present as vapours in the atmosphere is given below:

Global distribution of fresh water		Water volume (km^3)
1	Water in snow- caps, ice sheet, glaciers, etc.	24,000,000
2	Surface pond, lakes and reservoirs	280,000
3	Water in streams and rivers	12,000
4	Water present as soil moisture	85,000
5	Ground water	60,000,000

Figure 1: Proper management of available water resources can easily address the water demand of the country (Photo: Tamor River at Tapethok in Taplejung district by Sudeep Thakuri, 2016)

Figure 2: About 210 million liters per day (MLD or km^3/year) water flow out of the country (Photo: Sudeep Thakuri, 2015)

The freshwater systems are very important from the perspective of their hydrological regime, sediment regime, water quality, thermal regime, and biology.

2. Assessment of Water Resources

2.1 Water Sources and Availability

Water is a significantly abundant renewable natural resource in Nepal. Surface water (rivers, lakes, ponds), groundwater, solid snow and ice, and rainfall are the main source of water. The country extends from an elevation of 60 m in the southeast to above to 8,848 m above mean sea level, the highest peak of the world, Mt. Everest, in the north.

Total annual rainfalls appear to increase with increasing altitude in Nepal up to about 3,000 m; thereafter, the annual rainfall diminish with increasing altitude and increasing latitude. Above about 5,500 m, all precipitation is in the form of snow. The topographical barrier produces a rain shadow on its northern side. Thus, annual precipitation totals show marked differences over very short horizontal distances. The mean annual precipitation varies from less than 150 mm (in Upper Mustang, Lomanthang area of Mustang district; altitude 2,650 m) to above 5,000 mm (in Lumle of Kaski district; altitude 1,642 m) within about 50 km distance.

2.1.1 Surface Water

The surface water represents the river runoff, lakes, and overland flow. The main source of surface water is rainfall, snow and ice melt, and ground water.

A) Rivers of Nepal

All the rivers of Nepal drain south to Ganges river. Thirty-three rivers having their drainage areas exceeding 1,000 km^2 drainage density expressing the closeness of spacing of channels is about 0.3 km/km^2 (Figure 3).

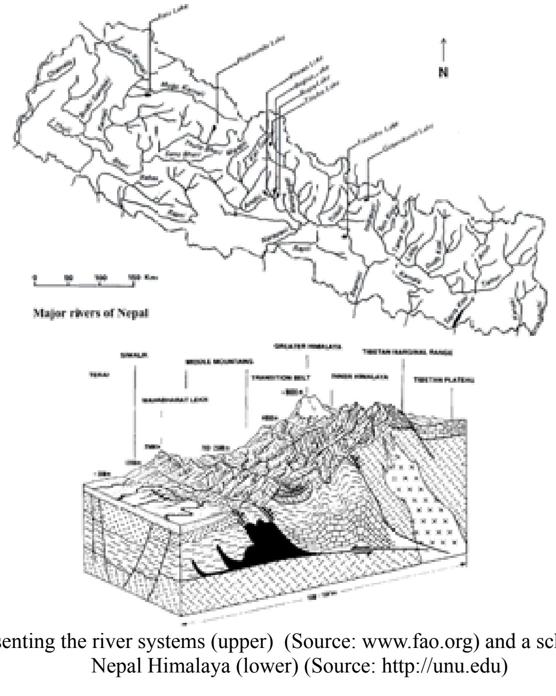


Figure 3: A map representing the river systems (upper) (Source: www.fao.org) and a schematic cross-section of the Nepal Himalaya (lower) (Source: http://unu.edu)

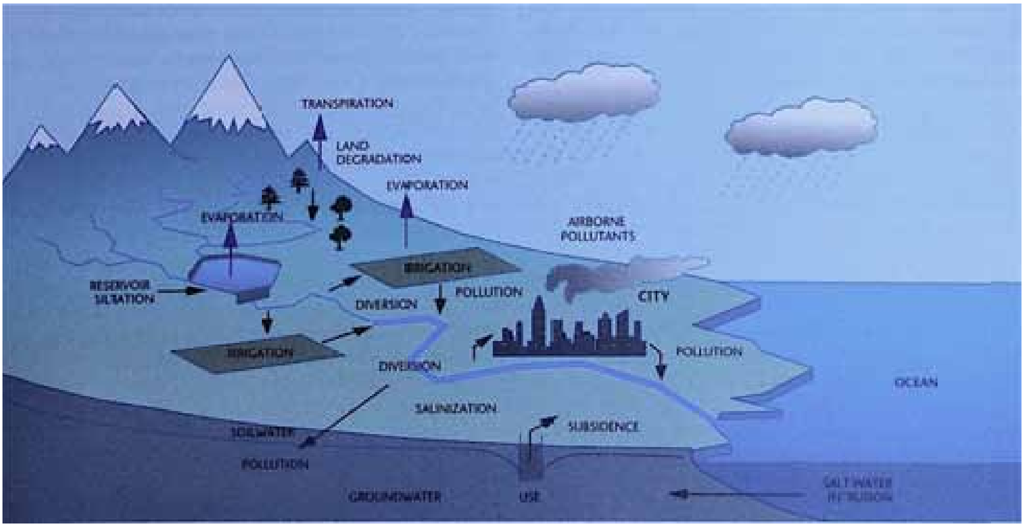


Figure 4: Idealized hydrological cycle (WMO, 1997)

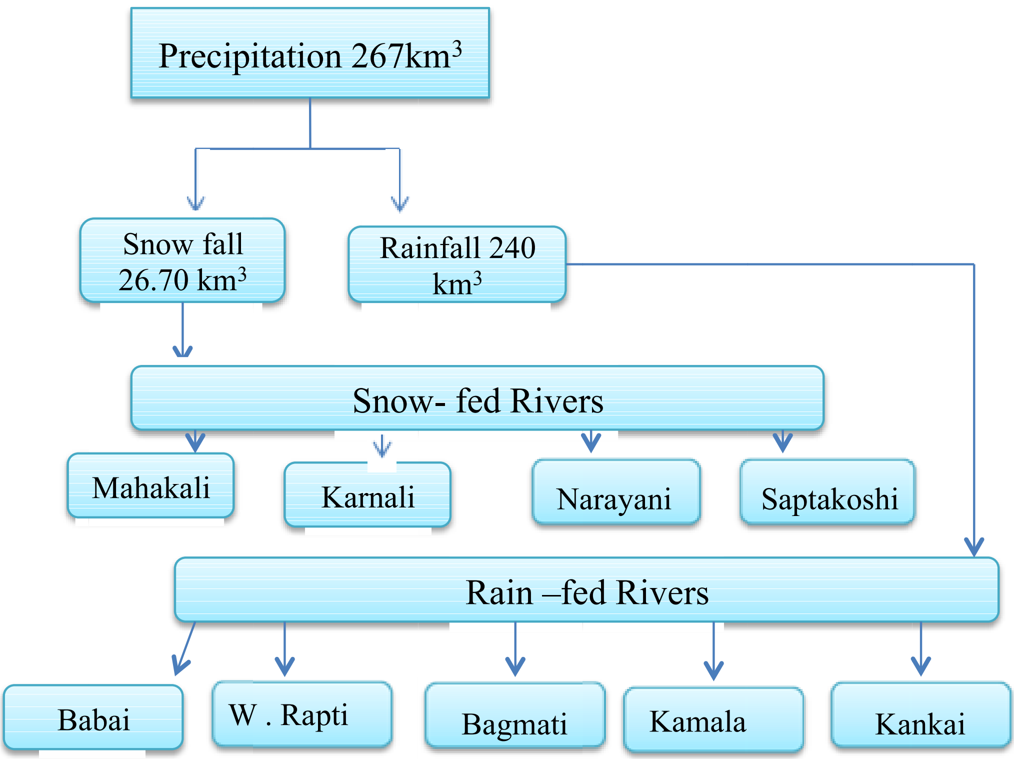


Figure 5: Rivers systems of Nepal (modified from UNEP, 2001)

Nepal includes typically three types of rivers depending on their source of water and discharge. Three major river systems: rivers originating in the (a) high Himalaya (e.g., Koshi, Narayani, Karnali), b) Mahabharat range, and (c) Chure range. The first type of rivers is large rivers that originate in the Himalayas and carries snow-fed flows with significant discharge even in the dry season. The second type of rivers are Babai, West Rapti, Bagmati, Kamala, Kankai and Mechi rivers, which are the medium type that originate in the Midlands or the Mahabharat range. The third type of rivers are more seasonal and mainly originated from Chure range in the sourthern part of the country (Figure 5, Table 1).

Figure 6: Monthly precipitation of Nepal (Photo: Sudeep Thakuri, 2015)

The seasonal distribution of flow is extremely variable, ranging from as low as 1.5-2.4% of the total runoff (in January, February and March), and as high as 20-27% (in July and August) for snowfed rivers, while the corresponding figures for purely rainfed rivers are 0.5-3% from March to May and 19-30% in July and August. The surface water resources produced internally are estimated as 198.2 km^3/year. The groundwater resources have not been fully assessed. Ongoing studies show that a good potential for groundwater extraction exists, especially in the southern Tarai lowland plains and inner valleys of the hilly and mountainous regions. Much of the Tarai physiographic region and some parts of Churiya valleys are underlain by deep or shallow aquifers, many of which are suitable for exploitation as sources of irrigation water. A rough estimate can be made by assuming a groundwater resource equivalent to 10% of surface water (Table 2), i.e. approximately 20 km^3/year, which corresponds to the base flow of the rivers. The total internal water resources would, therefore, amount to 198.2 km^3/year. Chinese statistics mention an average outflow to Nepal of 12 km^3/year, which brings the total renewable water resources of Nepal to 210.2 km^3/year. It is assumed that all the renewable water resources of Nepal flow out of the country to India (AQUASTAT, 2016).

Table 1: Water discharge from the rivers of Nepal (WECS, 2005)

River		Basin Area		Average Discharge (m^3/s)	Annual Discharge (km^3/yr)
		Total	In Nepal		
1.	Himalayan Rivers				
	Koshi	60,400	27,863	1409	45
	Narayani	34,960	31,464	1600	50
	Karnali	43,679	41,058	1397	44
	Mahakali	15,260	5,188	573	18
2.	Mahabharat rivers		17,000	461	14.5
3.	Churiya rivers		23,150	1682	53
Total			145,723	7122	224.5

Table 2: Water availability information of Nepal (AQUASTAT, 2016)

Renewable Freshwater Resources

Precipitation rate: 1500 mm/year (220,770 million m^3/year)

Internal renewable water resources (long-term average): 198.2 million m^3/yr

Total actual renewable water resources volume in 2005: 210.2 km^3/year (210.2 billion m^3/year)

Dependency ratio: 5.71%

Per Capita in 1990: 12,000 m^3/year

Per Capita in 2016: 8000 m^3/year

Breakdown of total actual renewable water resources

Surface water: 94 %

Ground water: 10 %

Overlap is water shared by both the surface water and groundwater systems: 10 %

Incoming waters: 6 %

Outgoing waters: 100 %

Total use of total actual renewable water resources: 5%

Water Withdrawal

Total water withdrawal (2005): 9787.1 million m^3/year

- Irrigation + livestock: 9610 million m^3/year
- Municipalities: 147.6 million m^3/year
- Industries: 29.5 million m^3/year
- Per inhabitant: 359 m^3/year

Surface water and ground water withdrawal: 9787.1 million m^3/year

- As % of total actual renewable water resources (2005): 4.7%

B) Lakes in Nepal

In Nepal, DOAD (1992) has reported around 5,000 lakes, 1,380 reservoirs, and 5,183 village ponds. According to IUCN inventory (1996), there are 163 wetlands in Tarai, and 79 in the Hills and Mountains. Similarly, 3,252 glaciers and 2,323 glacial lakes have been identified in the high (>3500 m a.s.l.) mountain region (Mool et al., 2001). Bhuju et al. (2010) has enlisted 5,358 lakes from different ecological regions using the topographical sheets. Among them, over 2,700 (51%) are distributed below 500 m, 2,227 (42%) above 3,000 m, and only 419 (<8%) in altitudinal range between 500 and 2,999 m (NLCDC, 2009; Bhuju et al., 2010). With respect to scientific studies of the lakes, the most of the lakes studies in Nepal seems to be confined within Mid-hills. Phewa, Begnas, Rupa, Khaptad, Tilicho, Phoksundo, Dudh Pokhari, Panch Pokhari are the popular lakes in Nepal.

Lakes of Nepal serve as some important wetlands. Wetlands are among the most important ecosystems in the earth and considered to be the corridors through which 'life' evolved, prospered, came ashore and conquered the terrestrial areas (Rao and Datye, 2003). They are vital link between aquatic and terrestrial ecosystems. Since wetlands moderate the flow of nutrients and silt from land to water by trapping them, they are also called as 'kidneys' of landscape. They are the perpetuators of global hydrological cycles. They harbor a significant portion of earth's biodiversity. These threatened landscapes are the last and only refuges for a wide variety of flora and fauna. Human lives are invariably intertwined with these ecosystems in the evolution of their civilization. More than three-quarters of the food required for mankind is still derived directly from the wetlands in the form of rice and fish along. A key to the future sustenance of human societies lies in the sustainable wise use of these highly fertile ecosystems. According to De Groot (1990), in many cases, wetlands host rare endemic species and species threatened with extinction (Rao and Datye, 2003).

In Nepalese context, wetland means land with perennial source of water. For instance, marshy lands, riverine floodplains, lakes, ponds, water storage/logged areas and agricultural lands like swampy rice fields are understood as wetlands. According to (Nepal) National Wetland Policy (2003), "wetland" denotes perennial water bodies that originate from underground sources of water or rains. It means swampy areas with flowing or stagnant fresh or salt water that are natural or man-made, or permanent or temporary.

Box 2: Wetlands conservation in Nepal

Nepal is the signatory of Ramsar Convention (17 April, 1988) listing Koshi Tappu in the Ramsar list. Since then, Government of Nepal has initiated the move for protection and management of wetlands. Presently, it has 10 Ramsar sites (Table 1), representing high altitude, mid-hills and low-land Tarai wetlands. A total of 60,561 ha area has been designated as Wetlands of International Importance or Ramsar sites in Nepal.

Table 3: Wetlands of international importance located in Nepal:

S.N.	Name of the wetlands	Location	Area (ha)	Declaration Date
1	Koshi Tapphu Wildlife Reserve	Sunsari	17500	17/12/1987
2	Beeshazari and Associated Lakes	Chitawan	3200	13/08/2003
3	Ghodaghodi Lake Area	Kailali	2563	13/08/2003
4	Jagadishpur Reservoir	Kapilvastu	225	13/08/2003
5	Gokyo and Associated Lakes	Solukhumbu	7770	23/09/2007
6	Gosainkund and Associated Lakes	Rasuwa	1030	23/09/2007
7	Phoksundo Lake	Dolpa	494	23/09/2007
8	Rara Lake	Mugu	1583	23/09/2007
9	Maipokhari	Ilam	90	28/10/2007
10	Pokhara Valley Lake Cluster	Kaski	26,106	02/02/2016

(Source: http://www.ramsar.org/wetland/nepal)

Since the accession to the Ramsar Convention in 1987, Nepal has made the following achievements in wetland conservation:

1. Designation of 10 Ramsar sites representing the major ecological zones
2. Development of a participatory methodology for inventory
3. Preparation of national lakes inventory and strategic planning
4. Preparation of participatory site management plans
5. Pilot project on collaborative management
6. Integration of wetlands into national biodiversity strategy and development plan
7. Networking of national and international organisations for wetlands
8. Capacity building at both national and local levels
9. Public awareness campaigns on wetlands
10. Mainstreaming of wetlands into production sectors
11. National Wetland Committee formation

2.1.2 Ground Water

Groundwater exists in the sediment pores and crevices, shallow and deep aquifers. Based on the geological formation, the groundwater distribution varies across the country. Tarai, the southern low-land plains, has productive aquifers and has a tremendous potential of groundwater resources. Groundwater resources have not yet been investigated in detail in the hills and mountains of Nepal, however an annual groundwater reserve in these regions are estimated as 1713 million m^3. The southern Tarai region of Nepal is expected to have 5-8 times more water resources than in the hills and mountains. Various studies have estimated groundwater reserve or annual recharge ranging from 8800 to 11,600 million m^3 in Tarai region.

2.1.3 Glacier, Snow and Ice

These represents the solid form of water (Figure 7). The meltwater contributes to the recharge of groundwater and surface flow. They are considered as a reliable source of water during low flow season (Bolch, 2017). Nepal Himalaya hosts a total of 3,252 glaciers covering 5,323 km^2 glacier surface area and 481 km^3 of estimated ice reserves (Bajracharya et al., 2011) (Table 4).

The annual mean flow from the snow-fed major rivers (Koshi, Narayani, Karnali, and Mahakali) of Nepal is estimated about 4,979 m^3/sec. This amount is about 70% of the total annual surface runoff. About 60-85% of the annual surface runoff occurs during the summer monsoon months (June-September).

Figure 7: Ice and snow, an important source of water (Photo: Sudeep Thakuri, 2015)

Table 4: Distribution of glaciers in the river basins of Nepal (Bajracharya et al., 2011)

Basin	Number of Glacier	Total Area (km^2)
Koshi	843	1180
Narayani	1337	1800
Karnali	1461	1120
Mahakali	267	112
Total	3808	4212

2.2 Water Uses

Water use describes the total amount of water withdrawn from its source to be used. Water is used in every activity, such as agricultural, industrial, household, recreational, and environmental activities.

The most common types of water use are:

- Hydropower
- Irrigation
- Domestic and public use
- Rural use (domestic and livestock)
- Industrial use
- Cooling
- Waste and wastewater disposal
- Navigation
- Recreation
- Fisheries
- Wildlife and nature preservation

Virtually all of these human uses require freshwater. Broadly, the uses of water are divided into two categories (Figure 8):

a) Consumptive
b) Non-consumptive uses of water

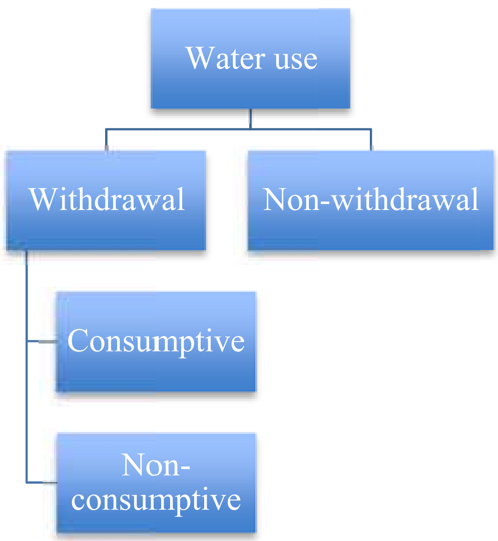


Figure 8: Water use

- A distinction can be made between consumptive demand (for households, industries and agriculture), and non-consumptive demand (for habitat preservation, fisheries, navigation, and salinity control at the river mouth)

Consumptive Use

- Water use that permanently withdraws water from its source; water that is no longer available
- Water consumption is the portion of water use that is not returned to the original water source after being withdrawn because it has evaporated, been transpired by plants, incorporated into products or crops, consumed by people or livestock, or otherwise removed from the immediate water environment.

Non-consumptive Use

- Water withdrawn for use that is not consumed e.g., water withdrawn for the purpose such as hydro-power generation, boating where the water is still available for other use at the same time

Withdrawal Use

- Withdrawal uses from diversion of water from groundwater or surface water such as hydropower, irrigation, domestic, rural, industrial and commercial water supply and cooling.

Non-withdrawal Use

- Non-withdrawal uses are onsite uses such as navigation, fisheries, wildlife, water based recreation and wastewater disposal by dilution

2.3 Water Demand

The demand of water is the amount required for a given purpose, for example, litre per person per day, or mm per crop. The demand can be present or future, and it can be actual (i.e., related to an available infrastructure) or potential (assuming full infrastructural development and no raw water shortage).

Types of Water Demands

- Domestic water demand
- Industrial water demand
- Institutional and commercial water demand
- Fire demand
- Demand for public uses
- Compensate losses in thefts and waste

Access to water for drinking and sanitation is the first priority of the country (Box 3), however two million people in Nepal have no choice of water. They get from where they can. Nepal's extreme landscape presents a range of challenges, such as remote sources, contamination, dwindling supplies of water.

Box 3: Water priority for different purpose

The Water Resource Act 1992 (2049 BS) determines which uses of water are given priority and in what order. The use of water for drinking and domestic purposes is given first priority. The priority given to the different uses of water is set out in Section 7 of the Water Resource Act 1992 (2049 BS) as follows:

Priority 1. Drinking water and domestic use

Priority 2. Irrigation

Priority 3. Agricultural use such as animal husbandry, fisheries

Priority 4. Hydroelectricity

Priority 5. Cottage industry (e.g., water mill or grinder), industrial enterprises and mining

Priority 6. Navigation

Priority 7. Recreational use

Priority 8. Other uses

Hydropower

In 2009, the total dam capacity was 85 million m^3, although the potential exists for at least 138 km^3. Hydroelectricity accounted for more than 96% of total electricity generation. The two main diversion barrages are the Koshi and Gandaki reservoirs.

Aquatic Ecosystem

Aquatic ecosystem plays an important role in cycling of chemical substances and influences the growth and activities of terrestrial ecosystems.

They are classified into three categories

a. Inland water: Water found on surface of the land in rivers, streams, lakes, pond, artificial construction and so on is called inland water. Inland water habitats are grouped as,
    1. Lentic habitats or standing water
    2. Lotic habitats or running water

b. Ocean water (salt)

c. Estuarine water (not as salty as ocean water but more than fresh water

Aquatic biodiversity of Nepal is insufficiently known. Data are available only of the large species.

- Maha seer, Katle fish
- More than 100 dolpins
- Gharial and Magar
- Habitat of large migratory and local bird species

3. Water Issues

Water resources issues are related to both quality and quantity of water, and its demand and supply. The presence of a large amount of water in a place cannot contribute benefits to the society; it should be present where it is needed. The available water should be portable i.e., good quality. Both the natural and human activities result to changes in the quality. Water issues in Nepal includes pollution and contamination, scarcity, floods, and siltation, etc.

3.1 Water Pollution

Water quality is determined by the physical and chemical composition of water. The constituents of water are generally grouped into several groups, namely (Domenico and Schwartz, 1990):

a) Major constituents: 7 constituents comprising > 99% of the TDS. Their concentrations exceed 5 mg/L

b) Minor constituents: 0.01 – 10 mg/L

c) Trace constituents: < 0.1 mg/L

Deviation from these composition of water can be regarded as pollution. Increasing pollution in both surface and groundwater is experienced in the country. Water bodies, located or passing through human settlements and urban areas are highly disturbed and polluted. For example, rivers in Kathmandu valley and other major cities in Nepal are with degraded water quality. Several studies on water quality has been conducted in Nepal, but most of them are focused on drinking water and the rivers in urban area. Some studies addressed water quality of rivers and lakes (e.g., Kannel et al., 2007; Kannel et al, 2008; Babel et al., 2011). The studies show even contaminations of *Escherichia coli* in the water used for drinking and sanitation (e.g., Rai et al., 2009). The presence of E. coli in several sites in Nepal indicates worse situation of the portable water.

The surface water and groundwater sources are deteriorated, especially in urban areas. A growing pressure on some rivers and mainly groundwater resources are experienced in some part of the country due to lack of management and increasing demand of irrigation systems. Extraction of groundwater is rising to meet the growing water demand of the population.

3.2 Water Scarcity

Freshwater Scarcity ranks among the most urgent environmental challenges of this century. Every place of the earth has a fixed quantity of water and not uniformly distributed. About one-fifth of the world's population does not have access to safe drinking water. Moreover, the quantity of freshwater is diminishing due to over harvesting and the changes in environmental conditions. Water stress or water scarcity occurs when the water demand exceeds the available water amount during certain period resulting to restricted use of water. The scarcity of water can exist due to population growth, over-exploitation, and inaccessibility. Furthermore, water scarcity can be introduced in the area having high evaporation and low precipitation.

Despite a large volume of water availability in the country, water in various parts of the countries, including large cities and villages, are in constant short supply. Demand for more water is increasing due to the increased population as well as the living standards. The problem of water scarcity in Nepal is attributable to inequitable access to the resource. Poor water management, poor infrastructure, and high population growth can exacerbate the availability of water.

Water Stress refers to economic, social, or environmental problem induced by water scarcity. Water stress is assessed using different indicators. The indices existing can be broadly categorized into the following classes:

i. Indices based on human water requirements

ii. Water resources vulnerability indices

iii. Indices incorporating environmental water requirements

The environmental water stress indicator considers water required for the maintenance of freshwater-dependent ecosystems per river basin.

Box 4: Water stress indicators

Defines the relationships between the water use and water availability.

i. Relative Water Stress Index (RWSI): This index represents domestic, industrial and agricultural water demand per available water supply. Total water use is divided by water supply during the same period to get an index of "local relative water use".

RWSI = water demand/water supply

ii. Index of Total Actual Renewable Water Resources (TARWR): The annualized total actual renewable water resource is the theoretical maximum annual volume of water resources available in a country. TARWR is calculated from a) sources of water within a country, b) water flowing into a country, and c) water flowing out of a country (treaty commitments).

TARWR (km^3 /yr) = (External inflows + Surface water runoff + Groundwater Recharge) - (Overlap + Treaty obligations)

Every country has a more or less fixed amount of internal water resources, defined as the average annual flow of rivers and aquifers generated from precipitation. Overtime, this internal renewable supply must be divided among more and more people, eventually resulting in water scarcity.

Per capita water used in Nepal is 359 m^3/year. This quantity is very low compared to per capita availability of water. A surplus of water is not used and is free-flowing out of the basin. Low access to water sources, less investment in developing water related infrastructures, inadequate water quality, inefficient water use, and leakages are identified as major causes for a low water use per capita.

3.3 Floods and Sedimentation

The southern parts of Nepal are prone to flood hazards. Every year, several flood events are affecting the area through loss of lives and properties. Due to topographic and geographic fragility, sedimentation is one of the main issue of the country. Due to lack of long term data, it is difficult to quantify sedimentation situation. The lakes like Phewa, Begnas, Rara, Shey Phoksundo has sedimentation issues and thus, shrinking the lake volume. It has impleaded to the maintenance of ecology and existence of lake themselves. In long-run such lakes can disappear. The Phewa Lake located in Pokhara, is highly affected by the siltation from surrounding areas of the watershed. The human disturbance due to agriculture and infrastructure development in the Phewa watershed contributes sediment load to Harpan Khola that is resulting to surface area and depth shrinkage of the lake.

3.4 Water Supply and Sanitation

Access to safe drinking water supply is an important indicator of quality of life. In 2011, less than half of the population used piped water supply (47.8%). The proportion of population with access to piped water supply is 59.2% in urban and 44.1% in rural areas.

Table 5: Sources of drinking water for urban and rural areas (CBS, 2012)

Drinking water source	Total HH*		% of HH in Urban/Rural		% of HH in Ecological Belt		
	Number	%	Urban	Rural	Mountain	Hill	Terai
Tap/piped	2591379	47.8	59.2	45.1	76.5	72.0	19.3
Tubewell/ handpump	1904965	35.1	24.5	37.7	0.0	3.1	72.3
Covered well/kuwa	132870	2.4	3.4	2.2	0.7	3.5	1.7
Uncovered well/kuwa	255658	4.7	1.6	5.4	3.0	6.2	3.5
Spout water	311394	5.7	2.9	6.4	16.1	9.2	0.7
River/stream	60580	1.1	0.3	1.3	2.6	1.6	0.5
Others	132551	2.4	7.4	1.3	0.5	3.9	1.2
Not stated	33900	0.6	0.7	0.6	0.5	0.5	0.7
HH number	5423297	100	1045575	4377722	363698	2532041	2527558

**HH = Households*

3.5 International Water Issues

Most of the rivers flowing to and from Nepal are transboundary rivers. For example, large part of the Koshi River basin falls in the Tibetan part of China and flow to the south into Ganges in India. Flood and sedimentation in the rivers, water sharing, and upstream-downstream linkages are some of the potential areas of international water issues. The adjoining countries should work in collaboration and cooperation to address these issues.

4. Climate Change and Water Resources

Pressures on water resources are increasing mainly as a result of human activity - namely urbanisation, population growth, increased living standards, growing competition for water, and pollution. These are aggravated by climate change and variations in natural conditions. Water sector is considered the most hit by the climate change and thus, considered water resources, the most vulnerable to changing climate (Babel et al., 2014) (Table 6).

Existing studies (e.g., Kattel et al., 2013; Salerno et al., 2015) indicates that the climate of the region is changing. Analysis of recent climatic trends reveals a warming trend for most part of the country in recent decades. Climate change scenarios for Nepal across multiple general circulation models meanwhile show considerable convergence on continued warming, with country averaged mean temperature increases of 1.2°C and 3°C projected by 2050 and 2100.

Warming trends have already had significant impacts in the Nepal Himalaya - most significantly in terms of glacier retreat and significant increases in the size and volume of glacial lakes (e.g., Thakuri et al., 2014; Thakuri et al., 2016), making them more prone to Glacial Lake Outburst Flooding (GLOF). Continued glacier retreat can also reduce dry season flows fed by glacier melt, while there is moderate confidence across climate models that the monsoon might intensify under climate change. This contributes to enhanced variability of river flows. A subjective ranking of key impacts and vulnerabilities in Nepal identifies water resources and hydropower as being of the highest priority in terms of certainty, urgency, and severity of impact, as well as the importance of the resource being affected.

Table 6: Potential climate change impacts in water resource of Nepal

Terrestrial Components	Climate Change Impacts
Glaciers and snow	Melting glaciers and snow rapidly and temporarily increasing stream flow
	Formation of glacial lakes; Increased risk of GLOFs and avalanche
	Changes in snowfall time and quantity, shift in snowline, changes in precipitation phase (snow to water)
Permafrost, baresoil, rocks	Degrading permafrost due to increased temperature
	Increased rock falls due to degrading permafrost
	Increased soil erosion and rock weathering
Alpine grasslands	Forage stock decreases due to the early melting of snow in high alpine grassland/meadows
	Disappearance of local species, increase of invasive species of plants and shifting of grassland-forest ecotone
Forest and grassland	Shift in habitat of wildlife, impact in wildlife migration
	Infestation of new diseases in species
	Declining recharge capacity of forest and grasslands
Water bodies (rivers, streams, springs, wetlands)	Changes in the water flow in stream and rivers during winter
	Reduction in ground water recharge
	Increase in evaporation; decrease in water storage capacity
	Drying up of streams and spring due to increased time and effort for collecting portable water
	Inadequate water supply systems in the uphill mountain slopes due to declining water recharge capacity of forested land or drying up of water springs sources
	Shifting and reduction in the number of water springs sources due to increase of temperature and drought prevalence, erratic rainfall and increased runoff
	Decline in water quality, especially due to increased soil erosion and intensive use of pesticides and insecticides (to compensate the loss due to the less water available for irrigation)
	Loss of water aquatic animals and shift of habitat
Agriculture	Increased dryness of land, less moisture content resulting in declining agriculture productivity
	Change in fruiting time of crops, loss in production of crops
	Shifting of crops towards higher elevations
	Insufficient water for irrigation purpose, affecting cropping calendar and agriculture productivity
	Increased soil erosion due to erratic rainfall
Human settlement	Increased incidence of flooding, debris flow, landslides, and droughts;
	Severe cold during winter and severe hot during summer

The most critical impacts of climate change in Nepal can be expected on its water resources, particularly glacial lakes, and hydropower generation. Water supply infrastructure and facilities are at risk from increased flooding, landslides, sedimentation and more intense precipitation events (particularly during the monsoon) expected to result from climate change. Greater unreliability of dry season flows, in particular, poses potentially serious risks to water supplies in the lean season. Hydroelectric plants are highly dependent on predictable runoff patterns. Therefore, increased climate variability, which can affect frequency and intensity of flooding and droughts, could affect Nepal severely. GLOF and increased run-off variability threatens the potential for hydropower generation. GLOFs have already been associated with the loss of a newly built multi-million-dollar hydropower facility in 1985, as well as significant loss of other infrastructure such as bridges, roads, livelihoods, and human life. Given that Nepal's electricity infrastructure heavily relies on hydropower - nearly 91% of the nation's power comes from this source – a reduced hydropower potential might imply that Nepal will have to seek for alternative sources of power generation, including from fossil fuel sources. In other words, failure to adapt to climate induced risks to hydropower might also be critical from the perspective of greenhouse mitigation. However, uncertainties in climate projections and lack of reliable hydrological records remain an important constraint for effective anticipatory planning.

The changing climate deteriorates water quality of rivers and lakes (Chen et al., 2015). Warming climate affects geochemical processes of waters and lake sediments through glacier melting, soil erosion, and sediment flux. Water quality is an essential issue for the inhabitants around the Himalayan area. The water quality in the region is threatened by climate change as well as by human activities. Global warming is releasing increasing amounts of carbon matter from permafrost into waters and then into the atmosphere. This will intensify the regional and even global climate change. It will affect livelihoods, rangeland degradation, desertification, the loss of glaciers and more.

5. Policy and Management Efforts

This section presents the policy and legal arrangements that are relevant for conservation and management of freshwater, including wetland and biodiversity.

The Government of Nepal (GoN) has prioritized management of water resources on a basin-wise approach by endorsing the National Water Plan (NWP) in 2005 that is an effort to operationalize the Water Sector Strategy (2002). In the NWP, the The Integrated River Basin Management (IRBM) was officially embraced by the GoN for the management of water resources in river basins. The main objective of the NWP is to contribute in a balanced manner to the overall national goals of economic development, poverty alleviation, food security, public health and safety, decent standards of living for the people and protection of the natural environment.

Further, the GoN has endorsed and currently, at the end of implementing Sacred Himalayan Landscape (SHL) strategic plan (2006-2016) to develop the SHL as showcase for a climate resilient landscape. Under the leadership of Water and Energy Commission Secretarial (WECS), Koshi River basin in the SHL was selected to present as a model for the IRBM. In 2015, WECS initiated a process for preparing river basin plans for selected rivers (Upper Karnali, Kali Gandaki, Babai, and West Rapti) in Nepal to utilize water resources in a sustainable manner with due consideration to environment and aquatic ecosystem. It is also preparing to develop integrated river basin development plan for the major river basins in Nepal. Furthermore, the Bagmati

River Basin improvement project financially supported by Asian Development Bank (ADB) and the Government of Nepal (GoN), WECS is also stepping towards developing Bagmati river basin decision support system, flood forecasting and early warning system, and water quality monitoring system and preparing the integrated basin master plan.

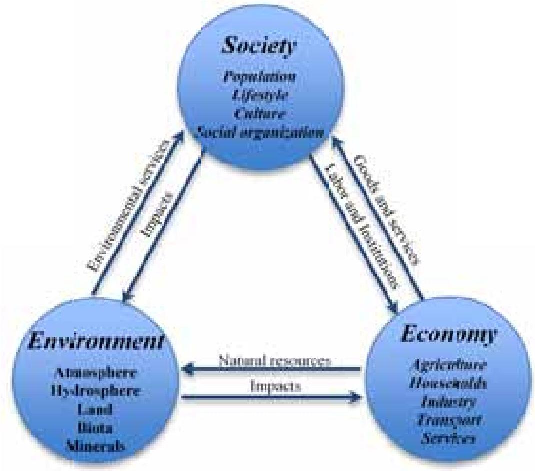


Figure 9: Three pillars of Integrated Water Resource Management (IWRM). The IWRM, a holistic approach, is evolving as a widely-accepted framework for water resource management in recent years.

Water Use Master Plan (WUMP), an integrated approach to the management of water resources and uses, is developed by the HELVETAS under the Swiss Cooperation Project in Nepal. WUMP is a planning tool and process similar to a Participatory Rural Appraisal (PRA) using some of its instruments. It is a tool that has been developed based on a series of experiences and it can be adapted to different contextual situations.

Box 5: Water-related policies and regulations of Nepal

1. Water Resources Act, 1992
2. Water Resources Regulation, 1993
3. Water Resources Strategy of Nepal, 2002
4. National Water Plan, 2005
5. Koshi River Basin Management Strategic Plan (2011-2021)
6. Sacred Himalayan Landscape – Nepal
7. Nepal Biodiversity Strategy, 2002
8. Forest Act, 1993
9. Forest Regulation, 1995
10. Department of National Park and Wildlife Conservation Act, 1992
11. Local Self-Governance Act, 1999
12. Climate Change Policy 2011
13. Electricity Act, 1992 and Electricity Rules, 1988
14. Soil Conservation and Watershed Management Act, 1982 and its Regulation
15. Solid Waste Management and Resource Mobilization Act, 1987
16. Aquatic Animals Protection Act, 1960
17. National Wetland Policy, 2003

Some of the identified key management and research recommendations based on the previous discussions are presented below:

Improving Access: To ensure water supply to meet the water demand of people living in the cities and villages, it should be addressed with management of the available water resources. Large-scale multipurpose projects can have efficient supply of water meeting the continuous water demand, while small-scale infrastructure can help meet immediate needs.

Improving Water Quality: Municipal drinking water treatment schemes can address the issues of poor portable water supply. Besides, promotion of local or household scale treatment methods and facilities can support to address immediate problem.

Tapping the Available Resources Locally Available Sources: Rainwater harvesting and reclaiming the used water comes under this plan. Rainwater harvesting is a technique of collecting and storing rainwater into natural reservoirs or tanks for their use. Rooftop harvesting is a method of rainwater harvesting.

Reclaiming or Recycling Water is the process of converting once used water into water that can be reused for other purposes. For example, reuse can include irrigation of gardens and agricultural fields, recharging surface and ground water.

Knowledgebase Development and Climatic Impacts Assessment: We need better quantification, documentation of the available water resources. Uncertainties in climate projections and lack of reliable hydrological records remain an important constraint for effective anticipatory planning. A better management of the water resources is necessary with long-term vision.

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