LAND AND WATER RESOURCE MANAGEMENT IN GAGAS RIVER VALLEY WATERSHED USING REMOTE SENSING AND GIS

Thesis

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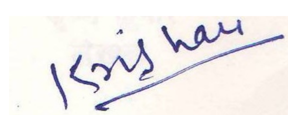
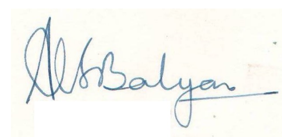


Pantnagar **(Krishan Kumar)**
September, 2016

CERTIFICATE - I

This is to certify that the thesis entitled, "**LAND AND WATER RESOURCE MANAGEMENT IN GAGAS RIVER VALLEY WATERSHED USING REMOTE SENSING AND GIS"** submitted for the degree of **Doctor of Philosophy** in **Irrigation & Drainage Engineering** with minor in **Soil and Water Conservation Engineering** of College of Post-Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of bona fide research work carried out by **Mr. Krishan Kumar,** Id. No. **45851** under my supervision and no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigation and source of literature have been fully acknowledged.



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CERTIFICATE - II

We, the undersigned, members of Advisory Committee of **Mr. Krishan Kumar**, Id. No. **45851,** a candidate for the degree of **Doctor of Philosophy** in **Irrigation & Drainage Engineering** with minor in **Soil and Water Conservation Engineering,** agree that the thesis entitled **"LAND AND WATER RESOURCE MANAGEMENT IN GAGAS RIVER VALLEY WATERSHED USING REMOTE SENSING AND GIS"** may be submitted in partial fulfilment of requirements for the degree.

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Head, Irrigation & Drainage Engineering
(Ex-Officio Member)

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LIST OF ABBREVIATIONS

A	Area
DEM	Digital Elevation Model
E	East
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
F.C.C.	False Colour Composite
G.I.S.	Geo graphical Information System
G.P.S.	Global Positioning System
GRASS	Great Revolutionary American Standard System
ILWIS	Integrated Land and Water Information System
IMSD	Integrated Mission for Sustainable Development
IRS	Indian Remote Sensing
i.e.	that is
J.	Journal
LISS	Linear Imaging Self Scanning
min.	Minute
msl	Mean Sea Level
N	North
No.	Number
RS	Remote Sensing
Sl. No.	Serial number
SOI	Survey of India
Soc.	Society
W	West

LIST OF SYMBOLS

%	Percent
<	Less than
>	Greater than
≥	Greater than or equal to
µS/cm	Micro Siemens per centimeter
C_v	Coefficient of variation
ºC	Degree centigrade
Cm	Centimeter
Ha	Hectare
ha-m	Hectare-meter
Hr	Hour
kg/ha	Kilogram per hectare
kg/m^2	Kilogram per square meter
km	Kilometer
km^2	Square kilometer
K_c	Crop coefficient
m	Meter
m^3	Cubic meter
mg/l	Milligrams per liter
ml	Millimeter
mmhos/cm	Milli mhos per centimeter
mm/day	Milli meter per day
min	Minute
N:P	Nitrogen phosphorus ratio
R	Coefficient of correlation
r^2	Coefficient of determination

1. INTRODUCTION

1.1 General

Population is growing day by day which accounts for increased demand for food grain production. This is hindered by constraints like finite and limited available arable land and water resources. Population pressure coupled with unscientific exploitation and improper management practices have led to depletion of natural resources in the last few decades. There is an urgent need to lay emphasis on raising productivity of the land. By intensifying the land use and by increasing crop yield per unit area, this can only be achieved.

Soil is the upper layer of the earth in which plants grow. The soils support all plants, animals and people either directly or indirectly. Soil loss due to erosion is a continuous process and is directly linked to impairment of soil health that brings down the soil productivity and sustainability. Erosion also takes away 14 million tons of major nutrients every year such as nitrogen, phosphorous and potassium. Particularly red and lateritic soils are prone to this problem. About 16% of land area is considered as wasteland **(Joseph, 2005).**

Soil is the habitat for plants and the plant growth is affected by physical, chemical, and biological properties of the soil. The physical properties viz. size, shape and arrangement of the particles largely determine the manner in which the soil can be used. The nutrient supply to the plants is regulated by chemical properties of soils along with physical and biological properties. Plant growth would cease without these nutrients supplied by the soil or applied as inorganic fertilizers, manures and other vegetative materials.

Macro and micro-organisms dictate the biological properties of the soil. For the right environment and sufficient nutrients to the organisms for optimal biological activity, good physical and chemical properties of soil are needed which ultimately improves soil structure and nutrient recycling. For quite some time ago, there were 16 essential elements for the plant nutrition, but recently the number of essential elements for plant nutrition has been increased to twenty viz. N, P, K, Ca, Mg, Fe, Mn, Cu, Zn, Mo, B, S, Cl, Na, Si, Co, C, H, O and V **(Das *et al.*, 2012)**.

Since, India has agrarian based economy, land evaluation using scientific methods is essential to assess the potential and limitations of a given area for agricultural purposes **(Rossiter, 1996)**. Land suitability is a measure of how well the qualities of a land unit match the requirement of a particular form of land use. The procedure of land suitability classification is the assessment and grouping of certain area of land in terms of their suitability for a defined use.

The rapid changes of land use and land cover than ever before, particularly in developing nations, are often characterized by widespread urban expansion, land degradation, or the transformation of agricultural land to shrimp farming ensuing massive cost to the environment **(Sankhala and Singh, 2014)**. Satellite remote sensing is a potentially sound means of monitoring historical land use/land cover change at high resolution and lower costs as compared to the use of traditional methods **(El-Raey *et al.*, 1995).**

1.2 Watershed Concept

In India watershed management programme was initiated more than four decades ago but the activities have become more significant since 1990s. The issues of enhancing productivity, sustainability, gender mainstreaming, capacity building, and equity concerns have become important.

A watershed is an area drained by a part or whole of one or several given water courses to a single outlet or a common drainage point. It is also referred to as Catchment Area. Watershed is the ridge or the crest line separating two drainage basins (catchments). In hilly regions, the divide lies along topographical peaks and ridges, but in plains, the divide may be invisible or a line on the ground on either side of which falling raindrops will move towards rivers. Roads and rail tracks often follow divides along ridge lines to minimize grades (gradients), and to avoid obstructions like marshes, canals and rivers. For achieving sustainable development and management of natural resources like land and water and for dealing with the impact of natural disasters, a watershed is an ideal unit.

Watersheds could be categorized into a number of groups depending upon the mode of classification on the basis of their size, drainage, shape and land use pattern. The categorization could also be based on the size of the stream or river; the point of interruption of the stream or the river; and the drainage density and its distribution **(Chopra *et al*., 2005).**

Watershed management is the practice of systematically and exhaustively preserving the quality and quantity of the soil and water resources within a drainage basin. It takes care of all the problems in a watershed like changes in land use, pollution and natural variations in the recycling of water and assure a continuing supply of pure water for drinking and other purposes and healthy soil necessary for the support of a watershed's biotic communities.

1.3 Remote Sensing and GIS in Watershed Studies

The remote sensing technology has been accepted as an effective tool in natural resource mapping the world over. Geo-informatics based morphometric analysis is a new technique for watershed management. Geo-informatics is the branch of science which combines Remote Sensing, Geographical Information System (GIS) and Global Positioning System (GPS) (**Bera and Bandopadhyay, 2011**).

1.3.1 Remote sensing

Remote sensing (RS) refers to obtaining information about objects or areas at the Earth's surface without being in direct contact with them. It is a technique to look upon the earth surface or the atmosphere from space using satellites or from the air using aircrafts. Remote sensing is a multi-disciplinary science which combines various disciplines like optics, photography, spectroscopy, photography, computer, satellite launching etc. These technologies act as one complete system, known as Remote Sensing System. Remote sensing imagery has many applications in mapping land-use and cover, soils mapping, agriculture, forestry, deforestation, city planning, military observation, archaeological investigations, geomorphologic surveying, land cover changes, vegetation dynamics, urban growth, water quality dynamics, etc.

1.3.2 Geographical information system (GIS)

Geographical Information System (GIS) combines three terms, viz. Geographical, Information and System. The term 'Geographical'- accounts for spatial objects or features that can be related to a particular location on the surface of earth. Similarly, the term 'Information'- deals with the large data about an object on the earth surface. The term 'system'-is meant for representing systems approach where the complex phenomenon (consisting of a very large number of features/objects on the surface of earth and their complex properties) is broken down into their components for understanding, for management and decision making.

Remote sensing and GIS are integral to each other. Remote Sensing is capable of providing large amount of data of the whole earth very frequently while GIS has capability of analyzing a large amount of data within no time. Manual handling of one-time remote sensing data would take years together, by the time a number of multi date data would have piled for analysis.

Morphometric analysis aids in quantifying and understanding the hydrologic characters and their results constitutes useful input for a inclusive resource management planning. Quantitative description of the basin morphometry requires the description of linear and areal features, gradient of channel network and contributing land slopes of the drainage area. Morphometry is the quantitative analysis of the configuration of the surface of earth, shape and dimension of its landforms (**Clarke, 1966; Babar and Kaplay, 1998; Obi Reddy *et al.,* 2002**). Morphometric study of the drainage basin aims to acquire precise data of quantifiable features of stream network. The natural stream network of drainage basin provides a basic for understanding of initial slope, inequalities in rock hardness, structural control, geological and geomorphologic history.

1.4 Problem and Objectives

Gagas River basin covers an area of 510 km^2 and lies between the latitude 29º 51′ 55′′ N and 29º 35′49′′ N and Longitude 79º 20′ 36′′ E and 79º 33′ 15′′ E in the Almora district of Uttarakhand. Geologically the area is a part of the lesser Himalayan zone.

Appearance of abandoned agricultural land; increasing dependence on rainfed farming systems due to drying of traditional water systems; complete drying-up of Irrigation systems and traditional water sources; decline in net irrigated area; soil compaction and vegetal changes affect water infiltration and surface run-off leading to low soil moisture and flash floods, and decreasing crop production are among the concerns of the Gagas River basin.

Keeping the above points in view, the present study was conducted with following objectives:

1. To study the natural resources of the area for the assessment of nutrient scenario and land use/land cover classification.

2. Morphometric analysis of the Gagas river valley watershed using remote sensing and GIS for hydrologic characters and management planning.

3. Prioritization of sub-watersheds of the study area for development and management of natural resources in different sub-watersheds.

2. REVIEW OF LITERATURE

The scientific database on soil and water resources is prerequisite for its efficient utilization in limited resource areas. In these areas, it becomes imperative to study the soil and land characteristics in a sustained manner. The soils should be used judiciously according to their potential to meet the overgrowing population's demand in the country. The works of previous research on the soil characteristics, watershed management, the application of remote sensing and GIS in management of watershed, morphometric analysis and prioritization of watershed were reviewed and presented here under in relevant sections.

1. Soil infiltration
2. Soil nutrients and plant growth
3. Land use suitability classification
4. Remote sensing and G.I.S. application
   4.1 Watershed management
   4.2 Morphometric analysis and prioritization of watershed

2.1 Soil Infiltration

There are various factors that affect infiltration behaviour of water into the soil. Some earlier research studies, related to this, are given bellow:

Kostiakov (1932) expressed the relationship between cumulative infiltration and time t in the form:

$$I_c = k\,t^n \qquad \ldots\ 2.1$$

Where, I_c = cumulative infiltration,

t = time of infiltration,

k = a constant, k > 0,

and n = a constant, 1 > n > 0

Above equation is not applicable for field conditions at larger value of time. According to this infiltration function, the infiltration rate tends to zero at larger value of time, which is contradictory to what is generally observed in the field. This equation is most commonly adopted due to its simplicity, to represent infiltration when t is small.

Swartzendruber and Olsen (1961) conducted double ring infiltrometer experiments in uniform sandy soil of fine texture and found that with the increase in depth of wetting front one-dimensional velocity was overestimated. On the basis of these experiments they suggested large ring infiltrometer for infiltration measurement to cover large soil area and minimize the replication.

Ram (1972) conducted experiments to assess the values of infiltration constants in above equation given by Kostiakov (1932). He compared the cumulative infiltration obtained from single infiltrometer method and the volume balance method. He found that the value of k by volume balance method was always more but value of n was less than that of cylinder infiltrometer due to true representation of field conditions in volume balance method in irrigated borders, while the ring infiltrometer prevailed only local conditions. For non- vegetated borders, the value of k and n measured by volume balance method lie in the range 0.390 to 0.630 and 0.567 to 0.521, respectively. By single ring infiltrometer method the values of k and n lied in the range 0.30 to 0.48 and 0.63 to 0.59, respectively.

Ghosh (1983) found that Philip's two term infiltration equation sometimes failed to describe field results precisely. Through physically less appropriate Kostiakov equation was advantageous in the sense that it can accommodate a variety of field results. For the case where n was greater than 0.5, the term t^n can be expanded suitably, and if only two terms of this time series were considered, the equation had following form:

$$I_c = k_0 t^{0.5} + k_1 t^{1.5} \qquad \dots 2.2$$

Where, k_0 and k_1 are constants. This equation described the field conditions more precisely than Philip's two term equation.

Ben-Hur *et al.* (1985) studied the effect of soil texture and CaCO3 content on water infiltration rate in crusted soil using rainfall simulator. Two types of soils viz., calcareous soils with a high silt-to-clay ratio (0.82-1.47) and non-calcareous soils with a low silt-to-clay ratio (0.13-0.35), were selected for study. Soil samples having 3-60 percent clay were collected from regions of different rainfall pattern. Distilled water and saline water were simulating rainfall and irrigation, respectively was sprinkled on the soil. The soils were exposed to 'rain' until steady state infiltration and corresponding crust formation were obtained. For both types of soils and for both types of applied water, soils with > 20% clay were found to be the most sensitive to crust formation and had the lowest infiltration rate. With increasing percentage of clay, the formation of crust was diminished as the soil structure was more stable. With soils having clay content < 20%, undeveloped crust was formed. Silt and $CaCO_3$ had no effect on the final infiltration rate for either type of applied water, whereas with saline water, the rate of crust formation increased with silt content.

Agnihotri and Yadav (1995) evaluated the effects of different land uses, viz. agriculture, grassland and afforestation in comparison to untreated ravine waste land susceptible to gully erosion under a semi-arid climate. The infiltration was measured with constant head double ring infiltrometer and the saturated hydraulic conductivities were computed with clay and texture based equations. The difference between the final infiltration rate, observed after 180 min, and the saturated hydraulic conductivity was taken as effect of different land use on the infiltration characteristics of the soils. The saturated hydraulic conductivities calculated by the two methods were comparable for loamy sand soil but different for sandy loam soil. A suppressed the infiltration rate was observed in the ravines forming up and down cultivation practice under grazing and trampling etc. whereas a marginal increase was observed on terraced agricultural lands.

Tanya (2007) reported that, dispersion of soil particles resulting in crust formation on the soil surface was found to be a dominant mechanism reducing infiltration characteristics. Water dispersible clay + silt showed better correlation with infiltration characteristics than total clay + silt. In terms of soil fractions, soil clay, fine silt, coarse silt, very fine sand, and fine sand fractions (< 120 pm) played a plasmic role in soil crust, i.e. filling in pores and restricting infiltration characteristics. At a content of these fractions in soils above ~5%, infiltration characteristics was predictably restricted, while below ~5% it was potentially maximum. High variability in infiltration characteristics of samples with a plasmic fractions (i.e. <120 ppm) content below ~5% indicated that some other fractions may play a primary role in these samples. The < 70 µm fractions appeared to play the most significant role in restricting infiltration characteristics, as at < 2% content of this fraction infiltration characteristics showed a trend of being higher than at > 2% content.

Soil texture played a primary role in crust formation along with EC and ESP of secondary importance. With clay + silt content above 70 %, in the silty loam group, infiltration characteristics were restricted where EC and ESP did not play a significant role. In the sand and loamy sand group with a clay + silt content below 18 %, however, EC and ESP played a significant role. In sand group, soils with high ESP had lower infiltration characteristics than soils with low ESP, gypsum application led to increased infiltration rates.

Osuji *et al.* (2010) carried out infiltration studies of soils with four types **of** land uses in Oswerri, South eastern Nigeria. Four types of land use namely bush fallow, arable crop land, pineapple orchard and continuously cultivated land were considered for study. In the study the highest average infiltration rate of 264 mm/hr was observed under bush fallow land while arable crop land exhibited the least average rate of infiltration of 164 mm/hr. Among treatment means, there was very significant difference (p = 0.01) in the infiltration rates. The coefficient of variation came out to be 3.35%. The relationships between steady infiltration rates and soil organic matter, bulk density and total porosity were in the order r = - 0.963, -0.898 and 0.899, respectively. Bulk density was found to be in negative correlation with the sand and clay per cent, and infiltration rates, respectively. The study indicated an insignificant relationship (p = 0.05) with infiltration rates of the order of r = 0.026 and 0.085. It was recommended that marginal lands, fragile and prone to soil erosion and degradation, be put back to bush fallow for build-up of organic matter.

Adeniji *et al.* (2013) developed a regression model between the soil texture and infiltration rate. After mixing fine and coarse fractions of a soil in seven ratios, (Fine/Coarse), of 100/0, 80/20, 40/60, 50/50, 40/60, 20/80 and 0/100), water was allowed to infiltrate and data on infiltration rate (f) and time (t), since infiltration started, were fitted to a simple polynomial expression:

$$f = at^2 + t + y \qquad \text{….2.3}$$

Where, a and y were infiltration coefficients, the polynomial in t accounted for at least 95% variation in f. The regression analysis was also done for infiltration coefficients a and y as a polynomial in fine fraction (F) of more than 84 % coefficient of determination (R^2).

The model suggested that with known value of fine fraction content alone, the infiltration rate could be predicted at any time or duration of the infiltration, with other factors being constant. Consequently, the model could predict the total infiltration depth by integration of the infiltration rate curve over time.

Jagdale and Nimbalkar (2015) estimated the constant infiltration rates of different soils in Sangola region in Solapur district of Maharashtra (India) under different soil conditions by using double ring infiltrometer method. Six regions i.e. three regions viz., compact, ploughed and harrowed under black cotton soil; two regions viz., unploughed and ploughed under clay soils and one region under sandy soils, were selected for experimentation for measurement of infiltration rate. The measured infiltration rates were compared with infiltration rates obtained from Kostiakov, Modified Kostiakov, Horton's and Green-Ampt infiltration models. Assessment of suitability of the different models for the estimation of infiltration rate was done on the basis of calculation of correlation coefficient and standard error. The study indicated that for all soil conditions Horton's model fitted best with higher degree of correlation coefficient and minimum values of standard error except under ploughed clay soil for which Green – Ampt model suited best.

Hasan *et al.* (2015) developed an infiltration characteristic model for BARI, Bangladesh by using the modified Kostiakov method. The experiments were conducted with the help of double ring infiltrometer. The constant values a, α, and b of the modified Kostiakov equation for accumulated infiltration $y = at^{\alpha} + b$ were 9.12, 0.683, and 0.145, respectively. The average value of percentage of error between the observed and values predicted by the model was 0.134 indicating a close agreement between the model and the field values of accumulated infiltration.

Sinha and Singh (2016) conducted a study at sixteen locations, selected randomly, in Jharia township area of Dhanbad (Jharkhand), to evaluate and relate the steady state infiltration rate with soil characteristics (bulk density, total porosity, organic matter) and soil texture. The infiltration rates were measured through double ring infiltrometer and was mapped by using ArcGIS software under slow, slow to medium and medium classes. The correlation and regression analysis of the data revealed a significant positive correlation with total porosity, sand organic matter, having r = 0.818, 0.811 and 0.573 whereas bulk density, silt and clay were significantly negatively correlated with r = -0.627, -0.693 and -0.444, respectively.

2.2 Soil Nutrients and Plant Growth

Plants require 17 essential elements viz., carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc for growth. These essential elements, also called nutrients, are grouped under three categories. The first group contains three macronutrients carbon, hydrogen and oxygen that a plants can obtain from water, air, or both. The remaining 14 elements are grouped as soil-derived macronutrients (nitrogen, phosphorus, potassium, sulphur, calcium, and magnesium) and soil-derived micronutrients (boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc).

Micronutrients' have also been called minor or trace elements, indicating that their concentrations in plant tissues are much smaller relative to the macronutrients **(Mortvedt, 2000)**. Micronutrients play vital role for the growth and development of crops. The essential micronutrients for field crops are B, Cu, Fe, Mn, Mo, and Zn. The accumulation of these micronutrients by plants generally follows the order of Mn > Fe > Zn > B > Cu > Mo. This order may change among plant species and as per the growth conditions.

Soil characteristics, land use pattern also play a vital role in governing the nutrient dynamics and fertility of soils **(Venkatesh *et al.*, 2003)**. Availability of micronutrients is influenced by their distribution in soil and other physico-chemical properties of the soil **(Sharma and Chaudhary, 2007)**. Micronutrient concentrations are generally higher in surface soil horizons (Ap) and decrease with soil depth.

The optimum plant growth and crop yield depends on the total nutrients and their availability to plants in the soil at a particular time. This is controlled by the physico-chemical properties such as: texture, organic matter and calcium carbonate, CEC, pH and EC of soil **(Bell and Dell, 2008).**

2.2.1 Levels of essential nutrients in soil and their importance for plant growth

Janssens *et al.* (1998) studied the relationship between soil extractable phosphorus and potassium, and plant diversity. The highest number of species was found below the optimum content of the soil for plant nutrition (5 - 8 mg-P/100g). For potassium, large number of species was found at (20 mg/l00g) a value near an optimum content of the soil nutrient. High potassium contents, in contrast to phosphorus contents, were found suitable with high diversity. The factors such as pH, organic matter, total nitrogen and calcium were not found in any relation with plant diversity. Apart from the atmospheric deposits, the $N\text{-}NO_3$ was derived mainly from the fixation of atmospheric nitrogen symbiotically by legumes and from the mineralization of the soil organic matter where the available soil phosphorus, though in small quantities, could be a limiting factor for the $N\text{-}NO_3$ supply. As per this hypothesis, nitrogen would be the main element limiting the plant diversity but the phosphorus would control the availability of nitrogen.

In India, two per cent of 90,000 soil samples were classed as deficient in Mn, 51 per cent were deficient in Zn and 10 per cent in Fe **(Nayyar *et al.*, 2001)**. Moreover, Mn deficiency was also found on sandy acid soils where Fe deficiency was unexpected **(Fageria *et al.*, 2002).**

Gupta (2005) reported that about 48.1 per cent of soils in India were deficient in Diethylene Triamine Penta Acetate (DTPA) extractable Zinc, 11.2 per cent in Iron, 7 per cent in Copper and 5.1 per cent in Manganese.

Oviasogie *et al.* (2007) conducted study for the determination of the levels of some essential micronutrients (Fe, Mn, Zn and Cu) in the soils and growing plants at the base and 25 m away from refuse dumpsites located in Akure, Ondo state, Nigeria using the Bulk scientific GVP 210 atomic absorption spectrophotometer. The concentration of Fe in the roots tissue was highest (142.50 mg/kg dry matter) in *Amaranthus cruentus*. The Fe level obtained at base was higher than that in the plants 25 m far from the dumpsites. The identical distributions of Mn, Zn and Cu were observed in different tissues of the plants around the dumpsites. The study also revealed that the accumulation or uptake of the micronutrients depended on the availability of these metals as enriched metals at the base of the dumpsites, along with other factors, not considered in the study.

Singh (2008) reported that 49 per cent of Indian soils were potentially Zn deficient, 12 per cent Fe, 5 per cent Mn, 3 per cent Cu and 33 per cent B (boron) deficient. The deficiency in Zinc was prevalent in the South, followed by the North, and it was least in the West.

Agarwal *et al.* (2013) studied the soils of Western Plateau Zone of Jharkhand for distribution of macro and micronutrients viz. N, P, K, S, Fe, Mn, Zn, Cu and B including soil acidity and organic carbon content. Available Fe, Mn and Cu were sufficient in all the districts under study. Boron and Zn deficiency was found to an extent of 63.3 and 4.4 percent, respectively. Phosphorus and sulphur deficiency was found to be 57.7 and 37.7 percent, respectively. Soil acidity was the major constraint. A considerable area (37.8 per cent of total geographic area) of the zone was found under very strongly to strongly acidic followed by moderately to slightly acidic (37.5 per cent of total geographic area). Organic carbon status was medium to high. Only 27.8 per cent area of the zone was found under low (<0.5%) category. Application of Lime + FYM to neutralize soil acidity, adequate phosphorus and sulphur fertilization and micronutrient application particularly Boron and Zinc were recommended for the zone.

Fayed and Rateb (2013) conducted a study to recognize and compare the impacts of different cropping systems for twenty years on some chemical and physical properties and fertility status of some alluvial soils at El-Behera Governorate, North West of Niledelta. The studied soils are generally characterized by clay and clay loam texture with bulk density (D_b) ranging from 1.18 to 1.35, 1.45 to 1.62 and 1.26 to 1.39 Mg/m^3, hydraulic conductivity (K_s) values ranged from 0.58 to 0.73, 0.29 to 0.39 and 0.55 to 0.62 cm/hr in surface, subsurface and deep horizons, respectively. Subsurface layer (25 - 50 cm) in the studied soil profiles was having relatively higher values of clay per cent and bulk density (D_b) while it had lower values of hydraulic conductivity (K_s) comparing with those of the upper and deeper horizons. The studied soils were having moderate contents of available macro and micro nutrients. As for the effect of cropping systems on soil properties, data exhibited that soils cultivated with vegetables showed a relatively higher values of fine fractions percentage, hydraulic conductivity (K_s), soluble salts, organic matter content, available macro nutrients (K and N) and micronutrients (Fe, Mn, Cu and Zn) at the surface horizon than those cultivated with field crops. They concluded that, intensification of vegetable's cultivation led to improved soil physical properties with increased OM content and available macro and micronutrients in the surface horizons.

2.2.2 Relationship among the soil properties and available nutrients

Lindsay (1972) reported that level of Cu in soil decreased with increasing pH due to stronger adsorption of Cu to soil particles. Some studies revealed that organic carbon had a positive effect on total Zn and Fe **(Arunachalam and Mosi, 1973). Frank *et al.* (1976)** reported that organic carbon predominantly controlled the distribution of micronutrients in soils. Some researchers have reported that organic C has a positive effect on available Zn, Cu, Mn and Fe **(Katyal and Sharma, 1991).**

A significant relationship between available P and organic carbon in Himachal Pradesh soils was reported by **Varma *et al.* (1991). Pandey *et al.* (2000)** reported a significant positive correlation between available P and soil pH. The same relation was also reported between P and organic carbon in some soils of central Uttar Pradesh.

Pandey *et al.* (2000) and **Sakal *et al.* (2001)** observed a significant and positive correlation between sulphur and EC. They indicated that with the increase in EC, the amounts of sulphate salts were also increased. **Bhatnagar *et al*. (2003)** reported a positive significant correlation between organic carbon and available S in some soils of Madhya Pradesh, Himachal Pradesh and Jharkhand. **Abhinaya *et al.* (2006)** found a highly significant and positive correlation (r = 0.496) between available sulphur and EC.

Yadav and Meena (2009) reported that soil properties (silt, clay, organic carbon, CEC, free $CaCO_3$ and soil pH) influenced the availability of micronutrients. Availability of micronutrients increased significantly with increase in organic carbon and clay content due to formation of chelates / complexes whereas, their availability reduced significantly with the increase in $CaCO_3$ and soil pH.

Wu *et al*. (2010) reported that the total Cu content was significantly and positively correlated with soil organic matter, total nitrogen, available phosphorus, available potassium and cation exchange capacity of soil, whereas, it was significantly and negatively correlated with soil pH.

Abreha *et al*. (2012) conducted a study in the Tsegede highlands of Tigray Region, Northern Ethiopia for determining the changes in the physical and chemical attributes across three adjacent acidic soil sites of different elevation and with three different land uses. Results of surface layer soil samples showed significant ($P \leq 0.05$) correlation of soil bulk density, organic matter (OM) and total nitrogen (N) with elevation. In the lower elevation site, soil OM content declined by about 43 and 52 % as compared to that of the two higher elevation sites. Forest soils were found less acidic in comparison to the cultivated and grazing lands. The organic matter content of the cultivated land soils was significantly lower (by about 25 and 35 per cent) than the grazing and forest land soils, respectively. Altitude did not affect the soil acidity. In contrast to altitude, land use type significantly affected not only the soil acidity but also the parameters related to soil fertility like organic matter, total N and available phosphorus. On the basis of their study they suggested that along with usual acid soil management and/or reclamation practices, the introduction of proper land use management systems was of paramount importance.

Tuma *et al.* (2013) conducted a systematic soil survey in the Ethiopian Rift. Samples were randomly collected from different land uses and analysed. The results showed that the concentration of micronutrients namely iron, manganese, zinc and copper varied from 6.41-40.25, 0.87 to 13.09, 0.65 to 1.27 and 0.50 to 1.75 ppm, respectively, for the surface soils following the order iron > manganese > zinc > copper in almost all land uses. Organic matter, iron, manganese, zinc, copper, nitrogen, phosphorus and potassium contents were observed at low concentrations in agricultural lands as compared to natural forests. Iron was in negative correlation with manganese; manganese negatively correlated with zinc; copper positively correlated with iron, manganese and zinc; and iron was positively correlated with zinc. Available iron, zinc and copper were negatively correlated with soil pH; manganese and copper were in positive correlation with silt. Iron, copper and zinc were in positive correlation with organic matter. The rest of physico-chemical properties of soil were either negatively or positively correlated with available micronutrient.

2.3. Land capability classification

For assessment of land suitability for arable crops, grazing, forestry, etc., the USDA land capability classification serves as a reference tool. Though majority of lands are not being used as per their capabilities, land capability classification in those areas helps in providing warning signals/ precautionary measures to sustain existing land use.

Tejwani and Dhruvanarayana (1961) proposed a soil conservation plan based on different capability classes. Class I lands needed no conservation measures. In Class-II lands, contour bunding and measures like contour cropping and strip cropping were suggested. Class III and IV lands needed peripheral bunding and safe outlets for the discharge of excess run-off, clearing and minor levelling on gully sides and beds, putting up of check-dams, brick masonry across the gully beds, good crop rotations, heavy application of manures and fertilizers for improving soil fertility, etc.

Murthy *et al.* (1968) recommended the construction of bench terraces with protected disposal drains for reducing the run-off velocity and checking the degree of erosion in sloping lands and used land capability classification system for sound watershed planning. For watersheds having moderately good to fairly good cultivable land with limitations of texture, soil depth, slope, wetness and erosion problems these measures proved to be promising remedy. The non-arable lands were moderately to well-suited for grazing or forestry due to wetness and soil erosion hazards.

Anderson *et al.* (1976) carried out land use and cover classification system for use with remote sensor data. The IRS data with different spatial resolutions for LISS II and LISS III, was used for delineation of land use/land cover categories up to level-II. Classification was based on Level I with typical data characteristics LANDSAT (formerly ERTS) type of data Level II High-altitude data at 40,000 ft (12,400 m) or above (less than l: 80,000 scale) Level III Medium-altitude data taken between 10,000 and 40,000 ft (3,100 and 12,400 m) (1:20,000 to 1:80,000 scale) and Level IV Low-altitude data taken below 10,000 ft (3,100 m) (more than 1:20,000 scale).

Walia *et al.* (1987) conducted the soil survey of Bilaspur district of Himachal Pradesh and interpreted soil survey data for land capability, land irrigability classification for optimum land use planning. Soil–physiography relationship was established during detailed soil resource mapping. The texture of soils was dominantly loam/silt loam to clay loam with varying proportions of gravel. The soils were rich in organic matter and slightly to strongly acidic in reaction. The distribution of soils in the watershed was related to physiography, land use/land cover, slope and aspect.

Madhavan and Khire (1992) carried out a case study on land use/land cover Mapping by visual interpretation of X-band Synthetic Aperture Radar (SAR) image and an IRS-IA satellite data of the Godavari in the eastern coastal of the Idian peninsula. Comparative studies indicated that SAR data were more useful than IRS-1A data in the visible and infra red ranges, mainly because of their fine resolution and the texture of the image but IRS-1A data were found to be more economical in comparison to SAR.

Rajinder Kumar *et al.* (1995) advocated for the adoption of suitable conservation measures based on land capability. This approach led to runoff decline from 65 to 30-34 per cent and the soil loss dwindling from 22.5 t/ha to about 3-4.3 t/ha in a 26 ha agricultural watershed in HPKV, Palampur farm.

Jaiswal *et al.* (1999) studied land use/ land cover chaanges over a period of 30 years, using remote sensing technique in a parl of Gohparu block, Madhya Pradesh by visual interpretation of remotely sensed data. The analysis revealed that synergistic use of SOI toposheet and remote sensing data can be conveniently used to detect the changes in land use/ land cover.

Sheng (2000) introduced a 'Treatment Oriented' land capability classification scheme for the development of hilly watersheds in the humid tropics. Its advantages, applications, and experiences are reviewed. Emphasis is put on field-level applications. Expert systems have been developed to facilitate field classification work. Explanations of procedures are given. It links capability classes to land treatments and conservation needs.

Patel *et al.* (2001) undertook a study in Solani watershed of Uttarakhand and Uttar Pradesh, using remote sensing and GIS approach, for assessment of the land capability in order to adopt the suitable soil conservation measures and the appropriate land uses. Thematic maps of soils, slope and land use were generated from remotely sensed data, SOI toposheet along with field survey. The basic resource maps like composite land use and land capability were generated by integration of thematic maps in GIS environment. Current composite land use (*kharif* + *rabi*) and land capability maps were used to frame suitable criteria to prepare land use adjustment plan for the appropriate soil conservation needs and land utilization in the Solani watershed.

Rodriques *et al.* (2001) used land capability classification approach and Geographic Information System for watershed planning in Brazil. The application of soil erosion models, like the Universal Soil Loss Equation (USLE) through GIS to predict soil loss and to assess crops and soil management was effectively used to elaborate soil erosion inventories by integration of physiography, soils, land use/land cover, slope map layers and land evaluation.

Sarkar *et al.* (2002) placed the high hill soils such as *Humic Dystrudepts* and *Humic Hapludults* in the land capability sub-class VIes due to the very steep slope, very severe erosion, low moisture holding capacity and high soil acidity while the foot hill soils (*Typic Palehumults*) into capability sub-classes IIIes and IIsw. The enrichment of clay content in lower horizon was due to illuviation or vertical migration of clay.

Sushil Pradhan (2002) used remote sensing to carry out **r**egional land cover mapping of the Hindukush-Himalayan (HKH) region using satellite image: The study acquired 12 scenes of the WiFs satellite data covering the whole HKH region. After the scenes were rectified and geometrically corrected with ground control points (GCPs) of defence mapping agency aerospace center (DMAAC), Missouri, USA, the verification of GCPs was done in the Operational Navigation Chart (ONC) of scale 1:1000,000, and same locations were also identified on the images and registered. Overall root mean square error (RMS) was limited within a pixel. Then it was re-sampled to pixel size 180m x 180m to maintain the original DN of pixels. Landsat TM data was used for the identification of different types of agricultural land use and forest which produced precise results, but the Landsat Data cost was 20 times more than that of the IRS-WiFs satellite data. Therefore, it was opined that WiFs data was good for the methodology proposed for a regional or national scale study. In this analysis, broadleaf forest and coniferous forest were found as the dominating land cover classes, 43.3 and 26.6 percent, respectively. The methodology worked well and recommended to use at a watershed level using medium or higher resolution satellite data.

Durbude (2004) analysed the temporal changes in the land use/cover pattern and the ground water availability in the watershed of Ralegaon Sidhi in Maharashtra. The integrated approach of the remote sensing and GIS techniques was used to identify the land use/cover changes during the year 1989 and 2001. Five major land use/cover classes were identified. Agriculture was identified as the major land use/cover unit in the study area, which increased by 8.97 percent over a period of time. He observed rise in the water table by 3 m, this ultimately increased the average depth of water available in the wells from 2.09 m to 6.32 m.

Sharma *et al.* (2004) classified the soils of Neogal watershed area in North-West Himalayas into land capability sub-classes IIIe and III and stated that the CEC in the soils of Neogal watershed in North-West Himalayas ranged from 4.9 to 14.3 c mol (p^+) per kg soil. The difference in CEC between the soils was due to the varied type / content of soil colloids and soil pH values. The characterization of the cultivated soils of the Neogal watershed in North-West Himalayas occurring on river terraces and hill slopes was done. Moderately sloping hill slope soils were classified as Typic Udorthents and of gently to moderately sloping river terraces were classified as Typic Dystrudepts and Typic Hapludalfs.

Shekinah *et al*. (2004) classified the soils of the Sahaspur block of Uttaranchal in to six land capability classes *viz*. class II (good cultivable lands), class III (moderately good cultivable lands), class IV (fairly good cultivable lands), class VI (non-arable lands), class VII (fairly suited to grazing and forestry) and class VII (non-arable lands).

Mahajan and Panwar (2005) used remote sensing and GIS approach to study land use/ land cover changes in Ashwani Khad watershed, located in mid hill zone of Himachal Pradesh. Remote sensing data- Geocoded false colour composite (F.C.C) of bands- 2, 3 and 4 of IRS- lD (LISS II) on 1:50000 scale and Survey of India (SOI) toposheet were used as reference to study the change over a period of 20 years. The results revealed that agriculture area in the watershed increased to 15.39 km^2, whereas forest area and wasteland area decreased by 1.81 km^2 and 13.58 km^2 respectively.

NRSA (2006) published a 'Manual of Nationwide Land Use/Land Cover Mapping using Satellite Imagery'. This manual gave a comprehensive list of land cover types of India and a well suited methodology for preparation of land use maps. A case study for preparation of the Land use map for the Nilgiris was given based on the guidelines in this manual.

Martin and Saha (2009) delineated four major land capability classes *viz.* IIe, IIIes, IVes and Ves in Dehradun district, Uttrakhand. Soil erosion was found to be the major limitation followed by wetness, soil depth, texture and slope. The SOI toposheet and remote sensing data were conveniently used to detect the changes in land use/ land cover.

Sahoo *et al.* (2010) studied eight representative soil profiles from different landforms *viz*. high hill, medium hill, low hill and foot hill slopes of the Langol hill, Imphal, Manipur. High hill soils were moderately shallow to deep and the soil depth showed an increasing trend in medium hill, low hill and foothill slopes. Soils were acidic in reaction with soil pH ranging from 4.35 to 5.80 and 4.10 to 5.65 in the at surface and sub-surface horizons, respectively. Organic carbon content of surface soils was high (22.1 to 39.0 g/kg). Cation exchange capacity (CEC) of the soils was found to be low (10.60 to 19.36 cmol (p^+)/kg). The soils had high available nitrogen content, low available phosphorus and medium to high available potassium. Two types of soil classification i.e., Lithic Dystrudepts and Typic Dystrudepts at high hills and four types of soil classifications viz., Typic Dystrudepts, Typic Kandiudults, Typic Hapludalfs and Typic Kanhapludalfs, were found in soils on low hill and foothill slopes. The soils on medium hill slopes were classified as Typic Dystrudepts. As per land capability classification, soils of high and medium hill were not suitable for arable purposes and require soil conservation measures to control soil loss while soils of low and foot hill slopes were suitable for the arable use.

Patil *et al.* (2010) studied the land capability sub-classes in Lendi watershed of Maharashtra and found that the watershed has moderately good to fairly good cultivable land with limitations of texture, soil depth, slope, wetness and erosion problems. The non-arable land was moderately to well-suited for grazing or forestry due to wetness and soil erosion hazards.

Kumar and Kumar (2011) carried out prioritization study in Sanjai river watershed located in Subernarekha basin under Kolhan Division of Jharkhand using remote sensing and GIS techniques. Saaty's analytic hierarchy process was used for scaling of the weight of different parameters. Composite Suitability Index was calculated for each composite unit by multiplying weightages with rank of each parameter and summing up the values of all the parameters. Categorization of the Composite Suitability

Index was achieved by ranging the Composite Suitability Index into different classes, indicated by amount of limitation acceptable for the specific class.

Zende *et al.* (2013) conducted morphometric analysis using remote sensing and GIS techniques in the sub-river basin of Krishna river, in west part of Maharashtra. For morphometric analysis, the study area was divided into 9 sub-watersheds namely SWS1 to SWS9. The morphometric study show that the drainage density of sub-watersheds was in the range 2.07 for sub-watershed SWS5 to 3.26 km/km^2 for sub-watershed SWS8. The low values of drainage density for sub-watershed SWS5 showed highly resistant and impermeable subsoil material of dense vegetative cover coupled with low relief. The elongation ratio, varied from 0.2 to 0.35, pointing towards low relief and gentle ground slope. The high circularity ratio values (0.6) for SWS8 indicated late maturity topography stage. The minimum compound parameter value of 1.68 for sub-watershed SWS3 and maximum compound parameter 3.08 for SWS 8 revealed highest and lowest priority for watershed management and development measures in sub-watershed SWS3 and SWS8, respectively.

Das *et al.* (2014) carried out a study for characterization and evaluation of land resources of Mawryngkneng block using IRS-P6 LISS III and LISS-IV data. Five major physiographic units viz., structural hills, denudational hills, plateau and intermountane valley were found upon visual interpretation of the satellite data. The results indicated that the area under dense forest, wastelands, open forest, cultivated land, built up land and water body was.32.2, 28.8, 16.1, 13.6, 8.2 and 0.9 % of the total geographical area, respectively. Ten soil series, belonging to 2 orders (Ultisols and Alfisols), 3 sub orders (Udult, Udalf and Humult), 6 great groups and 8 sub-groups, were identified. The soils were moderately acidic, deep to very deep and sandy clay loam to clay in texture, rich in organic carbon with medium to high nitrogen availability. Phosphorus availability was observed as low to medium whereas potassium availability was low in the entire study area. The soils were grouped into land capability class II & III.

Abd-alla (2015) conducted land capability classification study in two desert Oases (i.e. Al-Kharga and Al-Dakhla), located in the western desert of Egypt using remote sensing and GIS. Using SRTM space images, Digital Elevation Model (DEM) was elaborated and spot heights and contour lines, were derived from the topographic maps.

The land resource database so created, was used for evaluation and mapping land capabilities. The studies showed that 24.5% soils of Al-Kharga Oases were highly capable and 19.2% soils of Al-Dakhla Oases belonged to Typic Haplotorrerts and Typic Torrifluvents sub-great groups. The 1.5% of the total area of Al-Kharga Oases represented moderately capable soils and 6.1% of Al-Dakhla Oases belonged to sub-great group soil Typic Torriorthents. The low capable soils represented 36.0% and 20.3% of total area of Al-Kharga Oases and Al-Dakhla Oases, respectively. low capable soils were associated with the soils of Torripsamments great group. The rest of the Oases were considered as non-capable soils or rock land, representing 38.0% and 54.5% of total area of Al-Kharga and Al-Dakhla Oases, respectively.

Appala Raju (2015) studied the land systems, landforms, soils, land use and hydro-geomorphology in Vizianagaram district of Andhra Pradesh using IRS-P6, LISS III data on scale 1: 50,000. The land capability was evaluated based on the physical characteristics and seven classes of land are identified. Soils suitable for agriculture were grouped under classes I to IV and soils which were not suitable for agriculture were grouped into classes V to VII for pasture / forestry / wild life/ recreation. Class-II, Class-III, Class-IV and Class-VII land capability classes are identified in 3, 4, 1 and 5 mandals out of total 34 mandals, respectively. Four land suitability classes identified in the study area were highly suitable lands, moderately suitable lands, moderately suitable lands followed by unsuitable lands and unsuitable lands.

Mallika *et al.* (2015) conducted a study on Land Capability Classification in University of Agricultural Sciences campus, Raichur and found that the majority of the plots had the slopes in the range from 0 to 1.35 percent it indicated that the soils were less susceptible for erosion and suitable for cultivation. The soil infiltration rates on randomly selected nine plots were found to be in the range of 0.57 to 1.35 cm/hr that fall in low to medium category. The land use capability classification for the area was under two classes of IIIe and IIIes. The total of 164 plots were categorized under IIIe, i.e. moderately susceptible for erosion and 52 plots under IIIes i.e., susceptible for moderate to severe erosion.

Suji *et al.* (2015) carried out morphometric analysis for prioritization of eight sub-watersheds, designated as SW1 to SW8, in Vazhichal watershed of the Neyyar river basin, in Tiruvanathapuram district. Different morphometric parameters were determined for each sub-watershed and rank was assigned on the basis of value/relationship with erodibility for arriving at a compound effect to give final rank to each sub-watersheds. Land use /land cover mapping was done by using IRS LISS IV data. Upon morphometric and land use /land cover analysis the sub-watersheds classification of watershed into five priority levels namely, very high, high, medium, and low, was done for developmental planning. The morphometric based prioritization results indicated that sub watershed SW6 only fell under very high priority, while land use /land cover analysis based prioritization showed that sub watersheds SW2 and SW3 came under very high priority.

Tiruneh (2015) spatially classified the lands of Shinfa watershed in Ethiopia based on their capability for sustainable agricultural use by United States Department of Agriculture (USDA) criteria. Land use and land cover was determined from LANDSAT satellite image by applying the supervised classification method in ENVI 5.0 software. The slope was derived by using Digital Elevation Model (DEM) data of 30 m resolution. "Spatial Analyst Tool Extract by Mask" in GIS environment was used to obtain soil depth and soil texture map of the watershed from Amhara regional digital soil map. The study revealed that 1,540 ha (61.6%), 442.25 ha (17.69%) and 518 ha (20.52%) of the watershed was categorized in the range of land classes I to IV, V to VII and VIII, respectively. It was observed that present land use was not as per the capability of the land.

From the above it may be concluded that land capability classification have been used by many workers as a guide to sustained land uses.

2.4 Remote Sensing and GIS Applications

2.4.1 Watershed management

The Remote Sensing (RS) and Geographical Information System (GIS) have capabilities for easy solution of the problems occurring in the management of land and water resources. Satellite remote sensing technique can measure hydrologic parameters on temporal and spatial scales; the GIS integrates the spatial analytical functionality in order to provide spatially distributed data. Some of the works in watershed management, related to remote sensing and GIS applications are given below:

Cruise and Miller (1993) reported that remotely sensed spatial database could form the basis of appropriate and convenient modelling strategies for hydrologic simulation. Much of the data, necessary for application of watershed model, could be obtained from processed spectral images and digitized topographic and soil information.

Roza (1993) observed the advantages of GIS use in study of agricultural lands susceptible to soil erosion. The Universal Soil Loss Equation (USLE) was the most widely used predictor of soil erosion from agricultural lands. Potential erosion was calculated by multiplying empirically derived regression factors that relate climate and terrain characteristics to erosion.

Raju *et al.* (1995) carried out a study on hydro-geomorphology and lineament for the upper Gunjanaeru river basin, Cuddapah district of Andhra Pradesh. The objective of the investigation was to delineate various geomorphologic units and lineaments for the groundwater development. In land use / land cover studies, it was observed that waste land covered an area of 6025 hectares. The area could be brought under irrigation by providing the appropriate technology of water and soil management. Such an effort would be very beneficial because it doubled the area under irrigation in a zone that was under drought prone area programme.

Taher and Labadie (1996) found optimal design of water distribution network using GIS. A prototype decision support system WADSOP (Water Distribution System Optimization Program) was presented to guide water-distribution system design and analysis for changing water demands, use patterns and timing, and accommodation of new developments. WADSOP integrated a GIS for spatial database management and optimization theory analysis for water engineers with a decision support tool using computers. Improved performance was observed in several comparative studies over published results. A real case study for the city of Greeley water distribution network was also presented.

Biswas and Agarwal (1998) found that an integrated watershed development approach, in Baramasia watershed in the district of Giridih, Bihar, was adopted by the Soil

Conservation Department of Damodar Valley Corporation. Micro level analysis was made to pinpoint the appropriate measures along with fast availability of water resources through the construction of water harvesting structures. After almost all the schemes were implemented successfully, it was observed, that a drastic change had occurred with respect to the land use pattern in the watershed and also in the per capita income. ILWIS version of GIS was used to ascertain reduction in annual and per hectare soil loss through Universal Soil Loss Equation (USLE) method. IRS-IC PAN data along with many basic maps were used for the analysis. The results showed 56 per cent annual soil loss reduction in the watershed.

Abraham and Tiwari (1999) carried out a hydrological study in a lateritic hill slope watershed, a humid tropical region of Kerala, India. The soil moisture properties, hydrologic processes and watershed characteristics, were evaluated. To simulate these hydrological processes, a vertical column, 2-D lateral saturated flow model was developed. This model, calibrated with effective values of specific yield and hydraulic conductivity, was capable of hill slope hydrological process prediction.

Xu *et al*. (2001) integrated a physically-based distributed model with GIS in watershed-based water resources management. This model was selected to demonstrate the spatial database and developed modeling system. The spatial data was first processed by GIS. The model operated at a daily time step on 1 km x 1 km grid squares and simulated important hydrologic processes including evapotranspiration, snowmelt, infiltration, aquifer recharge, groundwater flow, and overland and channel runoff. It was then used to simulate runoff hydrographs. The study demonstrated that the integration of a physically based distributed model was efficiently implemented to the watershed based water resources management.

Singh *et al.* (2002) carried out the prioritisation on the basis of soil erosion from Bata river basin using remote sensing and GIS techniques. Assessment of soil loss was done using **Morgan *et al.* (1984)** model. From soil loss map it was found that the average annual soil loss of Bata watershed was 17.22 t/ha. When expressed in terms of depth, considering bulk density of 1.3 gm/cc, it was found that maximum depth of soil removed by erosion was 72.24 mm/year and average value was found to be is 1.32 mm/year.

Analysis of soil loss among dominant land use type showed that highest soil loss was from barren lands, current fallow and low intensity cultivated land. It was also found that the transport limited soil erosion was high in the agricultural land (79 per cent) and in case of barren lands it was 8 per cent. Detachment limited soil erosion was higher in the forest covered areas. They concluded that the soil loss erosion rate was more sensitive to the land / land cover parameters rather than to the slope steepness parameters. Prioritization showed that nearly 30 per cent of the area fall under high (20-40 t/ha/year) and very high (> 40 t/ha/year) priority classes.

Choi and Bernard (2003) found the real-time watershed delineation (WD) system using Web-GIS. The WD program obtained watershed boundary from point coordinates using a double-seed array-replacement algorithm. The system provided user interface for the selection of an output point from a map displayed in the web browser using map server Web-G.I.S. capacity. For all of Indiana, implementation of the WD and data extraction system with extensive verification was done (with 2082.7 km^2 area of Wildcat Creek watershed, Indiana). The time to obtain results and the quality of results were acceptable for use as a real-time system for WD via the Web.

Wagner *et al.* (2003) studied the characteristics and computational methodologies, for estimation of evapotranspiration in a river basin. The computational methods of Penman-Monteith and the Kimberly-Penman combination evapotranspiration were programmed and tested. The results were then compared to that calculated on the basis of annual basin inflow out of precipitation and import of water. The difference of the annual evapotranspiration quantities for both methods i.e. validating water balance and Penman computation method was found statistically insignificant.

Cho (2004) developed a GIS based water quality model, and to investigate data accuracy and sensitivity analysis with two types of DEM of different scales, 1 to 24000 and 1 to 250000 DEM. The study was accomplished by using the SWAT model, GRASS and Arc-Info. Water quality modelling was done by investigating the sensitivity of two DEMs on runoff volume. Results showed that runoff volume was higher for the l:24000 DEM data, probably due to the finer resolution and slope that increased the estimated runoff from the watershed. It was observed during sensitivity analysis that DEMs had significant effect on runoff volume.

Das *et al.* (2004) proposed a GIS based approach for qualitative assessment of the potential and utilization of ground water resources in Orissa for its sustainable management planning. For their study they considered various indicators of potential assessment parameters viz. depth to water table, geology, rainfall, etc. and utilization assessment viz. number of persons per tube wells or wells indicating domestic use, irrigated areas etc. These were integrated to find out the overexploited areas, deficit areas and problematic areas for conservation of the resources. The results of the study categorized various blocks under different categories of priority for conservation and sustainable management of ground water.

Durbude (2004) studied the temporal changes in the land use / cover pattern and the ground water availability in the watershed of Ralegaon Siddhi in Maharashtra. The integrated approach of the remote sensing and GIS techniques was used to identify the land use/cover during the year 1989 and 2001. Five major land use / cover classes were identified. Agriculture was identified as the major land use / cover unit in the study area, which increased by 8.97 percent over a period of time. He observed a rise in the water table by 3 m, this ultimately increased the average depth of water available in the wells from 2.09 m to 6.32 m.

Jaiswal *et al.* (2004) calculated reservoir sedimentation using remote sensing and GIS techniques. Bila reservoir in Dhasan river basin in Madhya Pradesh was selected to assess the sediment deposition, loss in reservoir storage and the revised cumulative capacity. The live storage capacity of the reservoir was 1845.9 M cu. ft. at 1462 ft with a dead storage of 157.10 M cu. ft. at 1426 ft. The revised live storage capacity of Bila dam was estimated to be 1703.25 M cu. ft., so, the live storage capacity loss was estimated as 142.65 M cu. ft.

Joshi and Gairola (2004) studied the land cover dynamics pattern and topography in the Balkhila sub watershed in Garhwal Himalayas using remote sensing and GIS methods. The land cover dynamics was depended on the aspect because of Sun illumination. The altitude and slope did not influence resource extraction and there was shifting of human activity zone to high altitudes and slopes. These changes were also observed along the roads and settlements.

Katpatal and Dube (2004) carried out a study by using remote sensing and GIS for monitoring and management of Pioli watershed near Nagpur urban area. Geology and geomorphology of this area was found to act as an important factor affecting the conditions and physical processes occurring in the watershed. Different parameters like geology, geomorphology, hydrology, land use / land cover were studied using IRS-LISS-III image of Indian Remote Sensing satellite. Different thematic maps were generated through G.I.S. tool, in ArcINFO software. Drainage analysis was carried out to classify the drainage order of Pioli watershed. Finally, guidelines for the preparation of the water management plan in the urban watershed were presented.

Pandey *et al.* (2004) proposed management options for agricultural watershed using GIS and remote sensing. The investigation revealed that AVSWAT 2000 model accurately simulated runoff, sediment yield and nutrient losses from the studied watershed on daily, monthly and seasonal basis. They observed that rice crop could not be replaced by other crops like groundnut, maize, moong-bean, sorghum and soya bean during monsoon season on the basis of reduction criteria of sediment and nutrient losses. Keeping nutrient losses within the permissible limit, conservation tillage practice along with 80:60 kg/ha of N: P was recommended to reduce the sediment yield by about 5.03 per cent as compared to conventional tillage.

Pramod Kumar *et al.* (2004) conducted a study for developing satellite stereo data for the DEM surfaces and derivatives for Chamba test sites in Uttarakhand. DEMs prepared from various algorithms were analyzed for the accuracy of surface and its derivatives. The correlation coefficient of 0.99 was found for most of the algorithms. Comparison of DEM surfaces and its derivatives was carried out for Nahan and Shimla test sites utilizing SPOT PAN and IRS-IC stereo pair, respectively. Stereo DEM surface derivatives for Shimla and Nahan test sites gave an overall accuracy of 56.50 per cent and 59.20 per cent for the slope; 49.79 per cent and 71.21 per cent for the aspect and 74.15 per cent for the topographic level slicing, respectively.

Murthy (2004) conducted a study for generation of GIS based flood risk hazard maps in Mahanadi delta in Orissa, India. Gumbel's distribution was used to find return period discharges. Geometric features were derived from topographic data and flood risk hazard maps were created subsequently at key return periods. The study concluded that G.I.S. as a tool could be used in the identification of the flood hazard, inundation boundaries and associated potential loss of public service, access problems and potential damages and formulating flood risk management policies.

Singh *et al.* (2004) calculated hydrological parameters for Anas catchment from watershed characteristics. A methodology for estimating the topographical and hydrological parameters from spatial data of a watershed for rainfall-runoff modeling was presented. The digital terrain modelling methods derived from available topographic map features and remote sensing image were compared for their accuracy. Methods for watershed delineation and hydrological parameters derived from raster digital terrain model were also presented. These model parameters included curve number, area, lag time and routing model for stream segments.

Suresh *et al.* (2004) did prioritization of ten sub watersheds of *Tarai* Development Project area using morphometric parameters and assessment of surface water potential on the basis of sediment production rate. Assessment of peak runoff and annual surface water potential was done for effective watershed management. Sediment production rate varied from 2.45 to 11.0 ha-m/100 km^2/year. The land use/land cover data was generated for land and water resources planning and management.

Vijay *et al.* (2004) carried out the land use mapping of Kandi belt of Jammu region. Digital image processing of IRS-1C-LISS-II data was used to map the land use classes in the part of the Kandi belt, the sub-mountain tract lying in the outer Himalaya of Jammu region of Jammu and Kashmir. Supervised classification was combined to delineate various land use in the area. Recognized land uses were forest, agriculture, riverbed, urban, fallow, wasteland and water. Forest was dominant along the upper boundary of the Kandi belt (along Siwalik) and on ridges, whereas, agricultural land was mainly along the lower boundary (Sirowal) of the study area.

Mahajan and Panwar (2005) utilized remote sensing and GIS approach to study land use/land cover changes in Ashwani Khad watershed, located in mid hill zone of Himachal Pradesh. Remote sensing data- Geocoded false colour composite (F.C.C) of bands- 2, 3 and 4 of IRS- 1 D (LISS III) on 1:50000 scale and Survey of India (SOI) toposheet were used as reference to study the change over a period of 20 years. The results revealed that agriculture area in the watershed increased to 15.39 km^2, whereas forest area and wasteland area decreased by 1.81 km^2 and 13.58 km^2 respectively.

Martin and Saha (2007) used USLE model for the estimation of soil erosion, with the integration of GIS and remote sensing, of the watershed having the area of 15000 ha, located in Dehradun valley of Uttarakhand. Land cover map from FCC was generated, using supervised classification module of image processing software. Different soil and land attribute's maps were generated in GIS environment and RKLSCP maps were derived. Integrating these maps, soil erosion map was generated.

Sharma and Thakur (2007) quantitatively assessed the sustainability of watershed development plans for 71 micro watersheds of Khorod watershed, Western India using remote sensing and GIS applications through the quantification of the three major water balance sub-components: evapotranspiration, ground water recharge and surface runoff . The thematic maps were used for the quantifying water balance parameter. The guidelines of the **GWREC report (1997)** were used to estimate aquifer's recharge of ground water. A decrease of 40.2 mm in surface runoff component, whereas increase of approx. 4 mm and 102.3 mm in the ground recharge and actual ET for post- development scenario was observed on annual basis, respectively. The surface water storage also increased from 2l .2 mm to 65.3 mm.

Haris *et al.* (2008) did irrigated crop mapping and delineation of a small watershed for two seasons (*rabi and kharif* using IRS P6 (Resourcesat-I) LISS-4 multispectral imagery. The irrigated crop area was in direct proportion to the bore well yield. The irrigated crop area and bore well yield relation (established using field validation of both the parameters for a representative field sample during *rabi* as well as *kharif* seasons) was 0.0144 m/day & 0.0103 m/day for the *rabi* and *kharif* seasons, respectively. The values so obtained were multiplied by the total irrigated area, obtainable from satellite imagery, and number of irrigation days of the season for the estimation of daily and seasonal groundwater abstraction, respectively. The seasonal abstraction was calculated as 7.126 million cubic meters and 9.639 million cu. m. for *rabi* and *kharif* seasons, respectively. These seasonal groundwater abstractions were further used as input for a Decision Support Tool prepared for the area.

Kewte *et al.* (2008) found critical micro-watershed areas in Katol tehsil of Nagpur by means of effective utilization of remote sensing and GIS techniques. Study showed that the area had good scope for irrigated horticulture and 60 per cent of the land could be brought under irrigated horticulture and 26 per cent of the land can be utilized for growing dry land horticulture crops. Water conservation structures were proposed on the basis of inherent watershed characteristics. Concept of ridge to valley development was considered for loose boulder structures (6 nos.) of runoff zone, Eastern Nala Bunds (3 nos.) were recommended on recharge zone and Cement Nala Bund (1 nos.) on storage zone.

Ramkrishnan *et al.* (2008) did the delineation of Kali watershed, Gujrat for potential water harvesting structure sites using RS and GIS. Thematic layers such as lithology, land use / land cover, soil, slope, drainage and rainfall were generated using PAN (IRS-1D), LISS-III, landsat thematic mapper (TM) data. Runoff potentials for different combinations of land use and hydraulic soil groups were computed and classified into three classes. Suitability map for potential sites of water harvesting/ recharging structures was made by an analytical hierarchy process and validated in field. On the basis of distance between derived and field validated sites, the accuracy of prediction was estimated. The sites derived for subsurface dyke, check dam and percolation ponds were accurate in 75 per cent cases.

Anil Kumar *et al.* (2013) identified various land use/ land cover features and their changes with the use of LISS IV data with GIS in Jhojju Kalan micro-watershed of 2060 ha area during period 2007-12. Upon interpreting land use/ land cover for both *rabi* and *kharif* seasons, the major changes in agricultural land during 2011-12 were compared with 2007-08. Double cropping was found dominant in the study area. The shifting of area under different categories was more substantial in agricultural land indicated that either *rabi* only or *kharif* only class changed into the double crop area or vice-versa.

Butt *et al.* (2015) applied the supervised classification-maximum likelihood algorithm in the ERDAS imagine software for detecting land cover/land use changes in the Simly watershed, Pakistan by use of multispectral satellite data. Five major land cover/use classes viz. agriculture, bare soil/rocks, settlements, vegetation and water were identified. ArcGIS software was used for generation of resultant land cover/land use and overlay maps. A significant shift from the vegetation and water cover to agriculture, bare soil/rock and settlements cover was observed. A decrease of 38.2% and 74.3% in the vegetal and water cover, respectively was observed in the watershed. These land cover/use changes were a serious threat to watershed resources.

Gebre *et al.* (2015) studied the significant hydrological parameters of the water resource management for alternative solutions for water harvesting in the Chelekot Micro-Watershed, Tigray, Ethiopia by introducing suitable soil and water conservation structures. Drainage pattern, topographic parameters, land use types and soil types were evaluated and interpreted. ArcGIS software was used for the morphometric analysis of the micro-watershed using the topographical maps and ASTER DEM data. The results indicated that the micro-watershed was dendritic in pattern with fifth stream order. The drainage density was medium which indicated that the area contained soils of medium infiltration rates and moderate relief. Drainage texture, stream frequency and the form factor were 4.1, 1.7 and 0.4 respectively. The bifurcation ratio ranged from 1 to 4.5 and the elongation ratio was 0.7 which revealed the micro-watershed belonged to the less elongated shape.

Rawat and Manish Kumar (2015) studied the spatio-temporal changes in land use/cover of the Hawalbagh block of district Almora, Uttarakhand, India for the period 1990-2010 by using supervised classification methodology and maximum likelihood technique in ERDAS 9.3 Software. The images were categorized into five different classes: vegetation, agriculture, barren, built-up and water body. The results indicated an increase in the vegetation and built-up land by 3.51% (9.39 km^2) and 3.55% (9.48 km^2), respectively while a decrease of 1.52% (4.06 km^2), 5.46% (14.59 km^2) and 0.08% (0.22 km^2) was observed in agriculture, barren land and water body, respectively during the two decades, i.e. between 1990-2010.

2.4.2 Morphometric analysis and watershed prioritization

The measurements and mathematical analysis of the geometry of the earth surface, its shape, dimension of its landforms is known as morphometry. The morphometric analysis of watershed provides the benefits such as potential sites for water harvesting structures, assessment of ground water potential zones, runoff, slope and characteristics of drainage channel network. The quantitative description of drainage basins and its channel network can be obtained using remotely sensed data.

Biswas *et al.* (2002) used remote sensing and GIS for morphometric analysis and prioritization of 44 micro watersheds (with areas less than 10 km^2) in Murli sub-watershed in the Subarnarekha basin of Midnapore district of West Bengal State in eastern India. Based on the prioritization study suitable soil conservation measures were suggested and location of suggested measures i.e., check dams etc, were identified. From this study, it was inferred that GIS could be used as a handy and effective tool for prioritization of watersheds and recommending proper treatment for the watersheds.

Vittala *et al.* (2004) morphometrically analysed nine sub-watersheds namely, Dalavayihalli, Maddalenahalli, Talamaradahalli, Puluvalli tank, Nagalamadike, Gowdatimmanahalli, Naliganahalli, Devadabetta and Byadanur in Pennar river basin of Tumkur district using GIS software(s). The drainage channel network was delineated by Geocoded FCC of bands - 2 3 4 of IRS 1 C and 1 D (LISS III+PAN merged) on 1:50,000 scale and the SOI toposheets. The terrain had dendritic to sub-dendritic drainage pattern with stream order equal to five. Drainage density ranged from 1.55 and 2.16 km/ km^2 with very coarse to coarse drainage texture. The mean bifurcation ratio, varied from 3.21 to 4.88, fell under normal basin category. The elongation ratio showed that Devedabetta sub-watershed had circular shape while remaining sub-watersheds were elongated.

Nookaratnam *et al.* (2005) used Sediment Yield Index (SYI) model and morphometric analysis for watershed prioritization for identification of the locations for check dams in the Tarafeni watershed in Midnapur District, West Bengal. Different thematic maps such as land use/land cover, slope, drainage, soil etc. were prepared from IRS l D LISS-3 digital data and SOI toposheet on 1: 50,000 scale. Sixty-two micro-watersheds were prioritized using SYI method while Twenty-three micro-watersheds were prioritized using morphometric analysis. Final priority was done by considering both Sediment Yield Index (SYI) method and the morphometric analysis. In the 21 highly prioritized watersheds, twenty-four locations were identified for construction of check dams.

Arpita and Pankaj (2009) used GIS techniques for morphometrically evaluate and compare the five sub-watersheds of 5^{th} to 6^{th} order of Song river basin of Uttarakhand, namely: Jakhan Rao, Song River, Bandal Nadi, Baldi Nadi and Suswa Nadi having dendritic to sub dendritic drainage patterns. The drainage pattern was structurally controlled and had high to moderate relief. Based on the asymmetric factor study, the tectonic rotation of the four sub-watersheds was found upward on the right side of the drainage basin and only one sub-watershed was downward. More landslide incidences occurred in the upward side as compared to the downward side.

Mishra and Nagrajan (2010) conducted a morphometric analysis using GIS and remote sensing techniques for prioritization of 12 sub-watersheds named SWS1 to SWS12 in Hati watershed of Tel river basin of Bhawanipatna area of Kalahandi district, Odisha, India. The drainage density of sub-watersheds varied from 1.09 for SWS11 to 3.77 km/km^2 for SWS8. The low drainage density values of sub-watershed SWS11 indicated the highly resistant, impermeable subsoil material with dense vegetative cover and low relief in the sub-watershed. The elongation ratio varied from 0.6 to 0.8 that indicated high relief and steep ground slope. The circularity ratio varied from 0.34 for SWS6 to 0.80 for SWS11. On the basis of the results of prioritization analysis sub-watershed SWS1 has been assigned the highest priority for development.

Ali *et al.* (2011) used digital elevation model (DEM) in conjunction with parameters related to lithology (dip, strike and rock types), structures (joints, fractures, faults and folds), soil types, land use and land cover for study of drainage morphometry and identification of stability and saturation zones in relation to landslide assessment in Shahbazan area on South-west Iran. The study revealed that the DEM provides a useful tool for rapid evaluation of natural hazards and mapping of large areas with less time and good results.

Javed *et al.* (2011) carried out a morphometric study of Jaggar watershed in Gambhir river basin of eastern Rajasthan. The watershed was divided into 14 sub-watershed namely SW1 to SW14 for prioritization on the basis of morphometric analysis and land use/land cover categories. The prioritization results, based on morphometry reveal that only SW7 and SW10 fall under very high priority, whereas SW6, SW11 and SW13 fall under very high priority on the basis of land use/land cover analysis for conservation and management of natural resources.

Sharma *et al.* (2011) studied land use changes and prioritized the watersheds in Jasdan taluka (district) of Rajkot in Gujarat, India on the basis of runoff generated using remote sensing and GIS approach. The Soil Conservation Service Curve Number (SCS CN) method was used for computation of runoff; and subsequently runoff yield in percentage for prioritizing the watersheds. Satellite data analysis was done for identification of the problems and potential solutios and soil and water conservation measures recommended in the watershed. The impact of these measures was assessed by calculating runoff under alternative land use and management practices. A 42.88% decrease in pre-conservation runoff yield was observed after using the suggested measures.

Das *et al.* (2012) analysed the morphometry of the Bandu watershed under the upper catchment of Kasai river of a drought prone Purulia District of the West Bengal. Different thematic maps used for prioritization of mini-watersheds through morphometric analysis. Sediment Yield Index and shape-size and morphometric analysis of drainage system approaches were also attempted. The drainage density of the micro watersheds correlated positively with the stream frequency indicating that there was increasing stream population in response to increased drainage density. The form factor (R_f) values ranged from 0.053 to 0.064 micro watershed suggesting almost circular shape. The elongation ratio of micro watersheds varied from 0.286 to 0.260 which showed that the Bandu watershed was elongated in shape. Compactness ratio varied from 2.03 to 1.32 with of the entire sub-watershed, upon morphometric analysis, showed parallel, dendritic to sub-dendritic, moderate drainage textured radial drainage patterns.

Kanth and Hassan (2012) did the prioritization of sub-watersheds in Wular catchment. The prioritization was done by ranking the individual indicators and afterwards with calculation of a compound value (C_p). Highest compound value watersheds were assigned the lowest priority whereas lowest compound value were given the highest priority. So, a high, medium and low priority index was produced. There were six, six and seven watersheds, under high, medium and low priority zones, respectively. High priority indicated that those watersheds were susceptible to greater degree of erosion and application of soil conservation measures became inevitable to preserve the land from further erosion and to alleviate natural hazards.

Panhalkar *et al.* (2012) assessed the morphometric characteristics of Hiranyakeshi basin of southern Maharashtra to prioritize the sub-watersheds for its planning and development. The study area was divided into 19 sub-watersheds viz., H-1 to H-19 using ARCSWAT software. The morphometric characteristics of the watershed were assessed by applying GIS techniques using SRTM data. The fluvial characteristics of the region were assessed by Strahler's, Horton's and Schumm's methods. Knowledge based weightage was assigned to each morphometric characteristic, considering it as a single parameter, based on its role in soil erosion. The compound parameter weights were calculated and the sub-watershed with lowest compound weight was given highest priority. The analysis revealed that sub-watersheds H-1, H-2, H-3, H-5 and H-13 being susceptible to soil erosion, were under high priority for watershed development.

Vasanthi *et al.* (2012) conducted a morphometric analysis, using GIS and Remote sensing techniques in upper watershed of Thoppaiyar River basin for prioritization of twenty mini-watersheds viz., mw1 to mw20. The low drainage density, between 1.15 and 10.92, indicated a highly permeable subsoil and thick vegetative cover in the study area. The elongation ratio varied from 0.6 to 1.0 over a wide variety of climatic and geologic types pointed the very low to high relief and steep ground slope. The circularity ratio, between 0.28 to 0.61, was influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. The morphometric analysis of the drainage networks of all 20 mini-watersheds exhibited the radial of dendritic drainage pattern. On the basis of elongation ratio, circulatory ratio and form factor the14th mini-watershed was assessed to have square shape, while the remaining mini-watersheds marked elongated pattern.

Aravinda and Balakrishna (2013) analyzed the morphometry of Vrishabhavathi watershed which was a constituent of the Arkavathi River Basin in Bangalore Urban and Ramnagara district. The drainage map of the study area was prepared with the help of GIS tools and morphometric parameters, such as linear, aerial and relief aspects of the watershed, were determined. From the drainage map of the study area dendritic drainage pattern was identified. The drainage density of the watershed was 1.697 km/km^2. Average bifurcation ratio was calculated for the watershed as 3.84. The value of bifurcation ratio (R_b) indicated that watershed had suffered less structural disturbance and the watershed may be regarded as the elongated one. Drainage density reflected land use and affects the infiltration and the response time in watershed between the interval of precipitation and discharge. The circularity ratio for the watershed was found to be 0.492, indicating mature nature of topography. Its low, medium and high values area correlated with young, mature and old phase cycle of the regions' tributary watersheds. The watershed had a total relief of 0.234 km. The relief aspect showed that the watershed had enough slope for runoff to occur from the source to the mouth of watershed.

Kedareswarudu *et al.* (2013) analyzed morphometry of Upper Provenance watershed of Karamana River Basin in Trivendrum District, Kerala of 128.75 sq. km. area with a length of 16.75 km of major stream using Remote Sensing data and GIS applications. The basin was of sixth stream order and had 671 number of total streams. The average bifurcation ratio was 4.22 indicating that no influence of geological structures existed on the drainage pattern. Total length of drainage channels inclusive of all order streams was 216.56 km and that for sixth-order stream was 7.91 km. Relief showed very high variations in the elevation gradient in Eastern and North-Eastern parts. Hypsometric curve was hyperbolic in shape which indicated a matured basin stage. Digital terrain map was prepared using ArcGIS software. Land-use was divided into 11 categories and compared from 1967 to that of 2008. A decrease in forest area by 24 per cent was observed in last 40 years.

Gajbhiye *et al.* (2014) carried out a morphometric analysis of Manot River catchment of Narmada river basin. After morphometric analysis the compound parameter values were calculated and prioritization of 14 sub-watersheds was carried out. The 13^{th} sub-watershed, having lowest value of compound parameter (3.63) was found prone to maximum soil erosion. Morphological parameters-based prioritization was found in good agreement with the geological field investigation carried out during the field work.

Singh *et al.* (2014) carried out morphometric analysis for the Orr watershed in Ashok Nagar district of M.P., India using Digital Elevation Model (DEM) and satellite images. Hydrological module of ARC GIS software was utilized for calculation and delineation of the watershed. The stream order of watershed ranges from first to sixth order showing dendritic type drainage network. The drainage density in the area was found to be low to medium indicating highly permeable soils and low relief the area. The bifurcation ratio of the watershed varied from 4.74 to 5, and the elongation ratio was found to be 0.58 which revealed that the watershed was of elongated shaped.

Rao *et al.* (2015) morphometrically analysed four sub-watersheds namely Pidhaura, Batesar, Balapur and Pariar forming parts of Yamuna River around Bah Tahsil of Agra district. Geocoded FCC of bands 2, 3 and 4 of IRS-1D, LISS-III, SOI toposheets number 54 J/5 and 54 J/9 and GIS softwares - ArcGIS, Arcview and 3 DEM software were used for preparation of DEM. The terrain exhibited dendritic to sub-dendritic drainage pattern, stream order ranged from third to fourth order; drainage density varied slightly from very coarse to coarse texture in Pidhaura and Balarpur sub-watersheds and fine drainage texture in Batesar and Pariar sub-watersheds. The mean bifurcation ratio revealed that the basin fell under normal basin category. The Balarpur sub-watershed was elongated, whereas, Pidhaura, Batesar and Pariar sub-watersheds possessed circular shape.

Prakash Kumar *et al.* (2016) carried out morphometric analysis of the Varuna river basin in Varanasi district of Uttar Pradesh, India using remote sensing and GIS. The dendritic drainage pattern diagnosed in the area exhibited homogeneous permeable substratum and gentle gradient. The study of Spatio-temporal changes (Land Use and Land Cover i.e. LULC) of the Varuna river basin, in Varanasi district, using Landsat multispectral imageries spanning 38 years (1972, 1988, 2002 and 2010) illustrated a shrinkage in that the salt affected waste land as compared to that observed in 80's. An increase in the area of agricultural and built-up land was observed in the study.

The above review shows that, the numbers of researchers have done works on infiltration as well as physical and chemical properties of soil, in order to develop relationship among soil properties and available nutrients. A lot of work has been done on remote sensing and GIS applications in watershed management, and prioritization of watersheds. But no work has been done by any one for the study area, therefore, keeping the above in view, the present study was taken up for the land and water resources management planning in the Gagas river valley watershed of Almora district of Uttarakhand.

Patents registered

No patents have been available for these kinds of studies.

3. MATERIALS AND METHODS

This chapter deals with the details of the study area, remote sensing and G.I.S. applications for the investigation of land use, DEM (Digital Elevation Model), aspect, and temporal changes in the land use / land cover. Besides this, categorization of soil nutrients, soil nutrient mapping, spatial distribution of soil properties and morphometric analysis of whole watershed and sub-watersheds, through the measurement of linear, aerial and relief aspects using Arc-G.I.S. software, has been elaborated. The method for prioritization of the sub-watersheds, on the basis of morphometric characteristics, is explained.

3.1 General Description of the Study Area

3.1.1 Location

The study area (Gagas river valley watershed) is located on Someshwar – Dwarahat – Ranikhet road in district Almora of Uttarakhand state, as shown in **(Figure 3.1)**. The watershed lies between 79° 26' 20"–79° 31' 50" E longitude and 29°45' 01"–29° 50' 32" N latitude with 52.94 sq km geographical area and 41.2 km perimeter. The elevation varied from 1226 m to 2750 m above mean sea level (msl).

3.1.2 Topography

There was a lot of variation in the topography of the study area as the altitude ranged from 1226 to 2750 m. In conformity with the dramatic altitudinal and climatic differences, the region supported variety of forest eco-systems and crops. Pine forests pre-dominate the watershed above 1400 m elevation from msl.

3.1.3 Soil

The soil of the region was generally sandy-loam type with high organic matter content and acidic in nature. Soil was well drained with average thickness ranging from 0.1 to 0.5 m. The color of soil was light to moderately dark. Coarse soil texture and high seepage losses through the soil do not permit sufficient moisture retention in the surface soil and upper horizons of the sub-soil. Because of this phenomenon, the crops suffer badly due to moisture stress at different critical stages of crop growth during pre- and post-monsoon periods and long dry spells during rainy season.

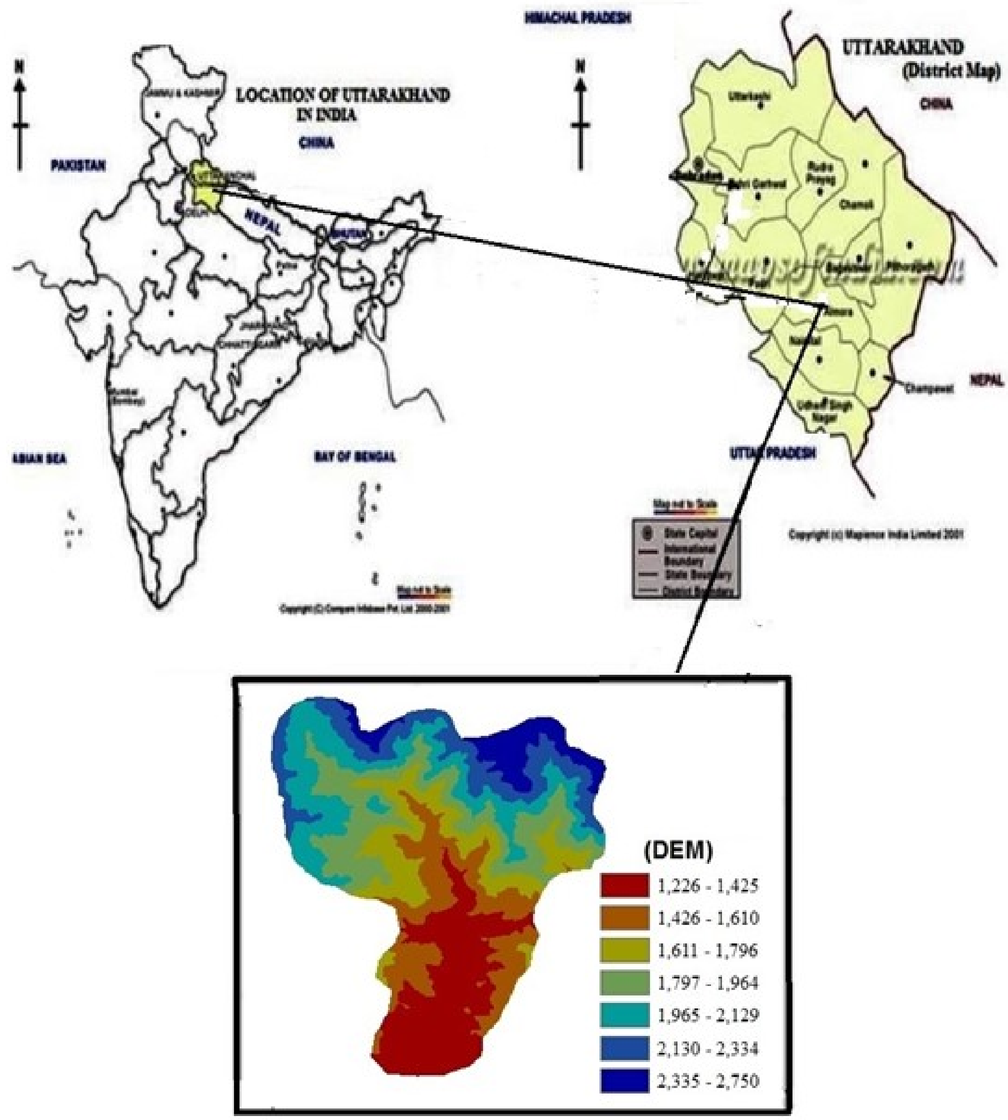

Figure 3.1. Index map of Gagas river valley watershed

3.1.4 Climate

The climate of the region is sub-tropical and humid with three distinct seasons i.e. summer, monsoon (rainy season) and winter. The rainy season starts from the middle of June and continue up to the end of September. It is followed by the winter season, which from the end of October and goes up to February. December and January are the coldest months in the area. More than 80% of the annual precipitation in the region occurs during the south-western monsoon, which starts in the third week of June and last up to mid-October **(Asthana, 2003).** Of the remaining 15% rainfall is caused by cyclones and 5% by thunderstorms distributed over the rest of the year **(Jalal, 1988).** The average annual rainfall is about 1152 mm. The maximum and minimum humidity ranged are from 98 to 66 per cent and 67 to 25 per cent, respectively. The temperature of the region varies from above 30° in summer to about -2° C in winter.

3.1.5 Irrigation

In the study area major source of irrigation was canal (i.e. Binta canal network) in the form of small guls in the valley region and another source of irrigation was natural water streams at high altitude.

3.1.6 Crops grown and cropping sequences

According to survey conducted at Gagas river valley watershed, it was found that there were more than l0 crops grown, out of which maximum area was under rice followed by wheat and finger millet. In Almora district, the highest area under rice was 15439 ha with average productivity of l221 kg/ ha, followed by wheat 14570 ha with average productivity of 1142 kg/ ha, respectively for rice and wheat. More than 8 vegetables were also grown in area under study, out of which maximum area was found under potato (543 ha) with the productivity of 198 q/ ha followed by raddish with the productivity of 110 q/ha.

The major horticultural crops were apple, walnut, mango, citrus, and peach but, productivity of these crops was quite low mainly due to hail storms. Among the horticultural crops the maximum area was found under mango followed by apple and citrus. The major crop sequences/ rotations followed in hilly regions of Uttarakhand are given in Appendix A.

3.2 Analysis of Meteorological Data

The weather data recorded at the nearest observatory located at Almora, about 35 km away from the study area, was obtained from the India Water Portal website, for the period of 1973 – 2002 and were used for weather analysis on decade basis.

3.3 Infiltration Studies

Owing to their easiness and yielding reasonably acceptable results in most applications, some of the available empirical models are widespread and commonly used in various water resource applications world over. The wide-spread application of the Kastiakov (KT) model in irrigation engineering **(Michael, 1982)** is an example worth citing. The empirical equation developed by **(Kostiakov, 1932)** was used to assess the infiltration constants k and n for different soils. The equation has the following form:

$$Z = k\,t^{n} \qquad \ldots\ 3.1$$

where Z is the cumulative infiltration in cm, t is the intake opportunity time in min., and k and n are the empirical parameters obtained from infiltration test on given soil. Both the parameters rely on soil type, initial moisture content, rainfall rate, vegetative cover, and these can be assessed empirically **(Michael, 1982).**

3.4 Assessment of Soil Nutrients in the Soils of Study Area

Soil is the main source of nutrients for crops. Soil also provides support for plant growth in various ways. Knowledge about soil health and its maintenance is critical for sustaining crop productivity. The health of soil can be assessed by the quality and stand of the crops grown on them. However, this is a general assessment made by the farmers. A scientific assessment of soil was done through data collected from Department of Soil Science, College of Agriculture, GBPUAT, Pantnagar.

Essential plant nutrients such as N, P. K, Ca, Mg and S called macronutrients and Fe, Zn, Cu, B, Mn and Mo called micronutrients were assessed because of the necessity to assess the capacity of a soil to supply nutrients in order to supply the remaining amounts of needed plant nutrients (total crop requirement - soil supply).

Simple correlation was obtained to relate the physical and chemical properties and macro as well as micro nutrient contents of the soil. The significance of correlation was tested at 1 and 5 per cent levels of significance.

3.4.1 Categorization of soil nutrient status and nutrient indices for agriculture soil

The soil nutrient status was classified as low, medium and high categories using standard soil nutrient rating values for each nutrient. Nutrient index value was calculated from the proportion of soils under low, medium and high available nutrient categories for each soil sample.

The following equation (**Parker *et al.,* 1951**) was used to calculate Nutrient Index Value:

$$\text{Nutrient Index (NI)} = \left[\frac{(N_l \times 1) + (N_m \times 2) + (N_h \times 3)}{N_t}\right] \quad \ldots 3.4$$

Where,

N_t= Total number of samples analysed for a nutrient in any given area.

N_l = Number of samples falling in low category of nutrient status.

N_m= Number of samples falling in medium category of nutrient status.

N_h= Number of samples falling in high category of nutrient status.

3.4.2 Mapping of soil nutrients

Inverse distance weighing (IDW) method was employed to delineate the spatial variation of the soil nutrients. The IDW is a simple spatial interpolator that often yields satisfactory results. The IDW directly implements the assumption that a value of a soil variable at an unsampled location is a weighted average of known data points within a local neighbourhood surrounding the unsampled location. The formula of this exact interpolator is **(Burrow and McDonneld, 1998)**

$$z = \frac{\sum_{i=1}^{n} z(x_i)\, d_{ij}^{-r}}{\sum_{i=1}^{n} d_{ij}^{-r}} \quad \ldots 3.5$$

where, x_o is the estimation point and x_i are the data points within a chosen neighbourhood. The weights (r) are related to distance between the estimation point and the data points. The IDW formula has the effect of giving data points close to the interpolation point relatively large weights while those far away exert little influence. The higher the weight used the more influence the points close to x_o are given.

3.4.3 Spatial distribution of soil properties

After digitizing the boundaries of the study area, location of sampling points, macro and micronutrient content of respective nodes were identified according to their geographic coordinates in Universal Transverse Mercator: (UTM) System and values were assigned to the map. The soil nutrient status was classified as low, medium and high categories using standard soil nutrient rating values for each nutrient. Nutrient index value was calculated from the proportion of soils under low, medium and high available nutrient categories for each soil sample. The IDW interpolation sub-routine within ArcGIS software was used 1o interpolate between sampling nodes and assigned an average value of the nutrients concentration on the map.

3.5 Remote Sensing and G.I.S. Application

3.5.1 Geo-referencing of toposheet

Survey of India toposheet No. 53 O/5, 53 O/6, 53 O/9 and 53 O/10 of the scale 1:50000 were used for the analysis of the study area, classification and watershed delineation. The map sheet covering the study area was scanned (*tiff format*) and translated to the pixel format and geo-referenced using utility option of the ArcGIS software. The geo-referenced map was used to delineate the boundary of the watershed.

The following local information was used as an input data in the geo-referencing of the toposheet:

Projection	-	UTM
Zone	-	44 N
Datum	-	WGS 1984
Resampling method	-	Nearest

3.5.2 Satellite data

Geo-coded satellite data were downloaded from USGS web site, details of which are as follows: SRTM Digital Elevation Model (DEM) having spatial resolution of 30 m for extraction of contour, aspects. drainage network and elevation information of watershed. The satellite imagery of LANDSAT-8 at 10 per cent cloud cover was downloaded from the same website. Before processing of any digital data, it was re-projected to UTM projection using projection and transformation option of the ArcGIS software. Then, the area of interest was masked with watershed boundary using clipping / sub-setting facilities of the software.

3.5.3 Base map preparation

Base map for the study area was prepared using Survey of India (SOI) toposheet No. 53 O/5, 53 O/6, 53 O/9 and 53 O/10 of 1: 50000 scale and Digital Elevation Model (DEM) downloaded from USGS website with the use of ArcGIS. Contour, drainage network, spring location, soil sampling and infiltration location maps were prepared by using ArcGIS with UTM projection.

3.5.4 Generation of thematic maps

Different basic thematic maps were prepared using surface option of spatial analysis tool of ArcGIS software. Thematic maps include DEM classes map, aspect map of watershed and land use / land cover maps from toposheet and imagery. The aspect was classified in nine classes as per guidelines of ArcGIS software. The land use/land cover of watershed by toposheet was classified into four major classes, whereas in case of imagery, it was classified into six classes.

3.6 Morphometric Analysis of Watershed

Morphological characterization is the systematic description of watershed geometry. Geometry of drainage basin and its stream channel system required the measurements of': (i) linear aspect of drainage network, (ii) areal aspect of drainage basin, (iii) relief aspect of channel network and contributing ground slopes. The first two categories of measurement were planimetric (i.e. projected upon a horizontal datum plane) and the third category compared the vertical inequalities of the drainage basin forms. This analysis was achieved through the measurement of linear, aerial and relief aspects of the basin and slope contributions.

3.6.1 Ordering of streams

The quantitative study of channel network used to begin with **Horton's (1945)** methodology of ordering of channels. **Strahler (1952)** proposed a modification of Horton's ordering scheme. Due to simplicity and greater freedom from subjective decisions Strahler’s method was preferred. There were three steps involved in Strahler's ordering

i. Channels that originated at a source were defined to be first order streams,
ii. When two streams of order 'u' join, a stream of order (u+1) is created, and
iii. When two streams of different orders join, the channel segment immediately downstream will have the highest order of the combining streams.

3.6.2 Linear aspects

In linear aspects, the parameters representing length were considered.

3.6.2.1 Number of streams of given orders (N_u)

The quantity N, represents total number of all streams, counted as the stream segments, having the order 'u' present in the watershed. The number of streams of each order was an important concept in hydrologic synthesis.

3.6.2.2 Bifurcation ratio (R_b)

It was obtained by determining the slope of the fitted regression of the plot of the logarithm of number of streams on ordinate versus order on abscissa. The bifurcation ratio will not be precisely the same from one order to the next, because of chance variations in watershed geometry, but will tend to be a constant throughout the series. Bifurcation ratio characteristically ranges between 3 and 5 for watersheds in which the geologic structures do not distort the drainage pattern. The theoretical minimum possible value of 2 is rarely approached under natural conditions. Because the bifurcation ratio is a dimensionless parameter, and because drainage systems in homogeneous materials tend to display geometrical similarity, it is not surprising that the ratio shows only a small variation from region to region (**Aravinda and Balakrishna, 2013**). Abnormally high bifurcation ratios may be expected in regions of steeply dipping rock strata where narrow strike valleys are confined between hogback ridges. The R_b was computed using Horton's law of stream numbers which stated, "The number of stream segments of each order form an inverse geometric sequence with order number"

$$R_b = \frac{N_u}{N_{u+1}} \quad \dots 3.6$$

Where N_u = number of segments of order ‘u’

3.6.2.3 Length of main channel (L_m)

It is the length along the longest water course from the outflow point of designated sub basin to the upper limit of the catchment boundary.

3.6.2.4 Mean stream length (L_{sm})

It is a characteristic property related to the drainage network components and its associated basin surfaces (**Strahler, 1964**). Channel length is measured with the help of ArcGIS. software directly from the Stream Order map. It is the total length of all streams of order 'u' in a given drainage basin divided by number of streams of order 'u'.

$$L_{sm} = \frac{\sum_{i=1}^{N_u} L_i}{N_u} \quad \ldots 3.7$$

3.6.2.5 Stream length ratio (R_L)

This was estimated as the ratio of mean stream length of order 'u' to the mean stream segment length of order (u-l) expressed mathematically as:

$$R_L = \frac{L_u}{L_{u-1}} \quad \ldots 3.8$$

3.6.2.6 Length of overland flow (L_g)

Horton (1932) defined length of overland flow L_g, as the length of flow path, projected to the horizontal, non channel flow from a point on the drainage divide to a point on the adjacent stream channel. He noted that length of overland flow is one of the most important independent variables affecting both the hydrologic and physiographic development of drainage basins. During the evolution of the drainage system, L_g is adjusted to a magnitude appropriate to the scale of the first order drainage basins and is approximately equal to one half the reciprocal of the drainage density. The shorter the length of overland flow, the quicker the surface runoff from the streams.

$$L_g = \frac{1}{2D} \quad \ldots 3.9$$

3.6.2.7 Basin length (L)

It was calculated as the distance between outlet and farthest point on the basin boundary.

3.6.2.8 Basin perimeter (P)

It was taken as the length of watershed divide which surrounds the basin.

3.6.2.9 Fineness ratio (R_{fn})

It was considered as the ratio of channel length to the length of the basin perimeter as defined by **Melton (1957).**

3.6.3 Areal aspects

In areal aspects different morphologic parameters were considered which represented the area. Some of them are given below in brief:

3.6.3.1 Drainage area (A)

It is represented by the area enclosed within the boundary of the watershed divide. It is the most important characteristic for hydrologic design.

3.6.3.2 Drainage density (D_d)

It indicates the closeness of spacing of channels (**Horton, 1932**). Closer investigation of the processes, responsible for drainage density variation, discovered that a number of factors collectively influence stream density. These factors include climate, topography, soil infiltration capacity, vegetation, and geology. In the areas of higher drainage density the infiltration r, will be less and surface runoff will be more. Low drainage density generally results in the areas of highly resistant or permeable sub-soil material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while drainage density leads to fine drainage texture. The drainage density was estimated as the ratio of total length of channels of all orders in the basin to the drainage area of the basin.

$$D_d = \frac{\sum_{i=1}^{w}\sum_{j=1}^{N_i} L_{ij}}{A} \quad \dots 3.10$$

3.6.3.3 Constant of channel maintenance (C)

It was calculated as the ratio between the area of the drainage basin and total length of all the channels expressed as square meter per meter. It was also equal to reciprocal of drainage density.

$$C = \frac{1}{D_d} \quad \ldots 3.11$$

3.6.3.4 Stream frequency (F_s)

It was calculated as the number of streams per unit area. **Melton (1957)** gave following relationship between drainage density and stream frequency:

$$F_s = 0.694 \times D^2 \quad \ldots 3.12$$

$$F_s = \frac{N_u}{A} \quad \ldots 3.13$$

3.6.3.5 Circulatory ratio (R_c)

It is the ratio between the area of watershed to the area of circle having the same circumference as the perimeter of the watershed (**Miller, 1953**). The value ranges from 0.2 to 0.8, greater the value more will be the circulatory ratio. It is the significant ratio which indicates the stage of dissection in the study region. It's low, medium and high values are correlated with youth, mature and old stage of the cycle of the tributary watershed of the region, and the value obtained. As basin shape approaches to a circle, the circulatory ratio approaches to unity.

$$R_c = 4\pi \frac{A}{P^2} \quad \ldots 3.14$$

3.6.3.6 Elongation ratio (R_e)

It is defined as the ratio between the diameter of a circle with the same area as the basin and basin length (**Schumn, 1956**). The value of R_e approaches to 1 as the shape of the basin approaches to a circle and it varies from 0.6 to 1.0 over a wide variety of climatic and geologic regimes. Typical values are close to 1 for areas of very low relief and are between 0.6 to 0.9 for regions of strong relief and steep ground slope. Smaller form factor shows more elongation of the basin. The watershed with higher form factor will have higher peak flow for shorter duration, whereas, elongated watershed with low form factor, will have a flatter peak of flow for longer duration.

$$R_e = \frac{2\sqrt{\frac{A}{\pi}}}{L_b} \qquad \ldots\ 3.15$$

$$R_e = \frac{d_c}{L_b} \qquad \ldots\ 3.16$$

3.6.3.7 Form factor (R_f)

For a perfect circular watershed the value of form factor would always be less than 0.7854 (**Aravinda and Balakrishna, 2013**). The watershed with higher form factor would normally be circular and have high peak flows for shorter duration, whereas elongated watershed with lower values of form factor have low peak flows for longer duration. The form factor is calculated as the ratio of basin area (A) to the square of basin length (Lu) as defined by **Horton (1932)**.

$$R_f = \frac{A}{L_n^2} \qquad \ldots\ 3.17$$

3.6.3.8 Unity shape factor (R_u)

It was estimated as ratio of the basin length, L_b to the square root of the basin area.

$$R_n = \frac{L_h}{\sqrt{A_w}} \qquad \ldots\ 3.18$$

3.6.3.9 Watershed shape factor (W_s)

The watershed shape factor was estimated as the ratio of main stream length. L_m to the diameter, D_e of a circle having the same area as that of watershed

$$W_s = \frac{L_m}{D_c} \qquad \ldots\ 3.19$$

3.6.3.10 Drainage texture ratio (T)

It is the relative spacing of drainage lines in the watershed and one of the important concept of geomorphology. Drainage lines are numerous over impermeable areas than permeable areas. Drainage texture ratio (T) was estimated as the ratio of total number of stream segments (N_u) of all orders to the perimeter (P) of that area **Horton (1945).** He recognized infiltration capacity as the single important factor which influences the drainage texture.

$$T = \frac{N_u}{P} \qquad \ldots 3.20$$

3.6.4 Basin relief aspects

In basin relief aspects, the parameters evaluated are given below in brief.

3.6.4.1 Total relief (H)

The basin relief or total relief is the maximum vertical distance between the lowest (outlet) and the highest (divide) points in the watershed. **Schumn (1956)** measured it along the longest dimension of the basin parallel to the principle drainage line, and **Strahler (1952, 1964)** obtained it by determining the mean height of the entire watershed divide above the outlet. Relief is an indicative of the potential energy of a given watershed above a specified datum available to move water and sediment down slope.

3.6.4.2 Relief ratio (R_h)

It is estimated as the ratio between the relief and the distance over which the relief was measured. It measures the overall steepness of the watershed and can be related to its hydrologic characteristics.

3.6.4.3 Relative relief (R_p)

It was estimated as the ratio of basin relief (H) to the length of the perimeter (P) as defined by **Melton (1957).** It is an indicator of general steepness of the basin from summit to mouth.

$$R_p = \frac{H}{P} \qquad \ldots 3.21$$

3.6.4.4 Ruggedness number (R)

Melton (1957) and Strahler (1957) defined a dimensionless number called ruggedness number (R l as a product of relief (H) and drainage density (D) in the same unit. It combined slope and length characteristics in one expression. The areas of low relief but high drainage density were as ruggedly textured as areas of higher relief having less dissection. The ruggedness number was estimated using the following formula:

$$R_n = H \times D \qquad \ldots\ 3.22$$

In the present study, the morphometric analysis for the parameters mentioned above was carried out using the mathematical formulae given in appendix A.

3.7 Land Use / Cover Map

The study area was delineated from SOI toposheets No. 53 O/5, 53 O/6, 53 O/9 and 53 O/10 (year 1965) with the use of editor tool available in ArcGIS software and was classified into three land use/land cover classes (i.e., Dense forest mainly of pine, agricultural land/ river bed and barren land/built up). To observe recent situation of land cover, different land use / land covers classes were extracted from imagery (i.e. LISS III 2008) downloaded from Bhuwan web site by converting it into FCC format satellite with the use of ArcGIS software. The satellite imagery was masked with the area of interest (watershed divide shape file) using clipping / sub setting tool by using unsupervised classification of the software. Spatial distribution of various classes for satellite data was found out.

3.7.1 Land suitability classification

Satellite remote sensing provides reliable and accurate information on natural resources, which is pre- requisite for planned and balanced development at watershed level (**Ravindran *et al.,* 1992**). Integration of Remote sensing and GIS techniques provides reliable, accurate and update database on land and water resources, which is essential for an integrated approach to identify land capability (LCC) and land suitability classes (LSC) and suitable sites for water harvesting and soil conservation such as check dam, percolation tank, farm ponds, terrace farming etc.

Land suitability classes indicate whether land is assessed as suitable or not suitable. Land Suitability classes reflect degrees of suitability which are: Class I - Dense forest, II - moderately dense forest, III - Agriculture land with severe limitations, IV - Agriculture land with no limitations and V- Scrub land **(Figure 3.2 and Table 3.1)**. Land suitability units are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level.

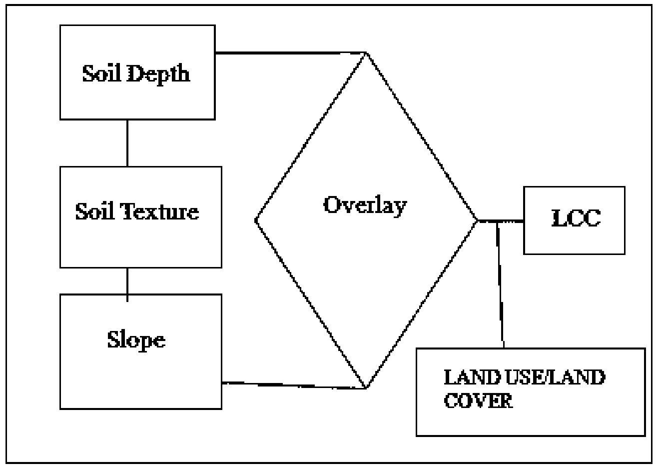

Figure 3.2 Methodology to derive LCC

Table 3.1 Land suitability classes.

SN	Class	Criteria		
		Soil depth*	**Texture**	**Slope**
I	Dense forest	Deep	Fine	Very steep
II	Moderately dense forest	Moderate deep	Moderate	Moderately steep
III	Agriculture land with severe limitations	Moderate	Fine	Moderately sloping
IV	Agriculture land with no limitations	Deep	Fine	Gentle
V	Scrub land	Shallow	Medium	Moderately steep

*Deep >100 cm, Moderately deep= 75 – 100 cm, Deep = 50 – 75 cm, Shallow < 50 cm

3.7.2 Temporal changes in the land use/cover pattern

The study area was delineated from SOI toposheets No. 53 O/5, 53 O/6, 53 O/9 and 53 O/10 (year 1965) with the use of editor tool available in ArcGIS software. Standard visual image interpretation method based on photographic recognition elements such as tone, texture, size, shape, pattern, association and field knowledge was followed to identify and delineate land use/land cover categories on remote sensing data. A reconnaissance survey was carried out to collect the ground information. Ground truth information was collected with the help of Google earth, toposheet and GPS. The image elements were correlated with the ground truthing. The tonal variations in the imagery, representing different classes, were marked on the hard copy image. In mountain area, especially in Himalayas, due to terrain complexity, the spectral signatures are influenced by elevation, aspect and slope. Different land uses/ land covers were digitized with the help of ArcGIS. software by visual interpretation using digital satellite data for year 2008 and SOI toposheets for year 1965 with l: 50,000 scale was classified into three land use classes (i.e. Dense forest mainly of pine, agricultural land, river bed and barren land).

To observe recent situation of land cover, different land use / land covers classes were extracted from satellite imagery (i.e. LISS III 2008) downloaded from Bhuwan website by converting it into FCC format with the use of ArcGIS software. The satellite imagery was masked with the area of interest (watershed divide shape file) using clipping / sub setting tool of the software. Spatial distribution of various classes for satellite data was classified into three classes namely, dense forest, agricultural land along with river bed, barren land plus built-up land.

3.8 Prioritization of Sub-watersheds on the Basis of Morphometric Parameters Analysis

Watershed prioritization based on morphometric analysis was carried out using Remote sensing and GIS which are effective tools for prioritization of sub-watersheds (**Patel *et al.*, 2012)**. The study area was divided into 11 sub-watersheds for prioritization. The morphometric analysis of sub-watersheds was achieved through the measurement of linear, aerial and relief parameters by using ArcGIS software. The morphometric parameters which affect the soil erodibility were considered to prioritise the sub-watersheds and assigned ranks on the basis of relationship with erodibility so as to arrive at a compound parameter (C_p) value for the final ranking of each sub-watershed. Previous studies have shown that shape parameters show negative correlation with runoff as well as soil erosion, while the other parameters show positive correlation with soil erosion **(Biswas *et al.*, 1999; Thakkur and Dhiman, 2007).** For first four parameters (bifurcation ratio, drainage density, texture ratio and stream frequency), rating was done by assigning highest priority i.e. 1 for sub-watershed having maximum value of the parameter, priority 2 for the next higher value and so on. The sub-watershed which got the lowest value was assigned the last priority number. Remaining four parameters (circulatory ratio, form factor, compactness ratio and elongation ratio) rating was done by assigning highest priority 1 for sub-watershed having minimum value of the parameter, and similar procedure was followed till the last priority number. Based on the value of compound priority value C_p, the sub-watershed with the lowest C_p value was given the highest priority and the sub-watersheds were categorized into three classes as high, medium and low in terms of priority **(Kumar and Kumar, 2011).**

4. RESULTS AND DISCUSSION

The planning and management of land and water resources in Gagas river valley watershed in Almora district of Uttarakhand, using GIS and remote sensing was carried out in this study. Different thematic maps viz. contour map, digital elevation model, aspect map, drainage map, present and past land use/land cover maps etc. were prepared using ArcGIS software, SOI toposheets and satellite imagery. Morphometric characterization of the watershed was done using drainage map of the study area which was extracted from digital elevation model by using ArcGIS software. The prioritization of the sub-watersheds was done by determining compound parameter value (C_p) and priority ranks were assigned to sub-watersheds for systematic watershed development.

4.1 Analysis of Weather Data

The weather data, recorded at the nearest observatory located at Almora, about 35 km away from the study area, were obtained from the India Water Portal website, for the period of 1973 – 2002 and were used for weather analysis on decade basis.

From the weather data (rainfall, maximum, minimum and average temperature) for the period 1973 – 2002 **(Appendix A - 5 & 6),** it was found that the average monthly rainfall was the minimum in the month of November (i.e. 4.76 mm) and the maximum in the month of August (i.e.298.76 mm). The maximum contribution of annual rainfall (84.17%) was observed during the months of June to September **(Figure 4.1 (a))**. The decadal analysis of rainfall data showed a repeated decrease in the average monthly rainfall in monsoon months (July and August) during three decades i.e. 1973-2002. This phenomenon may be due to reduced forest cover and increase in mean daily temperature.

Mean monthly temperature was the minimum in the month of January and the maximum in the month of June. The decadal analysis of temperature indicated an increase in the mean daily temperature **(Figure 4.1 (b))** which is a cause of concern for hilly areas as well as to Indian agriculture and ecology.

4.2 Infiltration Study

Infiltration studies were conducted at five locations in Gagas river valley watershed. Using ArcGIS software, aspect, land use and DEM were overlaid to get infiltration scenario **(Table 4.1)**. All five locations were under agricultural land. The infiltration rates at all the locations followed the fixed trend line in power form similar to the Kostiakov equation with a high coefficient of determination (R^2) of more than 80 % in all the five tests.

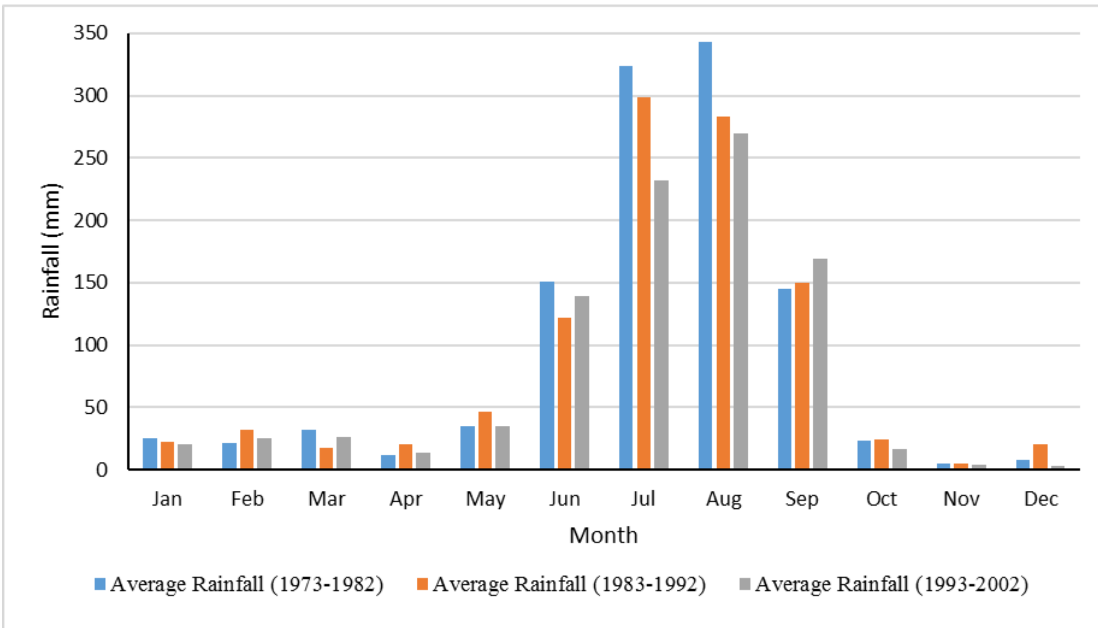

Fig 4.1(a) Variation in average monthly rainfall (1973-2002) in the study area

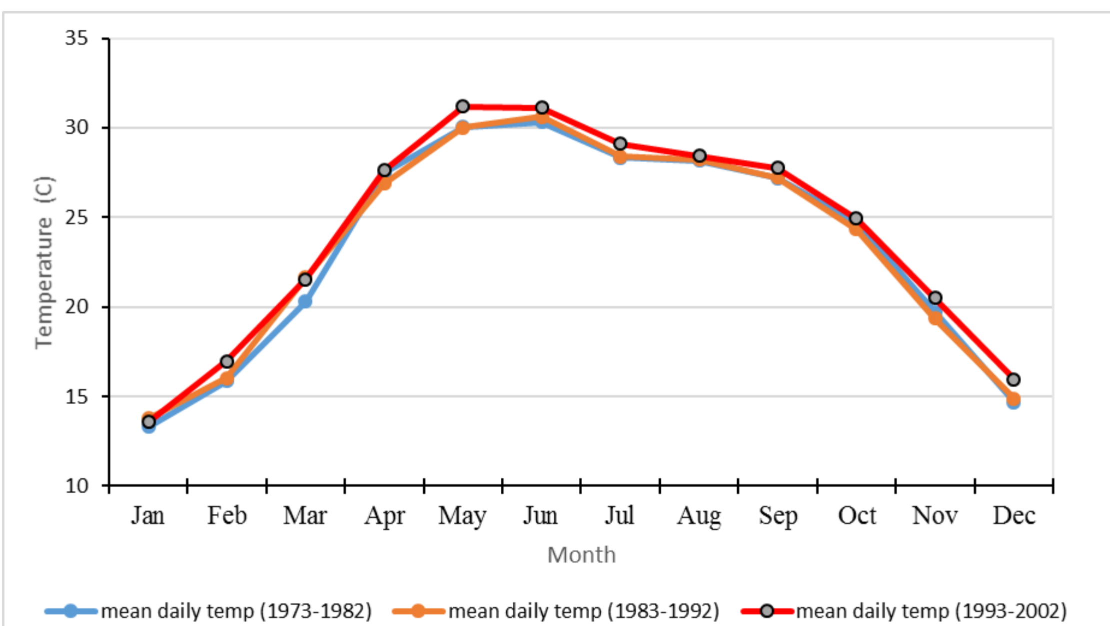

Fig 4.1 (b) Variation in mean daily temperature (1973-2002) in the study area

The study showed that, the location one had highest infiltration rate (i.e. 14 cm/hr). The average basic infiltration rate was found to be 6.0 cm/hr and 4.5 cm/hr for South and South-East aspects, respectively, whereas, it was found to be 2.0 cm/hr for North-West and North-East aspects at nearly saturated condition of soil in presence of crop. Results indicated relatively more water stable aggregates and more antecedent moisture content in northern aspect as compared to southern aspect **(Table 4.1)**. The infiltration rate was found more at high elevation on greater slope than the lower elevation on gentle slope.

Table 4.1 Aspects, land use and elevation of different infiltration points.

Infiltration points	Aspect	Land use	Elevation above msl (m)
P-1	East	Agriculture	1230
P-2	South	Agriculture	1250
P-3	South-West	Agriculture	1240
P-4	North-West	Agriculture	1230
P-5	North-East	Agriculture	1260

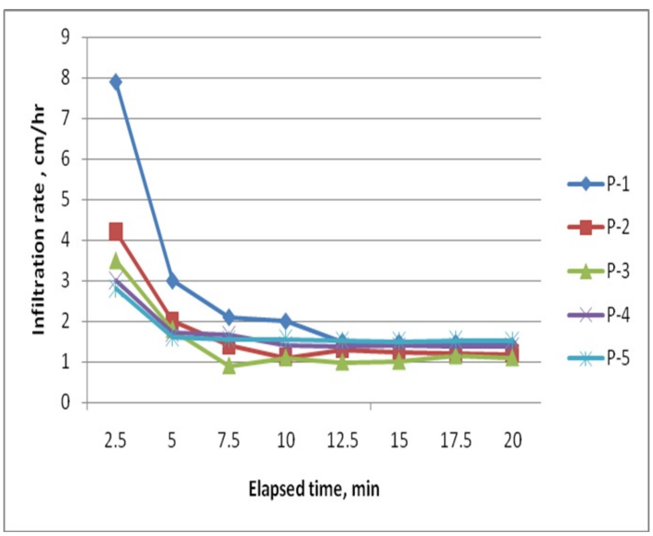

Figure 4.2 Infiltration rates at different locations in the study area

4.3 Analysis of Soil

Physico-chemical properties along with the status of primary, secondary and micro-nutrients in the soils of watershed were assessed from the relevant data (**Table 4.2 and Table 4.3**) collected from Department of Soil Science, College of Agriculture, GBPUA&T, Pantnagar. The relationship of soil texture with the infiltration rate and infiltration constants was studied.

4.3.1 Physico-chemical properties

A perusal of the data in **Table 4.2** revealed that the pH of soils of the study area ranged from 4.24 to 6.92 with a mean value of 5.30. The electrical conductance of soil samples varied from 0.02 to 0.23 dS/m with a mean value of 0.12 dS/m. Soil texture varied from loamy sand to silty clay loam. The soil organic carbon content varied from 7.68 to 18.55 g/kg with a mean value of l3.25 g/kg.

The spatial mapping of the physico-chemical properties and soil texture in the study area was completed with the ArcGIS software and are presented under mapping of soil characteristics in section 4.5.

Table 4.2 Physico-chemical properties of the soils in study area.

Sampling Point	pH (1:2)	EC (dS/m)	OC (g/kg)	Texture	Sampling Point	pH (1:2)	EC (dS/m)	OC (g/kg)	Texture
1	6.87	0.30	12.03	SaL	14	4.85	0.08	13.91	SaC
2	6.92	0.13	16.52	SaL	15	5.01	0.04	12.46	SaC
3	4.88	0.11	17.39	LSa	16	6.25	0.06	13.04	SaC
4	4.32	0.07	15.07	LSa	17	5.35	0.07	18.55	SaC
5	4.30	0.06	15.8	LSa	18	5.51	0.06	14.35	SaL
6	5.61	0.05	12.32	LSa	19	4.52	0.15	13.19	SaL
7	4.24	0.25	12.9	SiCL	20	4.98	0.13	7.68	SaL
8	6.25	0.15	8.41	SiCL	21	5.57	0.08	9.71	SaC
9	5.05	0.21	15.94	SiCL	22	5.92	0.13	10.43	SaC
10	4.56	0.13	10.43	SiCL	23	4.65	0.17	13.48	SaC
11	5.62	0.11	11.45	SiCL	24	4.75	0.20	13.77	SiC
12	5.51	0.09	13.19	SaC	25	5.15	0.07	12.9	SiCL
13	5.49	0.06	13.91	SaC	26	5.56	0.09	15.65	SiCL
Average						**5.30**	**0.12**	**13.25**	

Table 4.3 Available nutrient status in soils of study area.

Sample	Nutrient Concentration (kg/ha)				Nutrient Concentration (mg/ha)							
	N	**P**	**K**	**S**	**Ca**	**Mg**	**Zn**	**Cu**	**Fe**	**Mn**	**B**	**Mo**
1	213.25	36.45	352.8	13.02	1884	1536	1.85	1.13	13.25	6.96	0.23	0.15
2	288.51	33.14	431.2	10.42	1644	888	0.82	0.9	6.54	5.57	0.23	0.21
3	163.07	19.88	359.5	5.21	2524	1200	0.66	0.67	50.03	52.65	0.12	0.07
4	175.62	23.2	448.0	5.21	2444	1680	1.00	1.82	48.4	5.83	0.23	0.28
5	238.34	33.14	300.2	18.23	2204	1392	2.72	1.31	63.8	5.23	0.23	0.21
6	150.53	36.45	293.4	7.81	1244	864	1.54	1.56	51.31	11.58	0.32	0.06
7	175.62	31.48	425.6	10.42	1164	1176	1.52	1.36	127	37.52	0.32	0.15
8	125.44	21.54	403.2	13.02	1644	1200	1.57	2.09	13.81	6.09	0.32	0.07
9	263.42	29.82	322.6	18.23	1884	1536	2.28	0.78	33.14	12.22	0.32	0.02
10	163.07	11.6	498.4	5.21	2684	1608	1.26	1.29	44.3	42.03	0.[6	0.06
11	188.16	13.25	470.4	7.81	1964	960	0.80	1.13	33.22	51.74	0.48	0.15
12	213.25	33.14	515.2	5.21	2204	1344	1.32	1.22	14.6	8.29	0.32	0.24
13	125.44	33.14	465.9	10.42	2684	432	0.35	0.4	13.09	24.73	0.81	0.09
14	301.06	11.6	537.6	5.21	1564	672	1.17	3.5	13.29	14.95	0.32	0.07
15	150.53	16.57	537.6	13.02	1764	432	1.28	0.37	22.64	21.79	0.16	0.15
16	163.07	13.25	330.4	18.23	1644	1008	4.00	0.28	15.05	26.06	0.48	0.04
17	188.16	16.57	436.5	13.02	1964	1080	3.61	0.31	13.72	26.25	0.16	0.11
18	301.06	31.48	319.2	10.42	1644	1680	2.1	0.81	21.36	50.8	0.32	0.09
19	175.62	31.2	414.4	5.21	1484	1296	3.76	0.93	26.19	23.07	0.48	0.07
20	263.42	36.2	537.6	10.42	1364	1440	4.79	0.69	12.86	15.12	0.97	0.15
21	163.07	31.48	436.8	13.02	964	1032	2.04	0.36	16.61	16.67	0.81	0.13
22	238.34	28.17	358.4	10.42	1324	1050	6.53	0.49	15.02	10.09	0.48	0.06
23	213.25	19.88	366.2	10.42	1644	1728	3.14	0.57	22.18	16.63	0.65	0.11
24	125.44	23.2	515.2	7.58	2364	576	14.98	0.91	9.31	19.83	0.97	0.02
25	137.98	28.17	537.6	7.58	·1884	1680	7.69	0.66	24.37	8.7	0.32	0.17
26	175.62	28.17	424.6	7.58	2684	1608	1.80	0.78	23.4	10.18	0.32	0.22
Avg.	195.4	25.85	352.8	10.09	1864	1197	2.87	0.89	28.79	20.41	0.407	0.121

4.3.2 Soil nutrients

4.3.2.1 Available macronutrient status

The available macro-nutrient (N, P, K, S, Ca and Mg) in the soils of study area are presented in **Table 4.3**. From Table 4.3, it may be observed that available nitrogen content in the soils varied from l25.14 to 301.06 kg/ha with a mean value of 195.40 kg/ha. The concentration of available nitrogen was found lower as most of the area of the watershed was having light textured soils. The available phosphorus in the soils of study area varied from 11.6 to 36.4 kg/ha with the mean of 24.3 kg/ha. The values of available potassium in the soils of the study area ranged from 293.4 to 537.6 kg P/ha with a mean of 440.9 kg P/ha. The availability of sulphur in the soils of study area ranged from 5.21 to 18.23 mg S/ha with a mean of 10.09 mg S/ha. The available calcium ranged from 964 to 2684 mg Ca/ha with a mean of 1864 mg Ca/ha. The Magnesium availability in the soils of study area ranged from 432 to 1728 mg Mg/ha with a mean of 1197.23 mg Mg/ha.

As per the nutrient index calculated by using equation 3.4 and the rating limits (**Table 4.4**), the soils in the study area were found containing high amount of available macronutrient (P, K, S, Ca and Mg) except available N, which was low in the study area.

Table 4.4 Rating limits for available essential soil nutrients (Parker *et al.,* 1951).

Nutrient	**Low**	**Medium**	**High**
N(kg/ha)	<280	280 – 560	>560
P(kg/ha)	<10	10 – 25	>25
K(kg/ha)	<108	108 – 280	>280
Fe (mg/kg)	<4.8	4.8 - 8.0	>8.0
Mn (mg/kg)	<2.0	2.0 - 4.0	>4.0
Zn (mg/kg)	<0.6	0.6 - 1.2	>1.2
Cu (mg/kg)	<0.2	0.2 - 0.4	>0.4
Nutrient Indices (NI)	<1.5	1.5 - 2.5	>2.5

The spatial mapping of the available macro-nutrient in soil of the study area was completed with the ArcGIS software and are presented under mapping of soil characteristics in section 4.5.

4.3.2.2 Available micronutrient status

The available micronutrient (Zn, Cu, Fe, Mn, B and Mo) in the soils of the study area are presented in **Table 4.3**. From **Table 4.3**, it may be observed that the Fe content of soils in the study area varied from 5.54 to 127.02 mg/kg with the mean value of 28.79 mg/kg. Mn content ranged from 5.23 to 52.65 mg/ kg with mean value as 20.41mg/kg. Cu content in the soil samples showed high variation from 0.28 to 2.09 mg/kg with the mean value of 0.89 mg/kg. Zn content in soil samples was high ranging from 0.35 to 14.98 mg/kg with the mean value of 2.87 mg/kg, available B in soil samples ranged from 0.12 to 0.97 mg/kg with the mean value of 0.41 mg/kg and available Mo in soil samples ranged from 0.02 to 0.28 mg/kg with the mean value of 0.12 mg/kg.

Comparing the availability of micronutrients (Zn, Cu, Fe and Mn) in the soils of the study area with the rating suggested by **Parker *et al.* (1951)**, all the micronutrients were found in high category. The high availability of micronutrients indicated that the soils of the study area were rich in available micronutrients and provide conducive conditions for good crop production.

The spatial mapping of the available micro-nutrient in soil of the study area was completed with the ArcGIS software and are presented under mapping of soil characteristics in section 4.5.

4.3.2.3 Nutrient index (NI)

Parker *et al.* (1951) classified the nutrient index values less than 1.5 as the indicative of low nutrient status and between 1.5 to 2.5 as medium while higher than 2.5 as high nutrient status. The number of samples falling in low, medium and high categories of essential nutrients and nutrient indices are given in **Table 4.5.** It was found that the nitrogen (N) had low nutrient index, whereas phosphorus (P), potassium (K), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) content of soil had high nutrient index.

Table 4.5 Percent number of samples falling in low, medium and high categories of essential nutrients and nutrient indices (n=26).

Nutrient	Low	Medium	High	Nutrient Indices (NI)
N	23(88.46)	3(11.53)	0	1.12 (Low)
P	0	11(42.31)	15(57.69)	2.58 (High)
K	0	0	26(100)	3 (High)
Fe	0	1(3.85)	25(96.15)	2.96 (High)
Mn	0	0	26(100)	3 (High)
Zn	1(3.85)	5(19.23)	20(76.92)	2.73 (High)
Cu	0	6(23.08)	20(76.92)	2.77 (High)

Note: Values in parenthesis are per cent soil samples and n = total number of sample

4.4 Correlation Between Soil Properties and Available Nutrients

Simple correlation was obtained to relate the physical and chemical properties, and macro as well as micro nutrient contents of the soil. The significance of correlation was tested at 1 and 5 per cent levels of significance.

4.4.1 Relationship among the soil properties and available nutrients

It is evident from **Table 4.6** that in soils of study area, soil pH showed a significant and negative correlation with available Fe (r = -0.544) at 1 percent level of significance. The organic carbon showed a significant and positive correlation with available Ca (r = 0.431) at 5 percent level of significance but showed a significant and negative correlation with available B (r = -0.445) at 5 percent level of significance. From **Table 4.7** it may be observed that available nitrogen showed the positive and significant correlation with the iron (r = 0.407) whereas, potassium and iron showed negative and significant correlation with zinc in surface soil, (r = -0.148 and r = -0.160), respectively. Organic carbon showed positive significant correlation with available nitrogen (r = 0.218).

4.4.2 Descriptive statistics of soil physico-chemical properties and macro and micronutrients

The skewness coefficients of the macro nutrients ranged from -0.47 to 0.66 and micro nutrients ranged from 0.56 to 5.06. While the variables were not normally distributed, the IDW did not require any transformation to reduce the skewness of the data.

The coefficient of variation is a useful and an independent measure of relative dispersion of parameters in different units. The CV of the soil variables were very high The CV may vary dramatically for easily manageable soil parameters such as nutrients applied as fertilizers and is dependent on the farmer's habits and crop pattern at regional scale. Pearson's linear correlation coefficients and correlation coefficient among the soil properties and available nutrients in the soils of study area are shown in **Table 4.7** and **Table 4.8**, respectively in the correlation matrix.

Table 4.6 Correlation between soil properties and available nutrients.

Nutrients	pH (1:2)	EC (dS/m)	OC (g/kg)
N	0.105	0.080	0.169
P	-0.060	0.167	-0.262
K	-0.004	0.030	-0.111
S	0.273	0.081	0.025
Ca	-0.184	-0.132	0.431*
Mg	-0.162	0.223	0.012
Zn	-0.131	0.194	-0.090
Fe	-0.544**	0.199	0.112
Cu	-0.068	0.226	-0.202
Mn	-0.224	-0.058	0.082
B	-0.050	0.093	-0.445*
Mo	-0.026	-0.188	0.156

**Significant at the I % level and * Significant at the 5 % level of significance

4.5. Mapping of Study Area

The natural resources' planning, management and monitoring largely relies upon accurate data of slope, aspect, land use and drainage network. Survey of India (SOI) toposheets No. 53 O/5, 53 O/6, 53 O/9 and 53 O/10 of 1: 50,000 scale, procured from Survey of India, Dehradun and Digital Elevation Model (DEM) downloaded from USGS website were used for the preparation of base map, soil characteristics and soil nutrient maps, contour map, drainage network map and thematic maps of the study area.

Table 4.7 Simple correlation coefficient among the soil properties and available nutrients in the soils of study area

	pH	EC	OC	N	P	K	S	Ca	Mg	Zn	Cu	Fe	Mn	B	Mo
pH	1	0.164	-0.101	0.064	0.131	-0.196	0.27	-0.167	-0.187	-0.075	-0.14	-0.597	-0.224	0.0286	-0.067
EC		1	-0.2	0.091	0.305	-0.12	0.107	-0.22	0.387	0.028	-0.104	0.257	-0.078	-0.045	-0.064
OC			1	0.218	-0.027	-0.329	0.101	0.289	-0.057	-0.15	0.019	0.079	0.061	-0.484	0.103
N				1	0.222	-0.009	0.082	-0.269	0.279	0.181	0.407	-0.209	-0.129	0.021	0.153
P					1	-0.329	0.114	-0.248	0.233	0.123	-0.349	0.105	-0.406	0.311	0.274
K						1	-0.479	0.123	-0.312	-0.148	0.328	-0.227	0.007	0.248	0.291
S							1	-0.179	-0.016	0.41	-0.283	-0.051	-0.265	0.035	-0.162
Ca								1	0.12	-0.427	-0.167	-0.107	0.159	-0.184	0.171
Mg									1	0.296	-0.284	0.18	0.009	-0.157	0.155
Zn										1	-0.163	-0.16	-0.136	0.367	-0.189
Cu											1	-0.134	-0.127	-0.047	-0.153
Fe												1	0.263	-0.235	0.112
Mn													1	-0.03	-0.356
B														1	-0.101
Mo															1

Table 4.8: **Descriptive statistics of soil physico- chemical properties and macro and micronutrients**

	pH	EC	OC	N	P	K	S	Ca	Mg	Zn	Cu	Fe	Mn	B	Mo
Mean	5.3	0.12	13.25	195.4	25.85	424.56	10.09	1864	1196.1	2.87	2.22	28.79	20.41	0.41	0.12
Standard Error	0.14	0.01	0.51	10.58	1.62	15.61	0.8	96.11	77.17	0.6	1.31	4.92	2.93	0.05	0.01
Median	5.25	0.1	13.19	175.62	28.17	428.4	10.42	1824	1200	1.83	0.86	21.77	15.88	0.32	0.11
Standard Dev	0.73	0.07	2.61	53.95	8.25	79.61	4.07	490.1	393.49	3.05	6.7	25.08	14.93	0.24	0.07
Kurtosis	0	1.28	0.04	-0.57	-1.16	-1.19	-0.23	-0.77	-0.71	9.79	25.72	8.96	0.19	0.61	-0.45
Skewness	0.63	1.25	-0.17	0.66	-0.47	-0.05	0.63	0.23	-0.45	2.86	5.06	2.67	1.11	1.23	0.56
Range	2.68	0.26	10.87	175.62	24.85	244.2	13.02	1720	1296	14.63	34.72	120.46	47.42	0.85	0.26
Minimum	4.24	0.04	7.68	125.44	11.6	293.4	5.21	964	432	0.35	0.28	6.54	5.23	0.12	0.02
Maximum	6.92	0.3	18.55	301.06	36.45	537.6	18.23	2684	1728	14.98	35	127	52.65	0.97	0.28
CV	0.53	0	6.82	2910.09	67.99	6337.95	16.59	2401.6	1548.37	9.3	44.91	628.84	222.97	0.06	0.01

4.5.1 Base map

The toposheets were scanned and geo-referenced, and then joined together by data management extension using raster processing mosaic tool of ArcGIS software. The study area was then extracted using clip tool after digitizing the boundary of study area from the mosaic. The base map of the study area is shown in **Figure 4.3.**

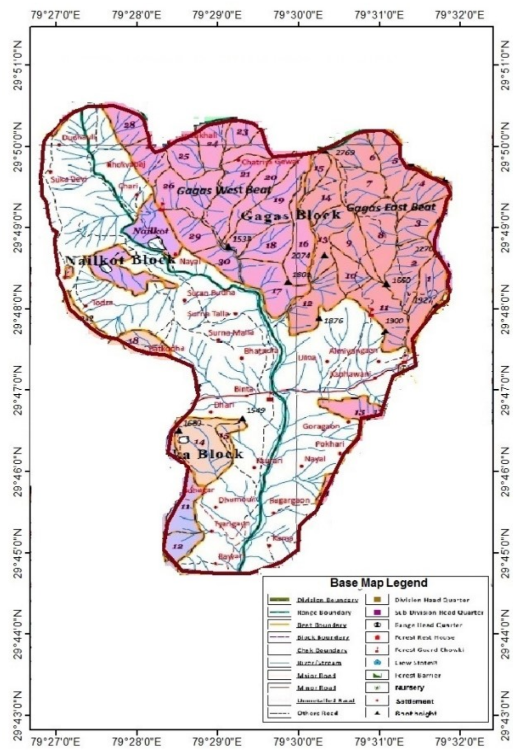

Figure 4.3 Base map of Gagas river valley watershed.

4.5.2 Soil characteristics and nutrient maps

After digitizing the boundaries of the study area, location of sampling points, macro and micronutrient content of respective nodes were identified according to their geographic coordinates in Universal Transverse Mercator (UTM) system and values were assigned to the map. Inverse distance weighing method was employed to delineate the spatial variation of the physical characteristics and available nutrients status of soils in the study area **(Figures 4.4 - 4.18).** Rating limits for available essential soil nutrients in the study area **(Table 4.4)** were adopted into low, medium and high categories and nutrient spatial distribution was deciphered.

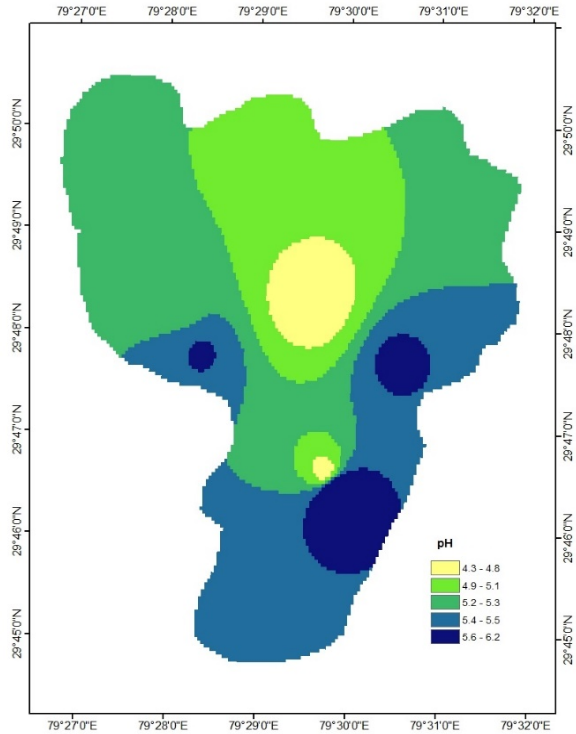

Figure 4.4 Spatial variation of soil pH.

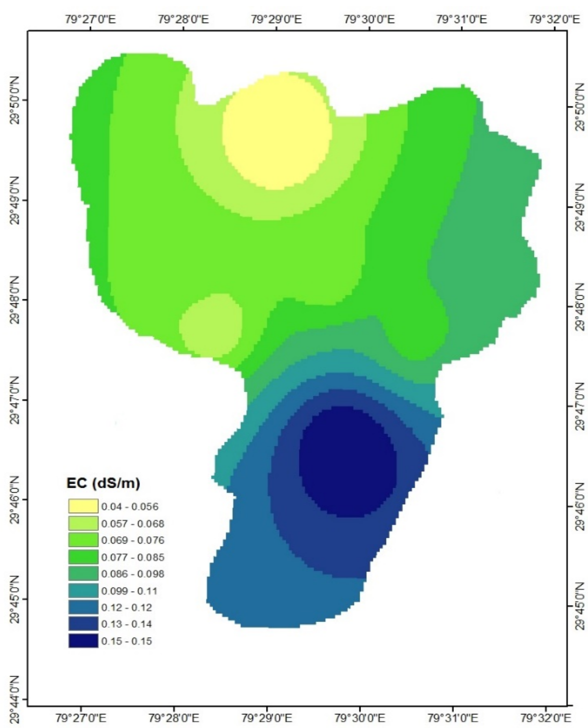

Figure 4.5 Spatial variation of electrical conductivity of soil.

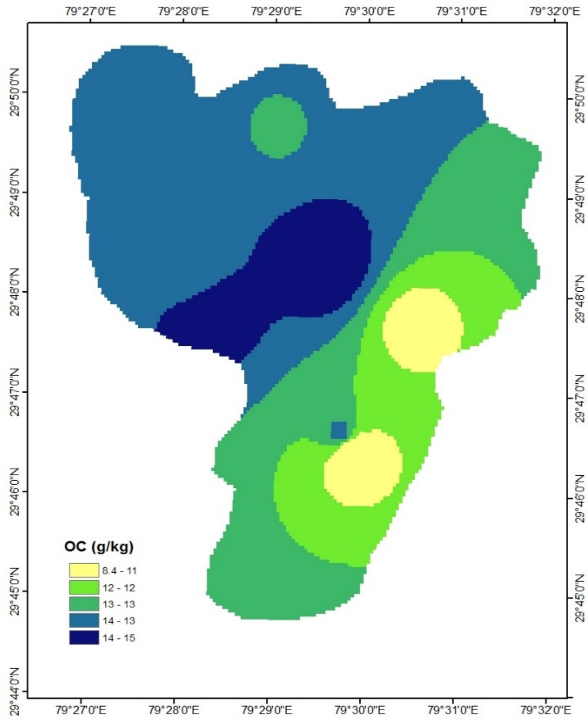

Figure 4.6 Spatial variation of organic carbon.

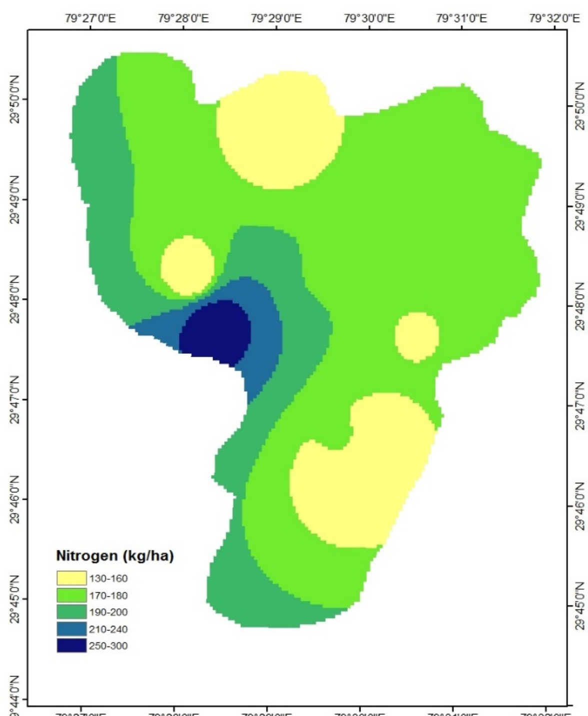

Figure 4.7 Spatial variation of N content.

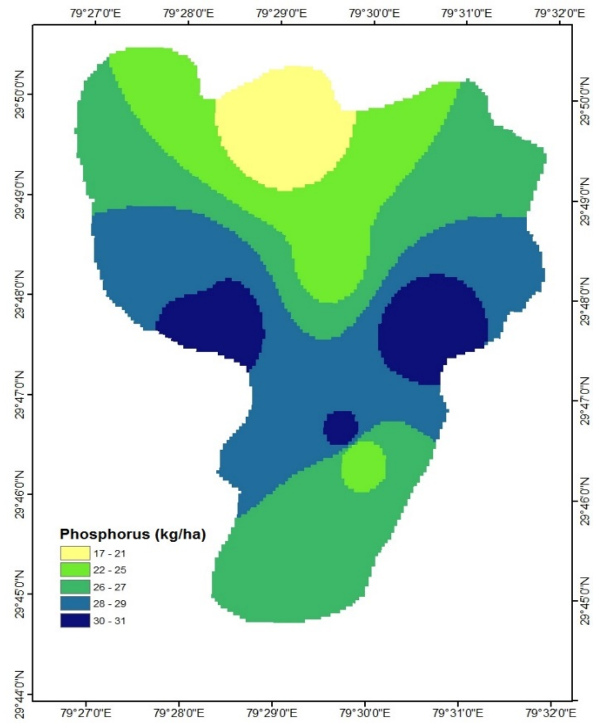

Figure 4.8 Spatial variation of P content.

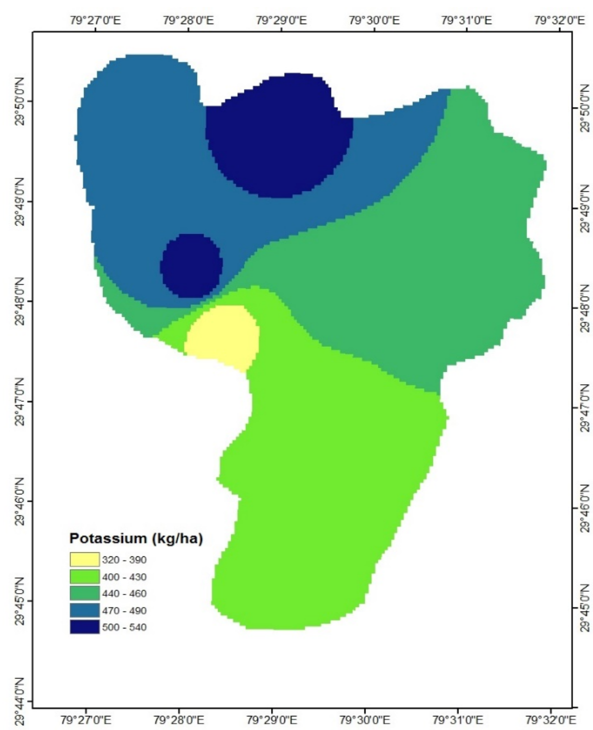

Figure 4.9 Spatial variation of K content.

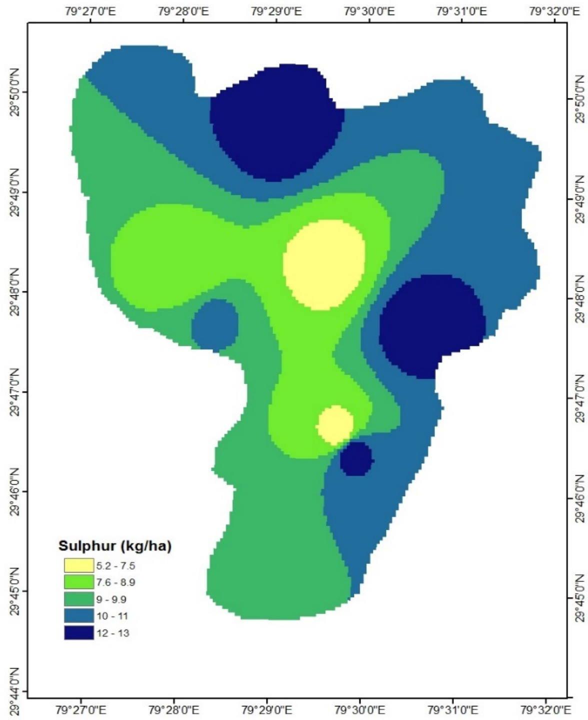

Figure 4.10 Spatial variation of S content.

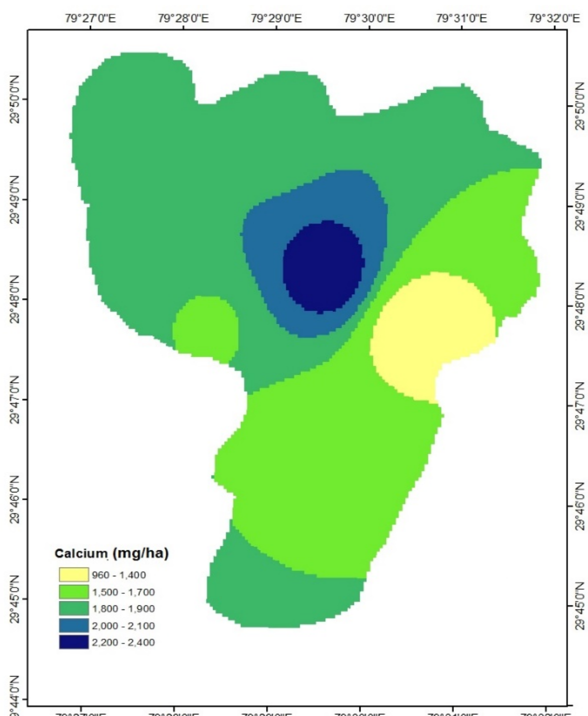

Figure 4.11 Spatial variation of Ca content.

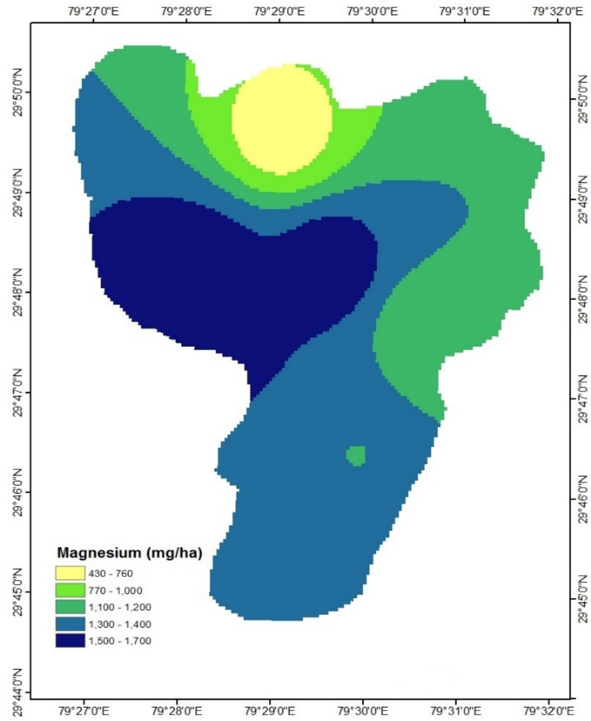

Figure 4.12 Spatial variation of Mg content.

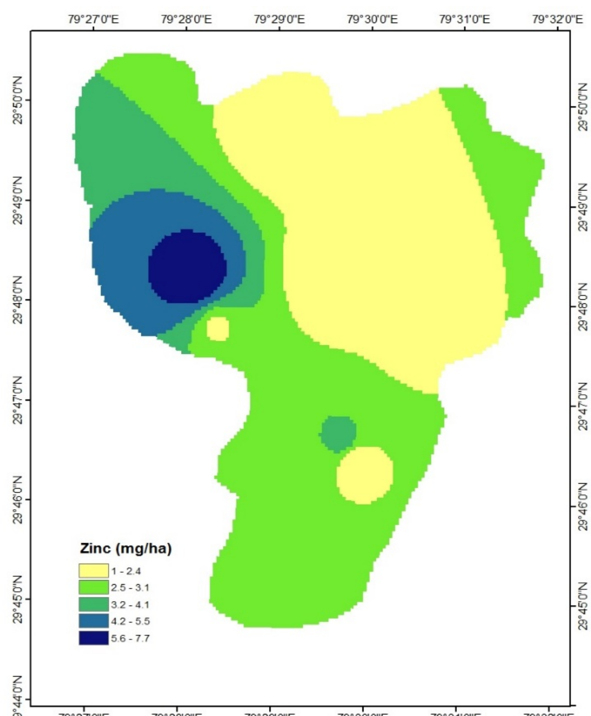

Figure 4.13 Spatial variation of Zn content.

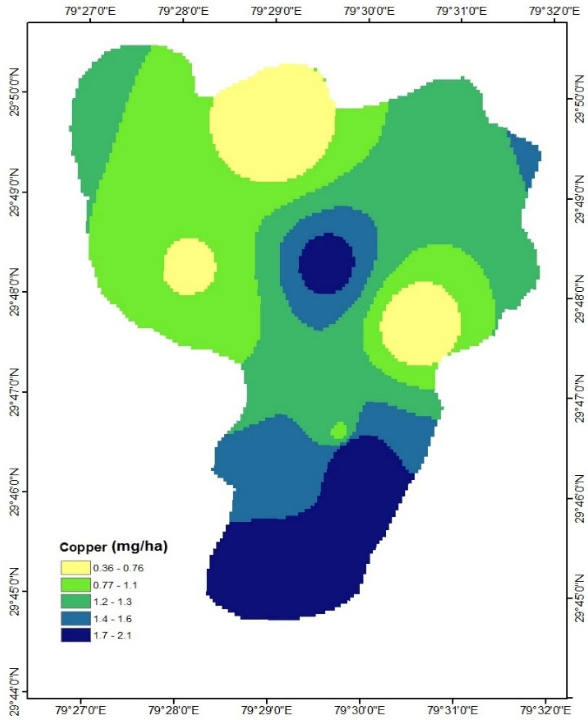

Figure 4.14 Spatial variation of Cu content.

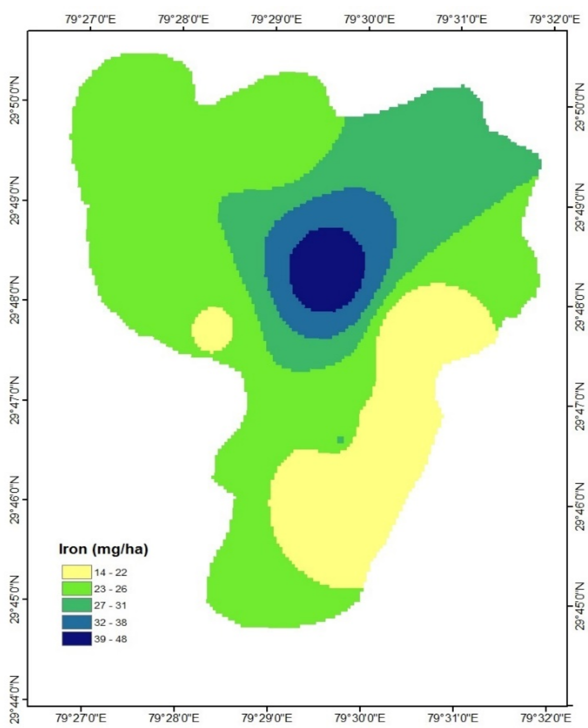

Figure 4.15 Spatial variation of Fe content.

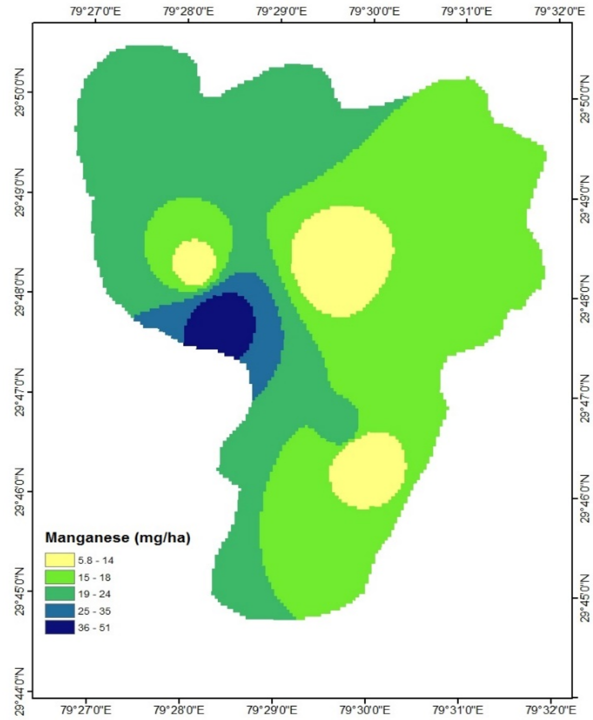

Figure 4.16 Spatial variation of Mn content.

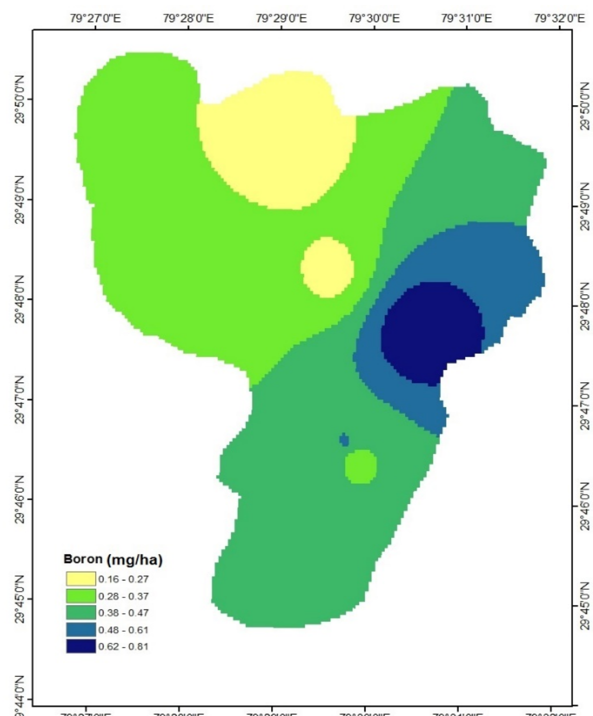

Figure 4.17 Spatial variation of B content.

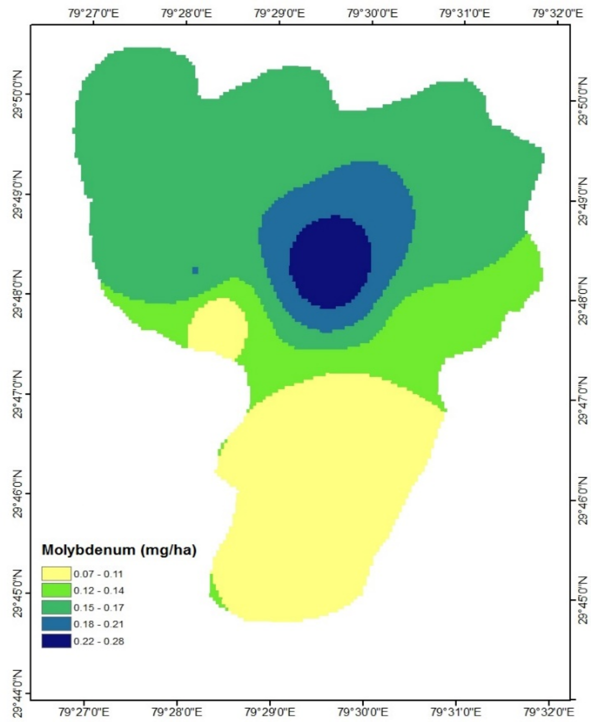

Figure 4.18 Spatial variation of Mo content.

4.5.3 Contour map

A vector layer of contours, at 40 m interval was extracted from Digital Elevation model (DEM) with contour option in spatial analysis tool of software. Contour map of study area is shown in **Figure 4.19**. Elevation of contours varied from 1200 m to 2600 m above mean sea level (msl). The outlet of the watershed was located at 1226 m above msl.

4.5.4 Drainage map

Spatial Analyst tool under 'Hydrology' menu of ArcGIS software was used for the extraction of raster layer of drainage network. Digital Elevation Model of the study area was converted into vector layer by 'stream to feature' option providing stream orders and flow directions as input. Drainage map of the study area is shown in **Figure 4.20** and the statistics of the drainage network is presented in **Table 4.9.**

Table 4.9 Statistics of drainage network.

Parameter	Stream order				Total
	I	II	III	IV	
Number of Streams	129	33	5	1	168
Stream length (km)	48.368	28.009	15.457	11.31	103.14

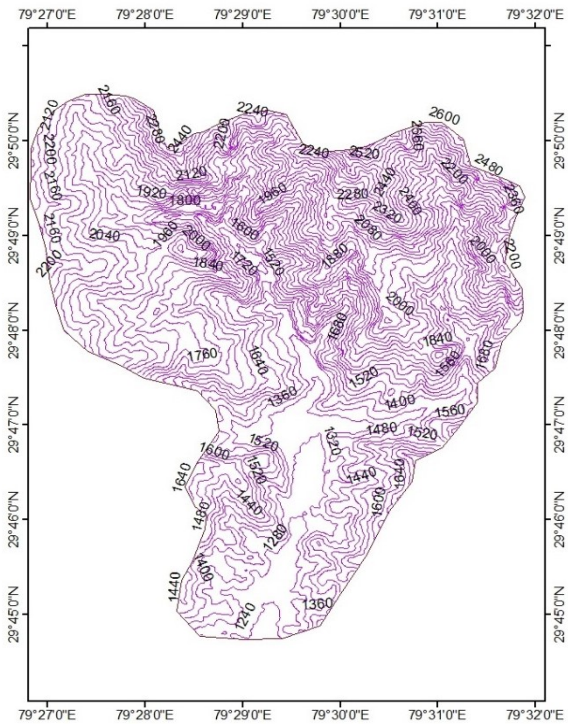

Figure 4.19 Contour map of Gagas river valley watershed.

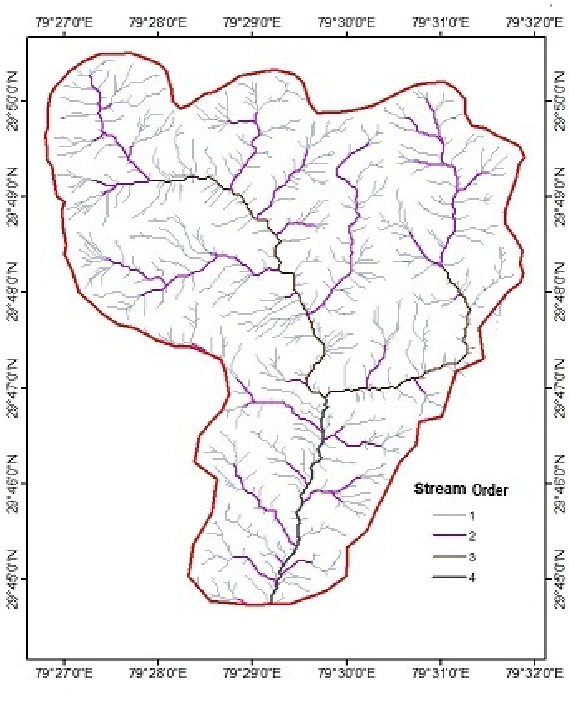

Figure 4.20 Drainage map of Gagas river valley watershed.

4.6 Thematic Maps of the Study Area

'Surface' option of 'spatial analyst' tool of ArcGIS software was used for the preparation of different thematic maps of the study area.

4.6.1 Digital elevation model (DEM)

Digital Elevation Model is a raster representation of the elevations of the ground. Along with elevation it also gives information of topography, flow patterns and accessibility. The DEM of the study area was downloaded from USGS website, having 30 m spatial resolution. The DEM of Gagas river valley watershed is shown in **Figure 4.21**, which was divided into seven elevation classes and elevation varying from 1226 to 2750 m. It was found that maximum area of watershed was under the elevation 1226-1425 m, which occupied about 22.84 % of the study area where agricultural activities were dominant. The remaining six classes of elevation were mostly occupied by forest followed mostly by barren land **(Table 4.10)**. Outlet of the watershed was located at 1226 m above mean sea level.

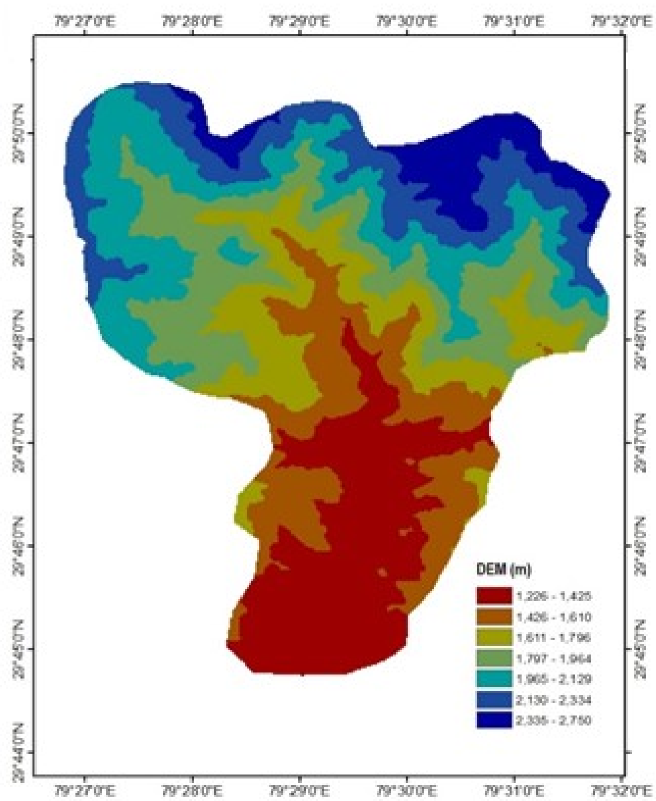

Figure 4.21 Digital elevation model of Gagas river valley watershed.

Table 4.10 Elevation classes and area contribution.

SN	Elevation Range (m)	Area (km^2)	% Area
1	1226-1425	12.27	22.84
2	1426-1610	7.59	14.13
3	1611-1796	6.97	12.99
4	1797-1964	8.52	15.86
5	1965-2129	8.84	16.45
6	2130-2334	6.20	11.54
7	2335-2750	3.34	6.22
Total		**53.73**	**100**

4.6.2 Slope and aspect map

Slope and aspect give degree and direction of slope, decide suitable land use any region can support. Slope algorithm from 'spatial analyst' tool of ArcGIS software was used to prepare spatial distribution of various slope classes, as shown in **Figure 4.22**.

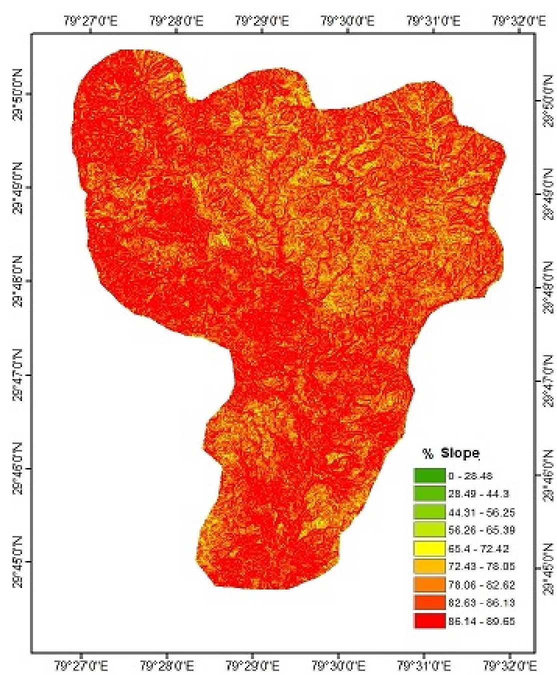

Figure 4.22 Slope map of Gagas river valley watershed.

Percent areal extent of different slope classes in Gagas river valley watershed is shown in **Table 4.11**. The dominant slope category in the Gagas river valley watershed was in the class 86.14 - 89.65% slope which occupied 42.25 % area followed by 82.63 - 86.13 % slope class occupying 28.96 % area. It was also noticed that the slope of major area of agriculture land varied from gently sloping to moderately steep sloping, whereas forest areas were mainly located on higher slopes (moderately steep slopes to above slope degree).

Table 4.11 Areal extent of various slope classes in the study area.

Slope (%)	Area (sq km)	% Area
0 - 28.48	0.09	0.17
28.49 - 44.3	0.23	0.43
44.31 - 56.25	1.09	2.03
56.26 - 65.39	1.32	2.46
65.40 - 72.42	2.09	3.89
72.43 - 78.05	3.24	6.03
78.06 - 82.62	7.41	13.79
82.63 - 86.13	15.56	28.96
86.14 - 89.65	22.70	42.25
Total	**53.73**	**100**

Aspect map was prepared using ArcGIS software, with aspect algorithm from spatial analysis tool, which required elevation layer as input. Further, aspect was divided into nine classes as shown in **Figures 4.23 - 4.24**. Areal extent of different aspect classes, with % area, is shown in **Table 4.12**. It was observed that maximum area (9.55 km^2) was under South aspect (17.78 %) followed by (9.09 km^2) of South - East aspect (16.92 %). Amongst all classes, North -1 aspect had minimum area (3.01km^2), i.e.3.74 % of the total area.

The cumulative areas occupied by North-l, North-East, North-West and North-2 were 24.77 per cent (13.31 km^2), whereas, South-East, South and South-West aspects occupied 50.97 per cent (27.38 km^2) area. Rest area of 13.03 km^2 (24.26 %) was occupied by East and West aspects. It was also observed that the aspect had a bearing on the land use pattern. It was found that North, North-East and East aspects had thicker vegetation in the form of forest, whereas, agricultural activities were mostly taken up on East, South-East, South and West aspects, as these aspects receive greater sunshine hours than northern aspects (North,North-East and North-West).

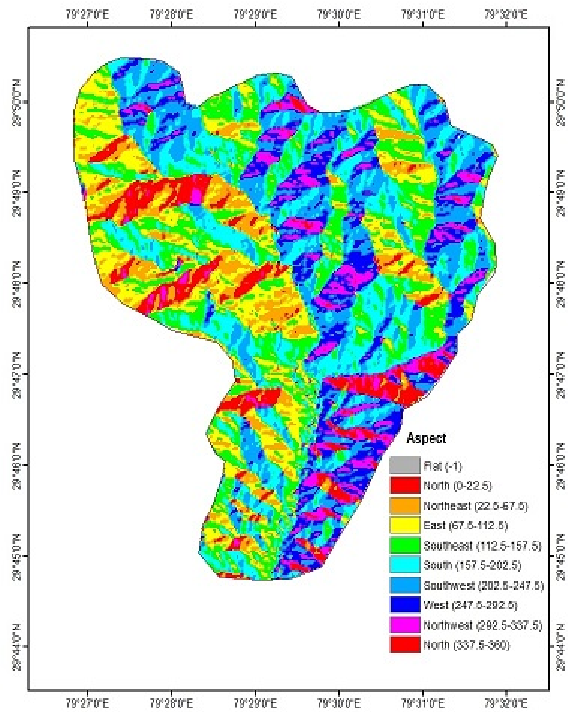

Figure 4.23 Aspect map of Gagas river valley watershed.

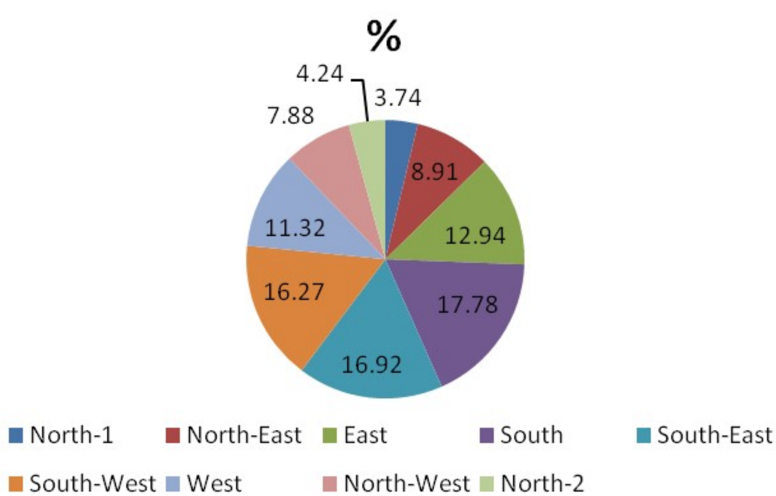

Figure 4.24 Pictorial representation of different aspect classes.

Table 4.12 Areal extent of various aspect classes in the study area.

SN	Aspect	Area (sq km)	Percent of total area
1	North - 1 (0º - 22.5º)	2.01	3.74
2	North - East (22.5º - 67.5º)	4.79	8.91
3	East (67.5º - 112.5º)	6.95	12.94
4	South (157.5º - 202.5º)	9.55	17.78
5	South - East (112.5º - 157.5º)	9.09	16.92
6	South - West (202.5º - 247.5º)	8.74	16.27
7	West (247.5º - 292.5º)	6.08	11.32
8	North - West (292.5º - 337.5º)	4.23	7.88
9	North - 2 (337.5º - 360º)	2.28	4.24
Total		**53.73**	**100**

4.6.3 Land use/land cover map

Integration of Remote sensing and GIS techniques provides reliable, accurate and update database on land and water resources, which is essential for an integrated approach to identify land capability class (LCC), land suitability class (LSC) and suitable sites for water harvesting and soil conservation structures such as check dam, percolation tank, farm ponds, terrace farming etc. Land-use planning is a decision-making process that facilitates the allocation of land to different uses that provide optimal and sustainable benefit. Geo-referenced soil information is required for land-use planning, and monitoring of soil and land quality for agriculture.

The delineated land use/land cover map was classified into three land use classes (i.e. Dense forest mainly of pine, agricultural land, river bed and barren land) as shown in **(Figure 4.25)**. Areal extent of different classes is shown in **Table 4.13**. This table shows that during the year 1965 the highest percentage of area (49.34 %) was occupied by dense forest mainly of pine followed by barren land (26.71 %) and by agricultural land (23.95 %).

To study the changes in the situation of land cover after 1965, different land use / land covers classes were extracted from imagery (i.e. LISS III 2008) downloaded from Bhuwan website by converting it into FCC format satellite with the use of ArcGIS software.

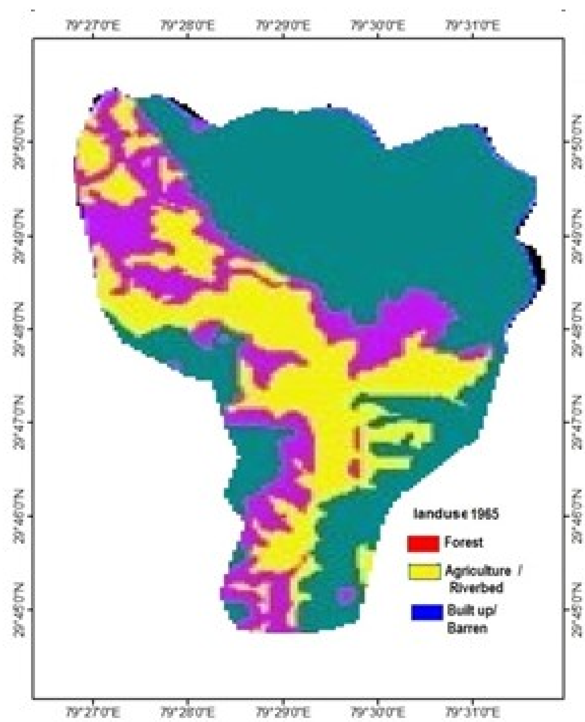

Figure 4.25 Land use / land cover map (1965).

The satellite imagery was masked with the area of interest (watershed divide shape file) using 'clipping / sub setting' tool using unsupervised classification of the software. Satellite data were classified into three classes namely, dense forest, agricultural land along with river bed, barren land plus built-up land. Spatial distribution of various classes for satellite data is shown in **Figure 4.26**.

It is evident from **Table 4.13** that out of total area under study, almost 42.53% was observed under barren and built up land followed by agricultural land (37.65 %) and dense mixed forest 19.82 %. Mostly traditional cultivation methods were being followed with local varieties of crops. The cultivation was being done on well-maintained terraces, especially in valley. The cultivation was being practiced on poorly maintained terraces on higher slope, where soil depth is very low (i.e. 5-10 m only) due to erosion activity. The crops grown were wheat, finger millet, paddy and *ragi*. Cash crops such as peas, tomato, garlic, *Beans* etc. were also grown under irrigated conditions. The produce obtained was not sufficient from these small land holdings because of local varieties having lower yield potential.

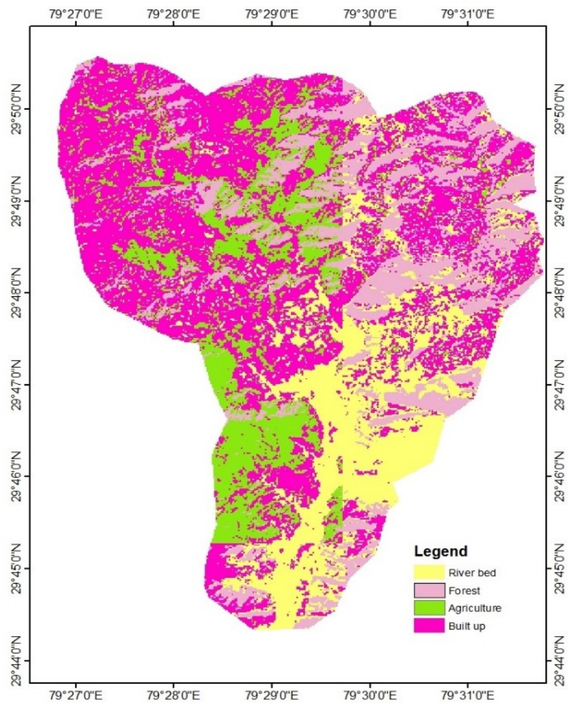

Figure 4.26 Land use / land cover map (2008).

Table 4.13 Area covered under different land uses on the basis of the toposheet of the year 1965 and satellite imagery for the year 2008.

SN	Land use	1965		2008	
		Area (km^2)	% area	Area (km^2)	% area
1	Agricultural land/River bed	12.87	23.95	20.23	37.65
2	Barren land/Built up	14.35	26.71	22.85	42.53
3	Forest	26.51	49.34	10.65	19.82
Total		**53.73**	**100**	**53.73**	**100**

4.6.4 Temporal changes in land use/land cover class map

Land use dynamics was studied on the basis of classifications made by visual interpretation, using digital satellite LISS III data for year 2008, downloaded from BHUWAN website and SOI toposheet No. 53 O/5, 53 O/6, 53 O/9 and 53 O/10 for year 1965 with 1:50000 scale. Due to limitation with regards to land use classification, based on toposheets, only three categories were identified. It was observed that agricultural area along with river bed over a period of 43 years, had increased from 23.95 percent to 37.65 percent, i.e. it increased by about 13.70%. At the same time forest including dense forest mainly of pine and mixed dense forest had decreased from 49.34% of total watershed area in 1965 to 19.82 % in 2008, registering a decrease of 29.52 %, which is an alarming condition for hills. The extent of barren land increased from 26.71 % of total watershed area during year 1965 to 42.53 % during the year 2008, i.e. it increased by 15.82 % over a period of 43 years.

It is clear from **Figures 4.25 and 4.26** that the forest land depicted in **Figure 4.25** had been converted into either agriculture or built up land at lower altitude. This might have happened due to plantation by the Forest Department on barren land, where agricultural activities were seized for years. The forest land at higher altitude during the year 1965 was converted into barren land by the year 2008. This may be due to severe erosion with landslides at higher altitude.

4.7 Land Suitability Classification

Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses.

4.7.1 Criteria for land suitability classification

Soil and climatic limitations in relation to the use, management and productivity of soils are the bases for differentiating capability classes. Classes are based on both degree and number of limitations affecting kind of use, risks of soil damage if mismanaged, needs for soil management, and risks of crop failure. To assist in making capability groupings, specific criteria for placing soils in units, subclasses, and classes are laid. Because the effects of soil characteristics and qualities vary widely with climate, these criteria must be for broad soil areas that have similar climate.

4.7.2 Soil depth

Effective depth includes the total depth of the soil profile favourable for root development. In some soils this includes the G horizon; in a few only the A horizon is included. Where the effect of depth is the limiting factor, the following ranges are commonly used: class A deep > 100 cm, class B moderately deep 75-100 cm, class C shallow 50 – 75 cm. These ranges in soil depth between classes vary from one section of the country to another, depending on the climate. In arid and semiarid areas, irrigated soils in class A are 150 cm or more in depth. Where other unfavourable factors occur in combination with depth, the capability decreases. The soils of Gagas river valley watershed vary greatly in depth, varying from deep to moderately shallow **Figure 4.27.**

4.7.3 Slope

The steepness of slope, length of slope and shape of slope (convex or concave) all influence directly the soil and water losses from a field. Steepness of slope is recorded on soil maps. Length and shape of slopes are not recorded on soil maps; however, they are often characteristic of certain kinds of soil, and their effects on use and management can be evaluated as a part of the mapping unit.

4.7.4 Land suitability classification of Gagas river valley watershed

The land suitability classification of the study area was done on the basis of soil depth, prevailing slope and existing land cover. The soils of the study area varied in depth from very deep (> 100 cm) to quite shallow (50-75 cm). They had moderate permeability in the upper part and rapid permeability in the lower part. The area under different land suitability classes in the Gagas river valley watershed are given in **Table 4.14**.

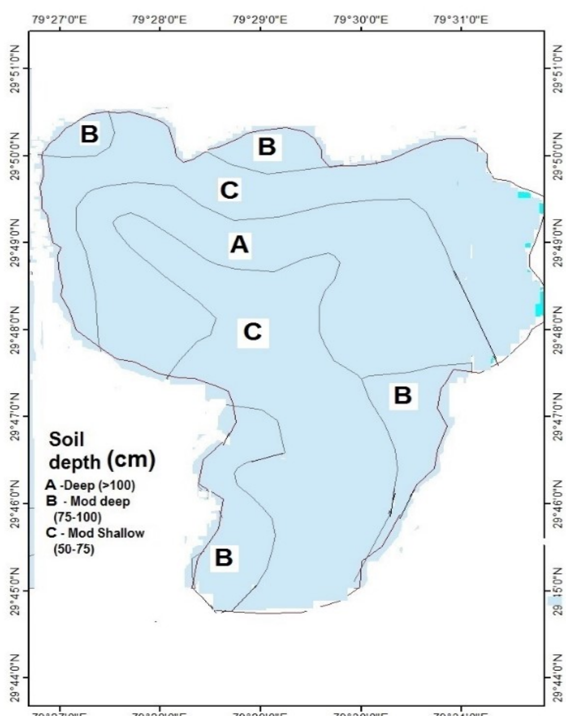

Figure 4.27 Soil depth map of Gagas river valley watershed.

Table 4.14 Land suitability classes in the study area.

Land suitability class	Area, km^2	% Area
I. Dense Forest	5.48	10.20
II. Moderately dense forest	10.53	19.60
III. Agriculture land with severe limitations	13.36	24.87
IV. Agriculture land with no limitations	19.75	36.75
V. Scrub land	4.61	8.58
Total	**53.73**	**100**

An area of 5.48 km^2 (10.20 %) under higher elevations with steep slope fell under dense forest suitability. Similarly, less slopy but high elevation area of about 10.53 km^2 (19.60 %) was found suitable for moderately dense forest. Low elevation but slopy lands of area 13.36 km^2 (24.87 %) were found fit for erosion resistant agricultural crops adopting suitable engineering and agronomic measures. An area of low plains of 19.75 km^2 (36.75 %) towards outlet of the study area was found to be suitable to agriculture with no limitations. Rest area of 4.61 km^2 (8.58 %) was under scrub land **(Figure 4.28)**.

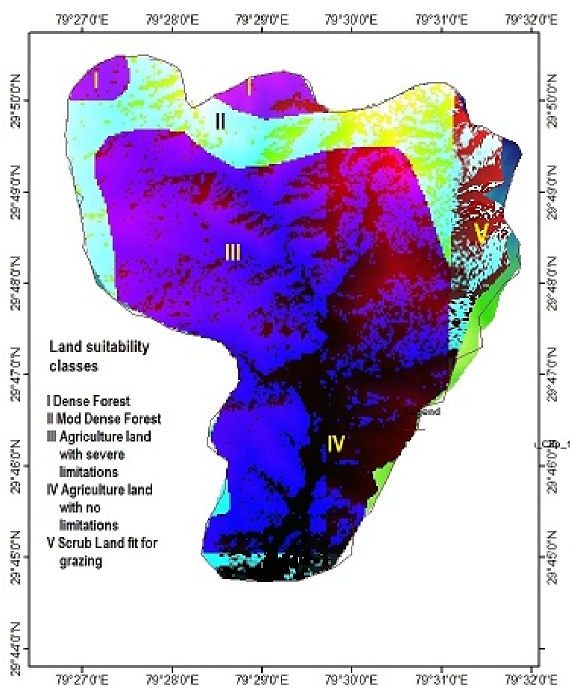

Figure 4.28 Land suitability map of Gagas river valley watershed.

4.8 Morphometric Characteristics of the Watershed

ArcGIS software was used for the digitization, computation and output generation of the drainage network of the watershed. The results of morphometric study are summarized in **Table 4.15**. Methodology adopted for the computation of morphometric parameters are given in **Section 3.6**. The analysis was done through the linear, areal and relief aspects' measurements of the basin.

4.8.1 Linear aspect

The linear aspects of the channel system are stream order (U), stream length (Lu), stream length ratio, bifurcation ratio, basin length, basin perimeter etc. Classification of streams is important to index the scale and size of watershed. Counting of number of streams of various orders and measurement of their lengths from point of origin to outlet was done by GIS software. The statistics of drainage network of the watershed is shown in **Table 4.15**. Gagas river valley watershed is of 4th order and drainage pattern being dendrite. The length of 1st, 2nd, 3rd and 4th order stream segments was found to be 48.368, 28.009, 15.457 and 11.31 km, respectively. It also showed that the total length of stream segments for 1st order streams was maximum. This is satisfying Horton's second law. The stream length ratio (R_L) was estimated as 1.73, 1.81 and 1.37 for II/I, III/II and IV/III orders, respectively. The increasing R_L from lower to higher order indicates matured stage of geomorphology. The change to one order from another order signifies late youth geo-morphological development of streams **(Singh and Singh, 1997).**

Table 4.15 Morphometric analysis for Gagas river valley watershed.

Parameter	**Function/Formula**	**Value**
Area	A	53.73 km^2
Perimeter	P	41.2 km
Stream Length	L_b	-
1st Order		48.368 km
2nd Order		28.009 km
3rd Order		15.457 km
4th Order		11.31 km
Total		103.144
Number of Streams	N_u	-

1^{st} Order		129
2^{nd} Order		33
3^{rd} Order		5
4^{th} Order		1
Total		168
Drainage density	$D_d = \frac{\sum_{i=1}^{w}\sum_{j=1}^{N_i} L_{ij}}{A}$	1.92 km/km^2
Drainage Texture	$T = \frac{N_u}{P}$	4.07
Bifurcation Ratio	$R_b = \frac{N_u}{N_{u+1}}$	5.17
Stream Length Ratio	$R_L = \frac{L_u}{L_{u-1}}$	II/I (1.73) III/II (1.81) IV/III (1.37)
Stream Frequency	$F_s = \frac{N_u}{A}$	3.13/km^2
Basin Length	----	13.6 km
Form Factor	$R_f = \frac{A}{L_n^2}$	0.29
Elongation Ratio	$R_e = \frac{2\sqrt{\frac{A}{\pi}}}{L_b}$ $R_e = \frac{d_c}{L_b}$	0.3
Circulatory Ratio	$R_c = 4\pi \frac{A}{P^2}$	0.4
Relief Ratio	$R_h = H \times L$	0.11
Ruggedness number (Rn)	$R_n = H \times D$	2.3

The classification of streams was done as per ordering of streams by Strahler's system. The main stream was of 4^{th} order and the frequency of 1^{st}, 2^{nd} and 3^{rd} order was

129, 33 and 5, respectively. It is also noticed that with the increase in stream order, there is decrease in stream frequency **(Table 4.15)**. This satisfies the Horton's law of stream numbers. The bifurcation ratio (R_b) is a relief and dissections index **(Horton, 1945)**. As per **Beaumont (1975)**, value of R_b often varies from 2 to 5 and reaches towards higher side for elongated basins. In the present study, R_b was estimated to be 3.91, 6.6 and 5 for I/II, II/III and III/IV orders, respectively, with an average of 5.17. The high value of R_b indicates structural complexity and low permeability **(Pankaj Kumar, 2009)**. It also indicated that the value of R_b was not same from one order to next order. The higher value of R_b reveal higher structural control on the drainage pattern. An elongated watershed has higher bifurcation ratio than normal and approximately circular watershed **(Singh, 2003)**. The watershed was not circular and so it would lead to delayed peak runoff. The basin length and basin perimeter were found as 13.6 and 41.2 km, respectively. Surface runoff moves from the basin perimeter to the nearest stream channel. The length of overland flow is the length, projected to the horizontal, of the non-channel flow, from one point on the drainage divide to another point on the adjacent stream channel **(Horton, 1945)**.

4.8.2 Areal aspect

Areal aspect of morphometric study of the watershed includes the description of areal elements, law of stream areas, stream area and stream length relationship, area to discharge relation, basin shape (circulatory ratio, elongation ratio and form factor), drainage density etc. Drainage area is the area within the boundary of the watershed divide. The drainage density was found to be 1.92 km/km^2. Lower drainage density shows coarse drainage pattern and effect of humid climate of the study area. The coarse texture allows more time for overland flow and ground water recharge. A low drainage density results in a slow stream response **(Singh, 2004)**. Drainage texture, being the important concept of geomorphology, means the drainage lines relative spacing. Drainage lines are more on impermeable areas in comparison to permeable areas. Drainage texture is the total number of stream segments of all orders with in the boundary of that area. It is influenced by infiltration capacity. In the present study, drainage texture ratio was 4.07 which indicated that the drainage was of coarse texture **(Smith, 1950)**.

The value of constant of channel maintenance (C) was found to be 0.52 km. It is defined as the surface area needed to sustain unit length of stream segment in watershed.

The value of C indicated that Gagas river valley watershed was undergoing high structural disturbance with low permeability having steep to very steep slopes with high surface runoff. Stream frequency (F_s) is the ratio of the total number of stream segments of all orders per unit area of the watershed **(Horton, 1932)**. The stream frequency for the study area was found to be 3.13. **Pankaj Kumar (2009)** indicated that the low value of F_s results in lower relief and low infiltration capacity of the bedrocks. It leads to decrease in stream numbers which shows moderate to high erodibility of the rock surfaces. The circulatory ratio (R_c) was estimated to be 0.4 whereas, form factor and elongation ratio were found to be 0.29 and 0.3, respectively. The value of R_c is influenced by stream length and frequency, land use/land cover, and slope and geological structures of the basin. Small form factor gives elongated basin and higher peak flows of lesser durations (**Javed, 2009**). Elongation ratio of 0.3 confirmed that the study area showed high relief with steep ground slope and elongated shape (< 0.7). Efficiency in discharging the runoff is more in circular basin compared to elongated basin **(Singh and Singh, 1997).**

4.8.3 Relief aspect

The relief ratio (R_h) was found to be 0.11. The R_h normally increases with the decreasing drainage area and size of the watersheds for a given drainage basin **(Gottschalk, 1964)**. It measures overall steepness of watershed and also considered as an indicator for the intensity of erosion process occurring in the watershed. The high value of relief ratio is characteristics of hilly region. **Strahler (1957)** defined a dimension less number, called ruggedness number (R_n), as a product of relief (H) and drainage density (D) in the same unit. The value of total relief (H) was found to be 1.524. The areas of low relief but high drainage density are regarded as ruggedly textured as areas of higher relief having less density. In the present study, R_n was found to be 2.93 km. This number represents that if drainage density is increased, keeping relief as constant then average horizontal distance from drainage divide to the adjacent channel is reduced. On the other hand, if relief increases by keeping drainage density as constant, the elevation difference between the drainage divide and adjacent channel will increase.

4.9 Prioritization of Sub-watersheds

Watershed prioritization is one of the most important aspects of planning for implementation of its development and management programs. The present study demonstrates the usefulness of GIS for Morphometric analysis and prioritization of the sub-watersheds of Gagas river valley watershed of Almora district. For that, Gagas river valley watershed was delineated into eleven sub-watersheds (i.e. SWS-I to SWS-XI) using ArcGIS software **(Figure 4.29)**. The morphometric analysis of all the sub watersheds was carried out under three different categories viz. linear, areal and relief aspects, as discussed below.

4.9.1 Linear parameters of sub watersheds

The linear aspects include stream order, stream number, stream length, bifurcation ratio, mean stream length, stream length ratio etc. which were determined and their results have been presented in **Tables 4.16** and **4.17**.

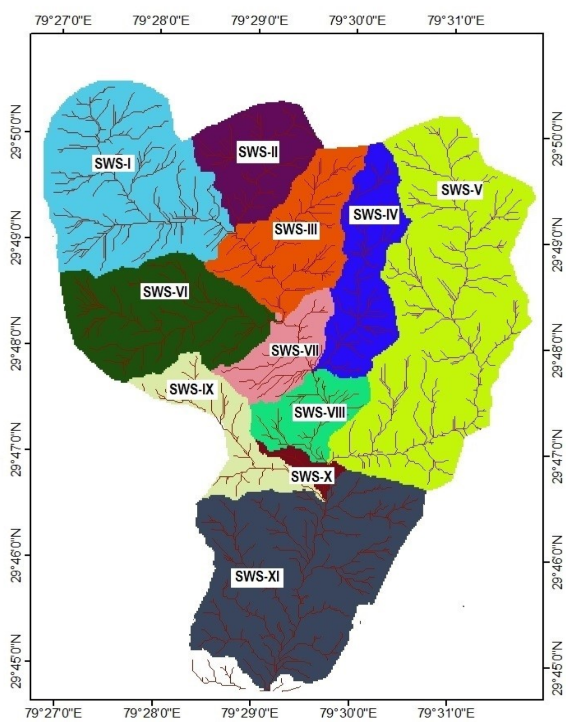

Figure 4.29 Sub-watersheds of Gagas river valley watershed.

Table 4.16 Order wise stream number and stream length of sub-watersheds.

Sub-watershed	Stream numbers in different orders				Order wise stream length (km)			
	1st	2^{nd}	3^{rd}	Total	1^{st}	2nd	3rd	Total
SWS-I	15	5	4	24	2.817	1.874	2.698	7.389
SWS-II	5	2	2	9	1.059	0.700	1.509	3.268
SWS-III	7	5	2	14	2.191	1.863	1.275	5.329
SWS-IV	7	7	-	14	2.312	2.956	-	5.268
SWS-V	31	6	9	46	6.345	2.857	6.274	15.476
SWS-VI	24	6	8	38	5.787	1.944	2.237	9.968
SWS-VII	4	3	-	7	2.843	0.703	-	3.546
SWS-VIII	9	7	1	17	1.141	1.546	0.393	3.080
SWS-IX	9	6	2	17	3.410	1.698	1.350	6.458
SWS-X	2	1	-	3	0.766	0.322	-	1.088
SWS-XI	15	10	11	36	8.151	3.452	2.234	13.837

4.9.1.1 Stream order

The designation of stream order (u) is the first step in morphometric analysis of a drainage basin and the ranking of streams has been carried out according to **Strahler, 1964** method. It is noticed from the **Table 4.16**, that the maximum stream frequency is in the case of first order streams and then for second order. Stream frequency decreases with increase in the stream order in the study area.

4.9.1.2 Mean stream length (L_{sm})

It is a dimensional property revealing the size of drainage networks' components and its contributing surfaces of the basin **(Strahler, 1964).** In general mean stream length increases with increasing stream order **(Table 4.17)**.

Table 4.17 Mean stream length, stream length ratio and bifurcation ratio values for different sub-watersheds.

Name of Sub-watershed	Mean Stream Length (L_{sm})			Stream length ratio (R_L)			Bifurcation ratio (R_b)		
	1st order	2nd order	3rd order	1st order/ 2nd order	2nd order/ 3rd order	Mean (R_L)	1st order/ 2nd order	2nd order/ 3rd order	Mean (R_{bm})
SWS-I	0.188	0.375	0.675	0.67	1.44	1.06	3.00	1.25	2.13
SWS-II	0.212	0.350	0.755	0.66	2.16	1.41	2.50	1.00	1.75
SWS-III	0.313	0.373	0.638	0.85	0.68	0.77	1.40	2.50	1.95
SWS-IV	0.330	0.422	-	1.28	-	1.28	1.00	-	1.00
SWS-V	0.205	0.476	0.697	0.45	2.20	1.33	5.17	0.67	2.92
SWS-VI	0.241	0.324	0.280	0.34	1.15	0.75	4.00	0.75	2.38
SWS-VII	0.711	0.234	-	0.25	-	0.25	1.33	-	1.33
SWS-VIII	0.127	0.221	0.393	1.35	0.25	0.80	1.29	7.00	4.15
SWS-IX	0.378	0.283	0.675	0.50	0.80	0.65	1.50	3.00	2.25
SWS-X	0.383	0.322	-	0.42	-	0.42	2.00	-	2.00
SWS-XI	0.544	0.345	0.203	0.42	0.65	0.54	1.6	0.91	1.26

4.9.1.3 Stream length ratio (R_L)

It is the ratio of mean length of stream segment of one order with its next lower order. It tends to be constant throughout the successive orders of a watershed and has an important relationship with the discharge of surface flow and erosional stages of the basin (**Horton, 1945**). The stream length ratio of different sub-watersheds ranged from 0.25 to 1.41 **(Table 4.17).** The change of stream length ratio in different orders indicates the late youth geomorphic development stage of streams (**Singh and Singh, 1997**).

4.9.1.4 Bifurcation ratio (R_b)

According to **Schumm (1956)**, the term bifurcation ratio (R_b) may be defined as the ratio between the total number of stream segments of one order to that of the next higher order in a drainage basin. **Horton (1945)** considered the bifurcation ratio as an index of relief and dissections. Bifurcation ratio shows variation only where powerful geological control dominates **(Strahler, 1957)**. The mean bifurcation ratio of different sub-watersheds ranged from 1.0 to 2.92 indicating a domination of geological control.

4.9.2 Areal parameters of sub watersheds

The areal parameters such as drainage density, stream frequency, drainage texture, circularity ratio, form factor, elongation ratio, compactness coefficient, shape factor and length of overland flow have been calculated and their results are summarized in **(Table 4.18** and **4.19).**

4.9.2.1 Drainage density (D_d)

It is the ratio of total stream length to the total area of the basin (**Horton, 1932 and 1945). Strahler (1964)** noted that low drainage density is favoured when basin relief is low and vice-versa. The drainage density of the sub-watersheds varied from 0.96 to 2.47. Lower drainage density represents coarse drainage having values not more than 5.0 indicating permeable subsurface strata.

Table 4.18 Areal aspects of sub-watersheds

Sub-watershed	Basin order	Area (A) km^2	Perimeter (P) km	Length (L_b) km	D_d (km/km^2)	F_s ($No./km^2$)	R_t (km^{-1})
SWS-I	III	7.62	11.28	4.94	0.96	3.15	3.02
SWS-II	III	2.89	7.12	3.14	1.13	3.11	3.51
SWS-III	III	3.90	9.30	4.10	1.37	5.64	7.73
SWS-IV	II	3.46	10.20	4.87	1.52	4.05	6.16
SWS-V	III	12.76	17.73	8.84	1.21	3.61	4.37
SWS-VI	III	5.56	10.09	4.46	1.79	6.84	12.24
SWS-VII	II	1.82	6.41	2.13	1.95	3.85	7.51
SWS-VIII	III	1.79	5.93	2.20	1.72	9.50	16.34
SWS-IX	III	4.21	9.70	4.23	1.53	4.04	6.18
SWS-X	II	0.44	4.20	1.79	2.47	6.82	16.85
SWS-XI	III	9.28	13.97	5.47	1.49	3.88	5.78

4.9.2.2 Stream frequency (F_s)

The stream frequency (F_s) is defined as the total number of stream segments of all orders per unit area (**Horton, 1932)**. Stream frequency for the sub-watersheds, in general, indicated positive correlation with the values of drainage density. The values of F_s for all the sub-watersheds varied from 3.11 to 9.5 streams/km^2 **(Table 4.18)**. Higher F_s values, indicate resistant subsurface strata, sparse vegetation and high relief with low permeability of rock formations of the area.

4.9.2.3 Drainage texture (R_t)

It is the product of drainage density and stream frequency. In the present study, the drainage texture values of sub watersheds ranged from 3.02 to 16.85 per km **(Table 4.18)**, showing that all the sub-watersheds come in the category of coarse to very fine texture **(Smith, 1950)**.

4.9.2.4 Form factor (F_f)

It is defined as a dimensionless ratio of the basin area to the square of the basin length **(Horton, 1932)**. The basins with higher form factor are normally circular and have high peak flows for shorter duration, while elongated basins having low form factor value have lower peak flows of longer duration **(Das and Mukherjee, 2005)**. The F_f values for all the sub-watersheds varied between 0.14 to 0.40 **(Table 4.19)**, suggesting more or less elongated shapes with lesser side flows for longer duration.

4.9.2.5 Circularity ratio (R_c)

It is a dimensionless quantity. It is the ratio of the basin area to the area of a circle with circumference equal to the perimeter of the basin. It expresses the degree of the basin's circularity **(Miller, 1953)**. The factors affecting R_c are, the length and frequency of streams, land use/cover, geological structures, climate, slope and relief of the basin **(Chopra *et. al.,* 2005).** The high R_c value indicated that the sub-watersheds were more circular and had high to moderate relief and drainage system was structurally controlled while the lower R_c values of sub-watersheds indicated an elongated shape. In the present study, the R_c values for all sub-watersheds ranged from 0.02 to 0.75 **(Table 4.19)**.

Table 4.19 Areal and relief aspects of sub-watersheds

Sub-watershed	F_f	R_c	S_f	C_c	L_g (km)	R_e	R (km)	R_r	R_n
SWS-I	0.31	0.75	3.20	1.15	0.52	0.63	0.904	0.18	0.87
SWS-II	0.29	0.72	3.41	1.14	0.45	0.61	0.710	0.23	0.80
SWS-III	0.23	0.57	4.31	0.14	0.37	0.54	1.226	0.30	1.68
SWS-IV	0.15	0.42	6.67	0.33	0.33	0.43	1.345	0.28	2.04
SWS-V	0.16	0.51	0.69	1.40	0.42	0.46	1.401	0.16	1.70
SWS-VI	0.28	0.69	3.58	1.21	0.28	0.60	0.785	0.18	1.41
SWS-VII	0.40	0.18	2.49	1.34	0.26	0.72	0.562	0.26	1.10
SWS-VIII	0.37	0.64	2.70	1.87	0.29	0.69	0.463	0.21	0.80
SWS-IX	0.24	0.56	4.25	1.33	0.33	0.55	0.814	0.19	1.25
SWS-X	0.14	0.02	7.28	1.79	0.21	0.42	0.186	0.10	0.46
SWS-XI	0.31	0.60	3.22	1.29	0.34	0.63	0.477	0.09	0.71

4.9.2.6 Elongation ratio (R_e)

The elongation ratio values of all the sub-watersheds range from 0.42 to 0.72 **(Table 4.19)**, indicating that the sub-watersheds were more or less elongated or oval shape, characterised by high relief and steep slopes.

4.9.2.7 Compactness coefficient (C_c)

It is defined as the ratio of basin perimeter to the circumference of a circular area having the same area of the basin **(Gravelius, 1914)**. This factor is indirectly related with the elongation of the basin area. Lower values of C_c indicate more elongation and less erosion, while higher ones indicate less elongation and more erosion **(Patel *et. al.*, 2012)**. The values of C_c in the study area vary from 0.14 to 1.87 **(Table 4.19)**, showing wide variations across the sub-watersheds.

4.9.2.8 Length of overland flow (L_g)

It is inversely related to the average channel slope **(Patel *et. al.*, 2012)**. The higher values of L_g infer the longer flow paths, less surface runoff and low relief with gentle slopes whereas lower L_g values indicate the shorter flow paths, high surface runoff and high relief with steep slopes. The computed values of L_g for all sub-watersheds ranged from 0.21 to 0.52 km **(Table 4.19)** showing lower L_g values, indicating short flow paths having less infiltration and areas of high relief with steep slopes.

4.9.2.9 Shape factor (S_f)

It is the ratio of the square of the basin length (L_b) to the basin area **(Horton, 1932)**. It is a dimensionless factor and is in inverse proportion with form factor. The values of shape factor obtained for study area varied from 0.69 to 7.28 **(Table 4.19)**, which indicated the elongated shapes of the sub-watersheds.

4.9.3 Relief parameters of sub-watersheds

Basin relief, relief ratio and ruggedness number are grouped under relief parameters which are determined and their results are discussed below.

4.9.3.1 Basin relief (R)

It is the difference between the maximum (H) and minimum (h) elevations in the basin and is an important factor to understand the denudation of the basin, which affects the stream gradient and influences the flood pattern along with the sediment quantity that can be transported **(Schumm, 1956)**. The values of R for sub-watersheds ranged from 0.186 to 1.401 km **(Table 4.19)**, which indicated high runoff and low infiltration conditions.

4.9.3.2 Relief ratio (R_r)

It is the ratio between the basin relief and the longest basin dimension parallel to the main drainage line **(Schumm, 1956)**. The areas with high relief and steep slope are characterized by high value of relief ratios **(Mahadeva Swamy *et. al.*, 2011)**. The values of R_r are given in **(Table 4.19)** and range varied from 0.09 to 0.28 for sub-watersheds.

4.9.3.3 Ruggedness number (R_n)

It is a dimensionless quantity, which is expressed as the product of basin relief (R) and drainage density (D_d), indicates the structural complexity of the terrain **(Schumm, 1956).** Mountainous region with higher rainfall and tropical climate exhibit high R_n values **(Kumar *et. al.*, 2011).** The R_n calculated for the study area ranged from 0.46 to 2.04 **(Table 4.19)**.

4.9.4 Sub-watershed priority assignment

The morphometric parameters like stream order, bifurcation ratio, stream frequency, drainage density, form factor, circularity ratio, elongation ratio, length of overland flow and compactness coefficient etc. are termed as erosion risk assessment parameters and have been used for prioritization of sub-watersheds **(Biswas *et. al.,* 1999)**. The linear parameters have direct and shape parameters have an inverse relationship with erodibility. Thus, for prioritization of sub-watersheds, the highest linear parameter value was given rank 1, second was given rank 2 and so on, and the least was given last rank. The lowest value of shape parameters was given rank 1, next lower value was given rank 2 and so on and the highest value was given last rank. Hence, the ranking of the sub-watersheds was determined by assigning the rank of highest value in linear parameters and lowest value of shape parameters. After ranking of every parameter, all the ranks of each sub-watershed were added up for each of the 11 sub-watersheds to obtain compound value and its average. Based on average value of compound parameters (C_p), the sub-watersheds which have lowest C_p value have been given priority one, next lowest have been second priority and so on. The compound parameter values of 11 sub-watersheds were calculated as shown in **Table 4.20.** The sub-watersheds were then categorized into three major priority classes i.e. high priority, medium priority and low priority, on the basis of the range of C_p value **(Table 4.21)**.

4.9.4.1 High priority

Highest priority indicates the greater degree of soil erosion in the particular sub-watershed and potential area for soil conservation treatment. The four sub-watersheds were grouped under high priority class occupying an area of 22.66 km^2 and should be provided with immediate soil and water conservation measures, as they are likely to be subjected to maximum soil erosion. This region is generally dominated by steep slopes, high drainage density, stream frequency and drainage texture with moderate to low values of form factor, shape factor and elongation ratio. Hence, higher priority sub-watersheds are potential watershed development and management zones.

4.9.4.2 Medium priority

There were five sub-watersheds, falling in medium priority, which encompass an area of 20.56 km^2 having moderate slopes, high to moderate drainage density, drainage texture, form factor, stream frequency, circulatory ratio and compactness coefficient.

Table 4.20 Priority rank of sub watersheds on the basis of morphometric analysis.

Sub-watershed	Linear parameters						Shape parameters					C_p value	Final priority
	R_L	R_b	D_d	F_s	R_t	L_g	F_f	S_f	R_c	C_c	R_e		
SWS-I	9	5	11	10	11	1	8	4	11	4	8	7.46	9
SWS-II	10	8	10	11	10	2	7	6	10	3	7	7.64	10
SWS-III	8	7	8	4	4	4	4	9	6	1	4	5.36	3
SWS-IV	11	11	6	5	7	6	2	10	3	2	2	5.91	5
SWS-V	7	2	9	9	9	3	3	1	4	8	3	5.36	3
SWS-VI	5	3	3	2	3	8	6	7	9	5	6	5.18	2
SWS-VII	1	9	2	8	5	9	10	2	2	8	10	6.00	6
SWS-VIII	3	1	4	1	2	7	9	3	8	11	9	6.18	7
SWS-IX	6	4	5	6	6	6	5	8	5	7	5	5.73	4
SWS-X	2	6	1	3	1	10	1	11	1	10	1	4.27	1
SWS-XI	4	10	7	7	8	5	8	5	7	6	8	6.82	8

Table 4.21 Priority wise categorization of sub-watersheds

Ranking range	Priority values	Priority class	Name of Sub-watershed	Area (km^2)	% Area
($4.27 \leq C_p < 5.36$)	1	High	SWS-III, SWS-V, SWS-VI, SWS-X	22.66	42.17
($5.36 \leq C_p \leq 6.82$)	2	Medium	SWS-IV, SWS-VII, SWS-VIII, SWS-IX, SWS-XI	20.56	38.27
($C_p > 6.82$)	3	Low	SWS-I, SWS-II	10.51	19.56

4.9.4.3 Low priority

Two sub-watersheds were found under the low priority class having slight erosion susceptibility zone and may require agronomical measures for protection from the sheet and rill erosion. It covers an area of 10.51 km^2 among all the priority class. This area mainly consists of moderate to low values of drainage density, stream frequency, texture ratio whereas values of shape factor, circulatory ratio, elongation ratio show moderate to high with moderate slope. Hence, low priority sub-watersheds have a low risk of land degradation. Thus soil measures can first be applied to highest priority sub-watershed and then to other sub-watersheds depending upon their priority in order conservation.

The prioritization of watersheds and sub-watersheds are considered as an important aspect of planning for development, management and conservation of the natural resources for their sustainable development. The remote sensing data provides detailed information of the morphometric features. The entire study area was delineated into 11 sub-watersheds and prioritization had been done on the basis of morphometric analysis. On the basis of priority, the sub-watersheds fall into three categories i.e. high, medium and low priority. The result of prioritization revealed that four sub-watersheds out of 11 were found under high priority class (42.17 % area), as they had low compound value (C_p), five sub-watersheds fall under the category of medium priority (38.27% area), having moderate C_p value and the remaining two sub-watersheds were given low priority (19.56% area) which had high C_p value. High priority indicates the greater degree of soil erosion whereas low priority shows the low risk of land degradation. The sub-watersheds which were falling under high priority were more susceptible to soil erosion due to higher erosivity values. Therefore, these sub-watersheds can be taken for suitable soil erosion control measures to preserve the land from further erosion in comparison to medium and low ranking sub-watersheds. Moderate priority region has high to medium values of drainage texture, form factor and circulatory ratio with moderate slopes whereas low priority zone had a low risk of land degradation.

4.10 Management of Natural Resources

On the basis of the study of physico-chemical properties of soil, DEM, Land use/Land cover and drainage maps the following suitable natural resource development plan for the study area has been proposed:

4.10.1 Management of soil and water resources

The soil of the region was generally sand dominated with high organic matter content and acidic in nature. Results of the correlation coefficients, among the soil chemical properties, indicated that the micro- nutrient cations were significantly correlated with each other suggesting about the dynamic equilibrium among them. Soils of the study area were found deficient in nitrogen (N), whereas high in phosphorus (P), potassium (K), Manganese (Mn), copper (Cu) and Iron (Fe) content. Therefore, for maintaining the fertility status of the soils of the study area, the deficient nutrients, as stated above, need to be enriched to enable sustainable agricultural production.

4.10.2 Management of forest land

Although areal extent under forest was good i.e. 19.82 per cent but it needs to be protected and effort should be made to enhance the area under forest. Dense forest area was decreasing in the high priority sub-watersheds (SWS-III, V, VI and X), which must be taken care through afforestation programme to increase the areal extent of dense forest area. Local tree species like *chirpine* and local varieties of bamboo can be used for afforestation programme.

4.10.3 Management of agricultural land

Agricultural production was low in the watershed due to poor irrigation facility, non- availability of good quality seeds and fertilizer. Different watershed management programmes must be undertaken to motivate the farmers for adopting new technologies like poly-house cultivation, agri-horticulture and improved vegetable production. There is an urgent need to promote water harvesting structures and in situ moisture conservation techniques along with efficient irrigation system.

4.10.4 Development of water resources through water harvesting

There was low availability of water resources due to incessant rainfall conditions and non-availability of recharge/harvesting structures in the study area. Construction of suitable water harvesting structures at locations, identified through GIS technology can add up in reducing the shortages of water availability for various developmental activities.

4.10.5 Proposed soil and water conservation measures

In the study area there is a severe problem of degradation of natural resource due to various natural and man-made causes, cultivation of land at higher slopes, whether the land is suitable for cultivation or not is being done for their livelihood, drying-up of water resources and enhanced soil erosion. Strategic implementation of technological intervention in the field of soil health management, erosion control mechanism, conservation of water resource is the need of the hour. Engineering or mechanical measures, are therefore, needed to stabilize the slope, arresting the fine soil which may create conditions conductive to plants growth, improve the moisture status in the region and finally contributes to the recharge of the natural springs.

4.10.5.1 Identification of possible sites of water harvesting structures

Watershed visualization is an important component to understand, analyze or explain the distribution of phenomena on the surface of the earth, and will become increasingly important as volumes of digital spatial data become more unmanageable **(Buttenfield and Mackaness, 1991)**. Geo-visualization has been characterized as a kind of geo-information use with emphasis on individuals using interactive visual tools in the search for unknowns **(MacEachren, 1994)**. Using this concept of Geo-visualization, probable zones of water harvesting sites were identified. To identify the suitable locations, site was visualized through ArcGIS, as per the priority assigned. The watershed was visualized for the best feasibility of positioning a water harvesting structure by overlaying of DEM, slope map, drainage map and Land use/Land cover map.

Decision rules: The decision rules used in the present study for identifying suitable sites for water harvesting structures are discussed below:

a) **Check dams:** Check dams are very popular type of water harvesting structures and have greater importance since it has got complimentary benefit of controlling soil erosion also. In general, they are constructed at lower order streams, the slope of the terrain should be flat to gentle so as to retain maximum quantity of water with less height of check dam. The soils should be less to medium permeable to allow some recharge to the downstream side of the dam, if necessary. It should be located nearer to the agricultural and settlement areas to convey the harvested water **(IMSD, 1995)**.

b) **Farm ponds:** Farm ponds are made either by constructing an embankment across a watercourse or by excavating a pit or the combination of both. According to **Critchley *et a1.* (1991)**, the areas having slope greater than 5 % may be considered unsuitable for water harvesting.

The recommended water harvesting structures, on the basis of guidelines and site conditions (**Table 4.22)** by **IMSD (1995)**, are shown in **Table 4.23**. The potential zones identified for installation of water harvesting structures in the study area are shown in **Figure 4.30**.

Table 4.22 Site conditions for installation of water harvesting structures (IMSD, 1995)

Structure	% Slope	Runoff potential	Stream order	Catchment area	Soil type
Farm pond	0 - 5	Moderate/High	I	1 to 2	Sandy clay loam
Check dam	< 15	Moderate/ High	I to IV	>25	Sandy clay loam

Table 4.23 Recommended water harvesting structures

SN	Land use/Land cover	Area %	Significance	Recommended rainwater harvesting structure
1	Agricultural land	37.65	Unsuitable	-
2	Barren/built up	42.53	Suitable	Percolation tank, check dam, Farm pond
3	Forest	19.82	Suitable	Check dam, Gully plug

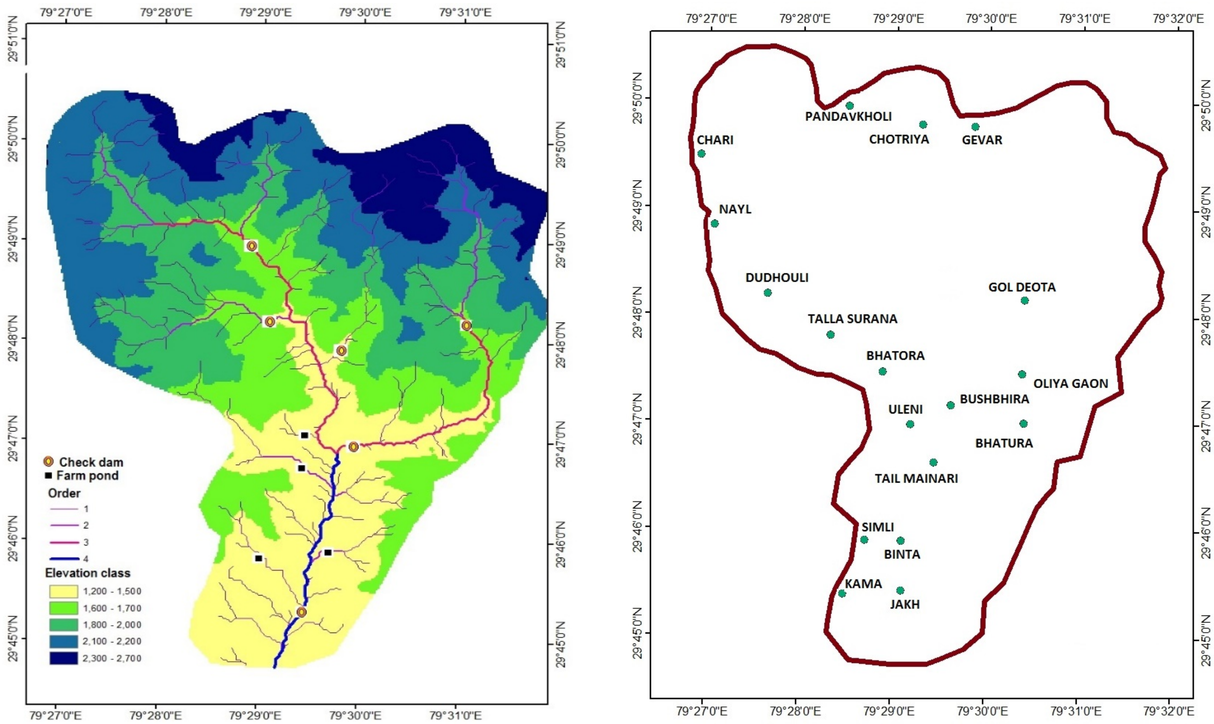

Figure 4.30 Potential water harvesting site of Gagas river valley watershed.

5. SUMMARY AND CONCLUSIONS

5.1 General

Soil and water are the most vital natural resources for agriculture. Agricultural productivity normally depends on efficient use of these resources through their conservation and management. Due to lack of proper planning and skills, there are many areas which suffer for need of utilizable land and water resources. The present study was undertaken to evaluate land and water resources, by assessing soil nutrient scenario, land suitability classification, morphometric analysis and prioritization of sub watersheds for erosion risk assessment and control, of Gagas river valley watershed, which is situated in Almora district of Uttarakhand state in India. The watershed, lies between 79° 26' 20"–79° 31' 50" E long and 29°45' 01"–29° 50' 32" N lat with 52.94 km^2 geographical area. The elevation varied from 1226 to 2750 m above mean sea level (msl). The average annual rainfall of the area was about 1241.2 mm. The maximum and minimum humidity ranged from 98 to 66 per cent and 67 to 25 per cent, respectively. A repeated decrease in the average monthly rainfall was observed during monsoon months in last 30 years (1973-2002) with an increase in mean daily temperature.

5.2 Soil Characteristics

The pH of soils of the study ranged from 4.24 to 6.92 with a mean value of 5.30 which implies the soils of the Gagas river valley watershed were acidic in reaction. The electrical conductance of soil samples varied from 0.02 to 0.23 dS/m with a mean value of 0.10 dS/m which showed that soils were not saline. Soils of Gagas river valley were mostly coarse textured with soil texture varying from loamy sand to silty clay. Major part of the Gagas river valley watershed was having loamy soil. The soil organic carbon content varied from 7.68 to 18.55 g/kg with a mean value of l3.25 g/kg which indicates that soils of study area were rich in organic content. The infiltration rate in the soils of study area was found more at high elevation on greater slope than the lower elevation on gentle slope. The highest infiltration rate observed was 14 cm/hr and average basic infiltration rate observed at two locations in the study area, were found to be 6.0 cm/hr and 4.5 cm/hr whereas, it was found to be 2.0 cm/hr for a location with nearly saturated condition of soil in presence of crop.

In the macro-nutrient analysis of the soils of the study area, the available (mineralizable) nitrogen, phosphorus and potassium content was found in the range of 125.44 to 301.06, 11.6 to 36.4 and 293.4 to 537.6 kg/ha, respectively, whereas the concentration of calcium and magnesium was found to be in the range of 964 to 2684 and 432 to 1728 mg/kg, respectively.

In the micro-nutrient analysis of soils of study area, the concentration of available copper, Zinc, manganese and iron content was found in the range of 0.28 to 2.09, 0.35 to 14.98, 5.23 to 52.65 and 6.54 to 127.02 mg/kg, respectively.

The nutrient index values, less than 1.5, were the indicative of low nutrient status and between 1.5 to 2.5 as medium while higher than 2.5 as high nutrient status. The nutrient index for nitrogen (N) was found low, whereas phosphorus (P), potassium (K), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) content of soil had high nutrient index value which means fertility of soils in the study area is low in nitrogen and it has to be enriched by supplementing with fertilizers and manures.

Soil pH showed positive and significant correlation with EC (r = 0.164) and P (r = 0.131) and S (r = 0.270), whereas, it showed significant negative correlation with Ca (r = - 0.167), Mg (r = - 0.187) and Fe (r = - 0.597).

Soil EC showed positive and significant correlation with P (r = 0.305) and Mg (r = 0.387) and Fe (r = 0.257), whereas, it showed significant negative correlation with Ca (r = - 0.220).

Organic carbon showed positive and significant correlation with nitrogen (r = 0.218) and Ca (r = 0.289) whereas, it showed significant negative correlation with K (r = -0.389), B (r = -0.484) and Zn (r = - 0.150).

Available nitrogen showed the positive and significant correlation with P (r = 0.222), Mg (r = 0.279), Zn (r = 0.181) and Cu (r = 0.407), whereas, it showed significant negative correlation with Ca (r = - 0.269), Fe (r = - 0.209) and Mn (r = - 0.129).

Available phosphorus showed the positive and significant correlation with Mg (r = 0.233) and B (r = 0.311), whereas, it showed significant negative correlation with K (r = - 0.329), Ca (r = - 0.248), Cu (r = - 0.349) and Mn (r = - 0.406).

Available potassium showed the positive and significant correlation with Cu (r = 0.328) and B (r = 0.248), whereas, it showed significant negative correlation with S (r = - 0.479), Mg (r = - 0.312), and Fe (r = - 0.227).

5.3 Land Suitability Classification

The land suitability classification of the study area resulted in five suitability classes (I – V) on the basis of soil depth, prevailing slope, texture and existing land cover. The soils of the study area varied in depth from very deep (> 100 cm) to quite shallow (50 - 75 cm) with coarse texture. They had moderate permeability in the upper part and rapid permeability in the lower part. The area under Class I (dense forest), Class II (moderately dense forest), Class III (agriculture land with severe limitations), Class IV (agriculture land with no limitations) and Class V (scrub land) was 10.20, 19.60, 24.87, 36.75, and 8.58 per cent of the total study area, respectively.

5.4 Morphometric Analysis

The morphometric analysis of whole watershed was achieved through the measurement of linear, areal and relief aspects of the basin using Arc-G.I.S. software. Total length of stream segments of first, second, third and fourth order streams was found to be 48.368, 28.009, 15.457 and 11.31 km, respectively. Stream length ratio (R_L) was calculated to be 1.73, 1.81 and 1.37 for II/I, III/II and IV/III order, respectively. Bifurcation ratio (R_b) was estimated as 5.17. Basin length and basin perimeter were found to be 13.6 and 41.2 km, respectively. Drainage area of watershed was found to be 52.04 km^2. Drainage density was found to be 1.62 km/km^2. Using Melton's equation, stream frequency of watershed was found to be 2.65 per km^2. The circulatory ratio (R_c), elongation ratio (R_e) and form factor (R_f) were found to be 0.47, 0.66, 0.34 and 1.88 respectively. Drainage texture ratio was found to be 4.30. Total relief and relief ratio of watershed were found to be1.524 km and 0.11 respectively. The ruggedness number was found to be 3.67 km.

5.5 Prioritization of Sub-watersheds

The study revealed that the highest number of streams was found in the sub-watershed number SWS-V (46), followed by SWS-VI (38), whereas the lowest number of streams was found in SWS-X (3). The sub-watershed SWS-V contributed the highest proportion of drainage length of 15.476 km (20.72%), followed by SWS-XI which was 13.837 km (18.52%), while the lowest contributors were SWS-VIII and SWS-X contributing about 3.08 km (4.12%) and 1.088 km (1.46%), respectively. The drainage density in the sub-watersheds exhibited a close range in its values from 0.96 km/km^2 (lowest) in SWS-l to 2.47 km/km^2 (highest) in SWS-X. It was found that, the lowest stream frequency was in SWS-II (3.11) and the highest stream frequency was found in SWS-VIII (9.50). The sub-watershed SWS-VIII had highest bifurcation ratio (4.15) followed by SWS-V (2.92). The lowest drainage texture was found to be 3.02 in SWS-I, while the highest was in SWS-X (16.85). The length of overland flow was highest in SWS-I (0.52 km), while lowest was found in SWS-X (0.21 km). Form factor was highest in SWS-VII (0.40) and lowest in SWS-X (0.14). SWS-X had the lowest circulatory ratio of 0.02 and it was highest in SWS-I (0.75). Sub-watershed SWS-VII had the highest elongation ratio of 0.72 and the lowest of 0.42 was found in SWS-X, which indicated that, all the watersheds represent an elongated shape, which indicated steep ground slope and high relief. Compactness coefficient was highest in SWS-VIII (1.87) and1owest in SWS-IV (0.33).

5.6 Soil and Water Conservation Structures

The location of soil and water conservation structures was identified using Geo-visualization concept. The higher reaches were found to be suitable for check dams so as to act as both erosion control and water harvesting structures whereas farm ponds were recommended at lower elevations. About 42.53% of barren/built up land in the study area was suitable for the construction of both check dams and farm ponds. About 19.82% area from forest was suitable for construction of check dams.

5.7 Conclusions

The study led to the following conclusions:

1) Most of the soils in the study area were coarse textured varied from loamy sand to silty clay and acidic in reaction. Organic matter of all soils was generally high.

2) Soils of the study area were deficient in nitrogen (N), whereas, they were high in phosphorus (P), potassium (K) and copper (Cu) content.

3) The slope of major area of agriculture land varied from gently sloping to moderately steep sloping, whereas forest areas were mainly located on higher slopes.

4) The maximum area (i.e. 1009 ha) of watershed was under the elevation of 1226 to 1425 m, which occupied about 19.57% of the watershed area, over which agriculture activities were dominant.

5) The North, North-East and East aspects had thicker vegetation in the form of forest, whereas, agricultural activities were mostly taken up on East, South-East, South and West aspects.

6) The four sub-watershed namely SWS-III, SWS-V, SWS-VI and SWS-X, dominated by steep slopes, high drainage density, stream frequency and drainage texture with moderate to low values of form factor, shape factor and elongation ratio were put under high priority category. These sub-watersheds, occupying an area of 22.66 km^2 (42.17% of total area under study), were found potential watershed development and management zones and, therefore, the soil conservation measures can first be applied to these sub watersheds and then to the other sub-watersheds depending upon their priority.

7) The five sub-watersheds, namely SWS-IV, SWS-VII, SWS-VIII, SWS-IX and SWS-XI, encompassing an area of 20.56 sq.km (38.27% of total area under study) and having moderate slopes, high to moderate drainage density, drainage texture, form factor, stream frequency, circulatory ratio and compactness coefficient were put under medium priority category.

8) Construction of suitable soil and water conservation structures like check dams and farm ponds, at the locations identified through geo-visualization technique, can add up in reducing soil erosion and shortages of water availability for various activities in the Gagas river valley watershed.

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APPENDICES

A-1 Methodology adopted for computation of morphometric parameters

S. No.	Morphometric Parameters	Formula	References
1	Stream order (u)	Hierarchical rank	Strahler (1964)
2	Stream length (L_u)	Length of the stream	Horton (1945)
3	Mean stream length (L_{sm})	**$Lsm = L_u/N_u$** Where, L_u= Total length of stream of order 'u', N_u = Total number of stream segments of order 'u'	Horton (1945)
4	Stream length ratio (R_L)	**$R_L=L_u/L_{u-1}$** Where, L_u= Total length of stream of order 'u', L_{u-1} = The total length of stream of its next lower order	Horton (1945)
5	Bifurcation ratio (R_b)	**$R_b = N_u/ N_{u+1}$** Where, N_u= Total number of stream segments of order 'u', Total length of stream of order 'u', N_{u+1} = Total number of stream segments of next higher order	Schumn (1956)
6	Mean Bifurcation ratio (R_{bm})	Average of bifurcation ratios of all orders	Strahler (1957)
7	Length of main channel(L_m)	Length along longest water course from the outflow point of designated sub-basin to the upper limit of the catchment boundary	
8	Length of overland flow (L_g)	**L_g= 1/2D_d** Where, D_d= Drainage density	Horton (1945)

9	Basin length (L_b)	Distance between outlet and farthest point on the basin boundary	
10	Basin perimeter (P)	Length of watershed divide which surrounds the basin	
11	Fineness Ratio (R_{fn})	**$R_{fn}= L_b/P$** Where, L_b= Basin length (km), P=Basin perimeter, (km)	Melton (1957)
12	Basin Area (A)	Area enclosed with in the boundary of watershed divide	
13	Drainage density (D_d)	**$D_d = L_u/A$** Where, L_u= Total length of stream of order 'u' (km), A= Area of basin, km^2	Horton (1932)
14	Constant channel maintenance (C)	**$C = 1/D_d$** Where, D_d= Drainage density	Horton (1945)
15	Stream frequency (F_s)	**$Fs = N_u/A$** Where, N_u = Total number of stream segments of order 'u', A= Area of basin, km^2	Horton (1945)
16	Circulatory ratio (R_c)	**$R_c=4\pi A/P^2$** Where, A= Area of basin, km^2 , P= Basin perimeter (Km)	Miller (1953)
17	Elongation ration (R_e)	**$R_e=2\sqrt{(A/\pi)}/L_b$** Where, A= Area of basin, km^2, L_b=Basin length (km)	Schumn (1956)
18	Form factor (R_f)	**$R_f=A/(L_b)^2$** Where, A= Area of basin, km^2, L_b=Basin length (km)	Horton (1932)
19	Unity shape factor (R_u)	**$R_u=L_b/\sqrt{A}$** Where, L_b= Basin length (km), A= Area of basin, (km^2)	Horton (1932)
20	Watershed shape factor (W_s)	**$W_s=L_m/D_c$** Where, L_m= Length of main channel, D_c = Diameter of circle having same area as that of watershed	Wu *et al.* (1964)

21	Drainage Texture (D_t)	**$D_t = D_d * F_s$** Where, D_d=Drainage density, F_s= Stream frequency	Smith (1950)
22	Compactness Coefficient (C_c)	**$C_c = P/(2\pi)\sqrt{(A/\pi)}$** Where, P= Basin perimeter (Km), A= Area of basin (km^2)	Gravelius (1914)
23	Shape Factor (S_f)	**$S_f = L_b^2 / A$** Where, L_b= Basin length (km), A= Area of basin (km^2)	Horton (1932)
24	Total relief (H)	Maximum vertical distance between the lowest (outlet) and highest (divide) points on the valley floor of a watershed	-
25	Relief ratio (R_h)	**$R_h = H/L_b$** Where, H=Total relief, L_b= Basin length (km)	Schumn, (1963)
26	Relative relief (R_p)	**$R_p = H/P$** Where, H= Total relief, P= Basin perimeter (km)	Melton (1957)
27	Ruggedness number (R_n)	**$R_n = H * D_d$** Where, H= Total relief, D_d=Drainage density	Melton (1957) and Strahler (1958)

A-2 Farming situations in hill zones of Uttarakhand

Farming Situations	Irrigated valley Zone	Rainfed lower hills zone	Mid hills south aspect zone	Mid hills north aspect zone	High hills zone	Very high hills zone
Geographical area (%)	12	8	36	24	14	6
Altitude range (m)	66-1200	600-1200	1200-1700	1200-1700	1700-2500	>2500
Climate	Sub-tropical	Sub-tropical	Sub-temperate	-	-	Humid temperate
Temperature (°C)	18-30	18-30	15-18.8	-	11-15	5.5-11
Rainfall	Medium	Medium	High	-	Less	Less
Humidity (%)	40-50	40-50	50-60	-	-	-
Soils	Alluvial sandy loam to loam	Residual sandy loam to silt clay loam	Eroded chert, gravely sandy loam to silt loam	Brown forest soil	Dark red to dark black clay loam	Dark red to dark black clay loam
Population	Dense	Sparse	Sparse	-	-	-
Vegetation	Chir pine	Chir pine	Chir pine	Oak and burans	Oak	Quersemecarpifolia, Abiespindrows and Picea

A-3 Major cropping sequences in hill zones of Uttarakhand

Irrigated crops	**Rain-fed crops**
Ragi – wheat / barley / pea / lentil / gram	Ragi – fallow – rice – wheat
Rice – wheat / pea / lentil / mustard / gram	Ragi – fallow – barnyard millet – wheat
Maize – wheat / barley / pea / gram	Soybean – wheat / barley
Soybean – wheat / barley / pea / lentil / rapeseed	Ragi – wheat / barley / lentil
	Rajmah – wheat
	Rice – wheat / rapeseed / mustard
	Barnyard millet – barley / wheat
	French bean – potato
	Potato – pea
	Tomato – cabbage

A - 4 Physiographic zones of Uttarakhand, their attributes and major produces

SN	Zone	Farming situation	Soil	Rainfall (mm/year)	Districts	Principal farm produces
1	Zone A Up to 1000 m above msl.	*Tarai* irrigated	Alluvial	1400	U.S.Nagar, Haridwar	Rice, wheat, sugarcane, lentil, chickpea, rapeseed-mustard, mango, litchi, guava, peach and plums
		Bhabar irrigated	Alluvial mixed with boulders and shingles	1400	Nainital, Dehradun and PauriGarhwal	Rice, wheat, sugarcane, rapeseed-mustard, potato, lentil, mango, litchi, guava, peach and plums
		Irrigated lower hills (600-1000 m)	Alluvial sandy soil	2000-2400	Champawat, Nainital, Pauri Garhwal, Dehradun, Tehri Garhwal	Rice, wheat, onion, chillies, peas, potato, radish, cauliflower, pulses, oilseeds, soybean, mango, guava, peach and plums
		Rainfed lower hills (600-1000 m)	Residual sandy soil	2000-2400	Champawat, Nainital, Pauri Garhwal, Dehradun, Tehri Garhwal, Bageshwar	Maize, finger millet, rice, wheat, mango, guava, pulses, peach and plums
2	Zone B 1000 - 1500 m above msl	Mid hills south aspect (1000-1500 m)	Sandy loam	1200-1300	Champawat, Nainital, Almora, Dehradun, Tehri Garhwal, Bageshwar	Rice, finger millet, wheat, potato, peas, tomato, Cole crops, pulses, peach and plums
3	Zone C 1500 - 2400 m above msl	High hills (1500-2400 m)	Red to dark	1200-2500	Pitthoragarh,Almora, Chamoli, Bageshwar	Amaranath, finger millet, French beans, Cole crops, potato, peas, peaches, and plum, pear, apple, stone fruits
4	Zone D >2400 m	Very high hills	Red to dark black clay	1300	Pitthoragarh, Chamoli, Uttarkashi	Amaranath, buckwheat, peas, Cole crops, apple and potato

A-5 Average monthly rainfall data of the study area for the period 1973 - 2002

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	28.55	19.80	24.34	0.15	29.86	288.78	174.25	397.19	128.70	101.16	0.01	0.75
1974	16.57	14.57	6.34	2.64	25.68	107.72	262.29	193.33	47.94	13.06	0.00	24.52
1975	65.55	25.70	25.16	3.57	8.76	159.66	364.81	332.36	290.80	21.79	0.00	0.00
1976	3.06	52.32	11.48	23.77	19.18	162.23	235.24	618.15	77.98	8.75	0.00	0.84
1977	30.64	4.04	2.02	29.24	78.58	185.45	345.54	205.20	135.59	15.23	0.15	17.18
1978	6.43	12.08	51.15	10.08	5.83	143.96	231.47	411.24	231.17	12.23	4.98	7.86
1979	22.80	37.36	28.78	12.19	52.27	71.55	227.51	192.88	41.26	2.82	17.29	7.60
1980	7.85	21.63	40.26	5.54	11.46	227.28	673.18	458.25	334.02	41.14	1.62	5.92
1981	41.69	14.35	54.57	4.97	64.10	116.42	513.49	144.06	91.38	1.41	25.82	2.19
1982	30.13	11.25	78.31	27.24	51.67	43.17	206.02	483.38	75.40	16.88	2.81	14.93
Avg	**25.33**	**21.31**	**32.24**	**11.94**	**34.74**	**150.62**	**323.38**	**343.60**	**145.42**	**23.45**	**5.27**	**8.18**
1983	62.40	11.66	26.06	63.64	67.75	212.02	294.31	175.55	399.62	42.48	0.00	9.83
1984	11.78	86.90	6.70	21.57	1.14	188.09	249.40	212.10	81.22	2.94	0.00	8.99
1985	23.36	1.79	2.61	19.56	40.90	165.13	370.92	344.19	181.50	103.60	0.00	40.67
1986	3.93	27.67	14.94	25.93	70.95	79.97	473.34	211.85	205.11	28.87	8.53	57.87
1987	20.33	29.92	6.94	8.01	69.31	12.81	85.49	252.82	76.46	9.35	0.00	10.53
1988	7.81	30.86	18.99	24.25	23.05	132.70	529.33	431.30	122.78	1.29	0.77	19.61
												Contd….

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1989	56.96	12.49	19.64	1.36	26.41	169.14	297.28	268.17	131.88	7.04	4.40	6.83
1990	0.76	55.74	36.21	9.02	67.54	104.67	452.69	351.42	123.90	21.05	11.02	43.04
1991	4.79	24.27	22.91	25.00	66.12	46.85	12.55	296.52	81.80	0.34	5.01	8.22
1992	31.92	42.29	15.75	9.15	28.82	107.23	224.33	290.73	94.74	20.48	23.71	0.00
Avg	**22.40**	**32.36**	**17.08**	**20.75**	**46.20**	**121.86**	**298.96**	**283.46**	**149.90**	**23.74**	**5.34**	**20.56**
1993	20.41	12.15	30.17	9.83	40.88	279.15	313.89	110.41	286.09	0.35	0.00	0.00
1994	4.14	2.62	28.30	12.79	40.32	86.26	361.61	345.52	70.55	0.56	0.00	0.94
1995	38.65	43.90	66.30	14.93	5.09	107.63	274.10	466.98	270.30	0.84	16.81	2.38
1996	50.16	37.93	14.04	12.43	38.08	183.46	266.39	336.13	263.77	36.92	0.00	0.57
1997	19.72	7.13	17.43	4.39	43.29	213.67	100.34	257.86	68.91	37.91	13.31	9.65
1998	11.04	26.73	44.55	32.52	23.74	8.80	342.75	472.41	91.86	39.05	5.27	0.52
1999	9.56	8.02	0.78	0.89	28.37	147.30	121.38	115.63	188.25	36.75	0.16	9.39
2000	11.80	52.85	11.47	5.53	45.79	222.56	193.08	304.37	96.82	0.55	0.00	0.24
2001	9.16	11.70	4.13	27.69	76.75	98.23	199.13	87.21	53.27	4.82	0.16	3.55
2002	30.07	48.36	49.16	13.87	3.80	45.80	148.04	195.74	306.67	5.94	0.87	0.26
Avg	**20.47**	**25.14**	**26.63**	**13.49**	**34.61**	**139.29**	**232.07**	**269.23**	**169.65**	**16.37**	**3.66**	**2.75**

A-6 Average monthly temperature data of the study area for the period 1973 - 2002

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	13.56	16.40	20.81	29.88	30.59	30.01	28.85	28.16	27.40	23.56	19.58	13.89
1974	13.13	15.87	23.39	29.07	30.29	30.19	28.41	28.22	27.27	25.85	19.00	12.94
1975	11.39	15.26	20.23	27.70	31.16	29.53	27.66	28.02	26.51	25.55	19.18	15.42
1976	14.21	16.02	20.60	26.06	29.58	29.77	28.50	27.41	27.37	24.66	21.18	15.47
1977	13.95	16.84	23.64	26.57	27.27	30.04	27.75	28.12	26.55	24.16	20.43	13.89
1978	12.73	14.81	17.73	26.14	32.43	30.76	28.00	28.12	26.80	24.95	18.57	15.03
1979	13.84	14.44	19.10	27.72	29.93	31.03	28.50	28.87	27.42	25.31	21.38	14.54
1980	13.63	16.93	19.96	28.54	31.93	29.86	27.94	28.25	27.26	23.97	19.74	15.88
1981	12.18	16.78	19.85	27.06	29.43	31.23	28.24	28.21	27.46	24.91	18.65	13.79
1982	14.33	15.19	17.51	25.72	27.88	30.73	29.57	28.21	27.76	24.36	19.49	15.83
Avg	**13.29**	**15.85**	**20.28**	**27.45**	**30.05**	**30.31**	**28.34**	**28.16**	**27.18**	**24.73**	**19.72**	**14.67**
1983	13.12	13.86	19.76	23.98	29.27	30.05	29.07	28.65	27.31	23.61	18.99	14.38
1984	11.88	14.82	23.74	26.98	32.78	31.05	27.96	28.51	27.21	24.80	18.69	14.88
1985	12.01	17.15	24.69	27.87	30.14	31.04	27.85	28.30	26.61	23.05	19.04	14.84
1986	14.02	16.14	20.06	26.23	27.69	30.39	27.86	28.26	26.96	23.46	19.88	13.34
1987	14.22	17.39	22.99	28.07	28.38	32.04	29.63	28.82	28.07	25.46	21.13	16.98
1988	16.62	18.29	22.05	29.17	31.84	30.62	28.15	28.21	27.56	26.10	19.69	15.09

Contd….

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1989	12.64	16.23	21.74	26.83	30.63	29.38	28.50	27.74	27.50	25.00	19.09	14.74
1990	18.05	15.34	18.51	26.29	29.32	31.67	27.85	28.21	27.05	23.61	19.89	14.97
1991	10.99	16.89	21.69	25.83	31.05	30.07	29.41	28.11	27.30	24.55	18.03	14.59
1992	14.01	14.25	21.29	27.63	28.89	29.94	27.86	27.35	26.51	23.61	19.24	15.08
Avg	**13.76**	**16.04**	**21.65**	**26.89**	**30.00**	**30.63**	**28.41**	**28.22**	**27.21**	**24.32**	**19.37**	**14.89**
1993	12.55	18.42	18.34	25.57	30.32	31.57	28.00	28.26	27.60	24.71	20.27	15.82
1994	15.53	15.70	23.19	25.58	31.39	32.12	29.00	28.40	27.35	24.36	19.49	15.57
1995	12.85	15.86	20.59	26.89	32.74	32.92	27.79	27.31	27.37	25.21	18.82	15.10
1996	13.77	16.24	21.42	27.13	30.60	30.22	27.82	26.30	27.11	24.41	19.27	14.27
1997	14.01	15.89	21.20	26.61	29.02	29.72	30.25	28.35	27.61	21.65	18.94	13.58
1998	7.82	16.89	19.74	27.12	31.54	32.67	28.50	28.17	28.26	24.85	21.58	18.52
1999	13.81	20.33	25.14	33.21	31.58	30.32	30.10	29.55	27.91	25.51	21.99	16.93
2000	15.66	15.69	20.54	29.53	30.73	29.72	28.90	29.01	28.85	26.56	22.05	17.43
2001	14.42	17.09	22.30	26.38	30.84	30.22	29.80	29.71	29.40	26.50	22.24	17.14
2002	15.12	17.39	22.90	28.37	32.98	31.88	31.01	29.30	26.26	25.70	20.38	15.19
Avg	**13.55**	**16.95**	**21.53**	**27.64**	**31.17**	**31.14**	**29.12**	**28.43**	**27.77**	**24.94**	**20.50**	**15.95**

A-7 Interpretation of correlation

Size of Correlation	Interpretation
0.90 to 1.00 (-.90 to -1.00)	Very high positive (negative) correlation
0.70 to .90 (-.70 to -.90)	High positive (negative) correlation
0.50 to .70 (-.50 to -.70)	Moderate positive (negative) correlation
0.30 to .50 (-.30 to -.50)	Low positive (negative) correlation
0.00 to .30 (.00 to -.30)	Negligible correlation

VITA

The author, Krishan Kumar, son of Balbir Singh was born on 11th of August, 1976 at Village Jakhoda of District Jhajjar, Haryana. He obtained his B. Tech. in Agricultural Engineering and M. Tech degree in Agricultural Engineering with specialization in Soil and Water Engineering from Chaudhary Charan Singh Haryana Agricultural University, Hisar in 1997 and 1999 with OGPA 3.38/4.00 and 3.31/4.00 respectively. The author has been working as Assistant Professor in CCS HAU Hisar since August, 2009 and joined Ph. D. programme at Department of Irrigation and Drainage Engineering, College of Technology, Gobind Ballabh Pant University of Agriculture and Technology, Pantnagar, as an in-service candidate of CCS HAU, in the year 2014.

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Thesis Title:	**Land and Water Resource Management in Gagas River Valley Watershed Using Remote Sensing and GIS**		
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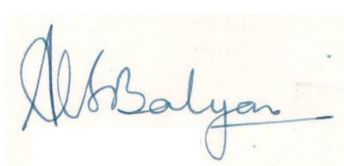
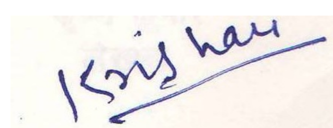
About 30 % of the total geographical area of India is drought prone, primarily, due to erratic pattern of rainfall distribution. Out of about 142 M ha total cultivable land, about 72% is categorized as rain-fed or drought prone. There is a wide scope to harvest the available rain water of the zone 1000-2500 mm. Uttarakhand's mid and high hills come under this category. Single most important key factor for sustaining mountainous agro-ecosystems is water. Mountains are called life giver since they are major sources of all the natural resources including forest, water, land, animal and mineral to not only to the inhabitants of the region but also to those downstream. Uttarakhand's 70% population of mountainous regions, depends mostly on agriculture for their livelihood, but due to various constraints such as climatic, geographical and socio-economic etc. have led to a poor agricultural productivity in the region.

Land and Water Resource management refers to the judicious use of natural resources such as soil, water, plant and animals, resulting in better quality of life for both present and future generations. With this approach in view, the present study of Gagas river valley watershed of Almora district of Uttarakhand state in India, was undertaken in with the objectives to study soil nutrients status, water resources, topography, land use pattern, detailed morphometric analysis for eleven sub-watersheds and their prioritization on basis of morphometric analysis.

Most of the soils in the study area were coarse textured varying from sandy loam to clay and moderate to slight acidic in reaction. The surface soil under cultivated lands were more acidic in reaction than sub-surface soils. Soil of the study area was deficient in zinc (Zn), whereas, Manganese (Mn) and copper (Cu) content were in medium range. Iron (Fe) content of soil was very high in the soil of study area. Water quality was good for irrigation and domestic purposes in the study area. ArcGIS software was used to prepare different thematic maps of the study area by using toposheets and satellite image. The very steep slopes and escarpments were present in majority of study area and forests were on these higher slopes. North l, North-East and East aspects had thicker vegetation in the form of forest whereas agricultural activities were prominent in East, South-East, South and West aspects.

The morphometric parameters' quantitative analysis is of immense importance in watershed prioritization for the purpose of soil and water conservation programmes and natural resources management. The soil conservation measures can first be applied to sub-watershed SWS-III, V,VI and X and then to the other sub-watersheds depending upon their priority. The sub-watershed SWS-II received last priority rank for management. From the results it was concluded that morphometric and land use/land cover analysis could be an effective methodology for identifying the critical areas within the watershed for initiating soil and water conservation programme having scientific flavor, in ungauged watersheds.





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सत्र एवं प्रवेश वर्ष	: द्वितीय समिस्टर 2013-14	उपाधि	: पी0एच0डी0
मुख्य विषय	: सिंचाई एवं जल निकास अभियान्त्रिकी	विभाग	: सिंचाई एवं जल निकास अभियन्त्रण विभाग
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शोध शीर्षक	: **"उत्तराखण्ड के गगास नदी घाटी जल विभाजक में जीआईएस एवं रिमोट सेसिंग के द्वारा प्राकृतिक संसाधनों का प्रबंधन"**		
सलाहकार	: डा0 विनोद कुमार		

प्राकृतिक संसाधन प्रबंधन का मतलब होता है प्राकृतिक संसाधनो (भूमि, जल, मृदा, पौधे एवं जानवर) का प्रबंधन तथा प्रबंधन कैसे वर्तमान एवं भविष्य की पीढियों के जीवन की गुणवक्ता को प्रभावित करता है। जल विभाजक प्रबंधन, भूमि एवं जल संसाधनों के नियोजित विकास के लिए अत्यावश्यकता ग्रहण कर चुका है, और पर्यावरण एवं पारिस्थितिकी संतुलन को बनाए रखने के लिए भूमि क्षरण की प्रक्रियाओं की रक्षा करता है। मृदा और जल संरक्षण का काम शुरू करने के लिए पूरे जल विभाजक के भीतर महत्वपूर्ण क्षेत्रों की पहचान समय, धन और मानव शक्ति की कमी के कारण संभव नहीं है। इन तथ्यों को दृष्टिगत रखते हुए उत्तराखण्ड राज्य के अल्मोडा जनपद अवस्थित **गगास नदी घाटी** जल विभाजक के 11 उप जल विभाजकों में मिट्टी के पोषक तत्वों की स्थिति, जल संसाधन स्थलाकृति, भूमि उपयोग प्रणाली, विस्तृत मार्फोमेट्रिक विश्लेषण का अध्ययन **किया गया।**

अध्ययन क्षेत्र में मिट्टी अधिकांशतः रेतीली दोमट से दोमट एवं मामूली अमलीय पायी गयी। खेती की भूमि की उपरी सतह ज्यादा अम्लीय पायी गयी। अध्ययन क्षेत्र में मिट्टी में जिंक, मैगनीज एवं तॉबा की मात्रा कम एवं लौह की मात्रा अधिक पायी गयी। अध्ययन क्षेत्र के विभिन्न नकशे टोपोशीट एवं आइ जी आइएस सॉफ्टवेयर का उपयोग करके तैयार किये गये। कृषि के बडे क्षेत्र की भूमि कम ढलान से उच्च ढलान पाया गया, जहॉ उच्च ढलानों पर वन क्षेत्र की अधिकता पायी गयी। उत्तर पूर्व और पूर्व के क्षेत्रों में वृक्षों की सघनता एवं कृषि गतिविधिया अधिकतर पूर्वी दक्षिण–पूर्व, दक्षिण और पश्चिम दिशा में पायी गयी।

मार्फोमेट्रिक मापदण्डों कि मात्रात्मक विश्लेषण पर मृदा जल एवं प्राकृतिक संसाधनों के प्रबंधन के लिए अपार उपयोगिता पायी गयी। मृदा संरक्षण के उपायों को पहले प्राथमिकता के आधार पर उप–जल विभाजक 3,5,6 व10 में लागू किये जाने की संस्तुति की गई है। तत्पश्चात अन्य जल विभाजक में प्राथमिकता के आधार पर संस्तुत किया गया है उप जल विभाजक 2 प्रबंधन का प्राथमिकता के आधार पर अन्तिम स्थान प्राप्त हुआ। परिणामों से यह निष्कर्ष निकलता है कि मार्फोमेट्रिक एवं भूमि के उपयोग/भूमि आवरण विश्लेषण, मृदा और जल संरक्षण कार्यक्रम के लिए एक प्रभावी साधन हो सकता है।

कृष्ण कुमार

विनोद कुमार
सलाहकार

कृष्ण कुमार
लेखक

MORPHOMETRIC ANALYSIS OF OF GAGAS RIVER VALLEY WATERSHED IN ALMORA DISTRICT OF UTTARAKHAND USING REMOTE SENSING AND GIS

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ABSTRACT

The measurement of morphological parameters is laborious and cumbersome by the conventional methods, but using the latest technology like GIS, the morphometric analysis can be better achieved. Morphometric parameters play very important role in generating water resources action plan for location recharge and discharge areas. Nowadays, integration of Remote Sensing and GIS is helpful in planning and management of land and water resources for adoption of location specific technologies. In the present study, Morphological characteristics of the Gagas river valley watershed are described and their inter-relationship has been established. Drainage morphology along with slope map is also explored for locating and selecting the water harvesting structure like percolation tank, pond, check dams etc.

Keywords: Watershed, GIS, Morphology and Drainage Network

PRIORITIZATION OF SUB-WATERSHEDS OF GAGAS RIVER VALLEY USING REMOTE SENSING AND GIS

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ABSTRACT

Watershed prioritization based on morphometric analysis is important for soil and water conservation and management at micro level. Remote sensing and GIS are effective tools for prioritization of sub-watersheds. Gagas river valley watershed located in Almora district of Uttarakhand has been taken up for the study. The watershed was divided into 11 sub watersheds and the morphometric analysis of areal, linear and relief parameters was done by using ArcGIS software. The morphometric parameters that affect the soil erodibility are considered to prioritize the sub watersheds and assigned ranks on the basis of relationships with erodibility so as to arrive at a compound parameter (C_p) value for final ranking of each sub watershed. The sub-watershed with the lowest C_p value has been given the highest priority and then categorized the sub-watersheds into three classes as high, medium and low in terms of priority. The analysis reveals that high priority zone consists of four sub-watersheds (22.66 sq.km), medium of five (20.56 sq.km) and low of two sub-watersheds (10.51 sq.km). The sub-watersheds which are falling under high priority are much more susceptible to soil erosion and should be given high priority for land conservation measures.
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Keywords: Morphometric parameters, Prioritization, Sub-watersheds, Remote sensing, GIS

Introduction

Watershed prioritization is the ranking of different sub-watersheds of a watershed according to the order in which they have to be taken for treatment through water and soil conservation measures. Morphometric analysis could be used for prioritization of sub-watersheds by studying different linear, aerial and relief aspects of the watershed. Remote sensing and Geographic Information System (GIS) are the most advanced tools for watershed prioritization studies. Morphometry is the measurement and mathematical analysis of the configuration of the earth surface, shape and dimension of its landforms [Clarke, 1966][1]. In the present study, an attempt has been made to prioritize the sub-watersheds of Gagas River Valley Watershed on the basis of morphometric analysis for watershed conservation, management and developmental planning by using remote sensing and GIS techniques.

Study Area

Gagas river valley watershed comprises of an area 53.73 sq km and perimeter 41.2 km. It lies between 79° 26' 20"–79° 31' 50" E long and 29° 45' 01"–29° 50' 32" N lat. The topography of the region varies from 2750 m above mean sea level in the head reaches in the northern part to 1226 m above mean sea level at the outlet in the southern part of the basin. Geologically the study area is a part of Lesser Himalayan Zone [Valdiya, 1989][2]. More than 80% of the annual precipitation in the region occurs during the south-western monsoon, which starts in the third week of June and last

LAND USE AND LAND COVER CHANGE DETECTION INGAGAS RIVER VALLEY WATERSHED USING REMOTE SENSING AND GIS

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ABSTRACT

Land use and land cover change is digitally detected by using remote sensing and geographical information system (GIS) techniques. In the present study, theland use and land cover changein the Gagas river valley watershed is quantitativelyanalyzed. To find the change from 1965 to 2008, Survey of India (SOI) toposheets of the year 1965 and LISS III 2008-year data have been used. Supervised classification method with maximum likelihood technique has been used in ERDAS and ArcGIS softwares to categorize the images into three classes, viz., forest, agriculture and barren land. During the last four decades, it was found that due to afforestation in the Gagas river valley watershed the forest cover has been increased by about 8.4 % (or 2.20 km^2) and the agricultural and barren land have decrease by 0.13 % (0.164 km^2)and by 7.3 % (3.864 km^2), respectively.

KEYWORDS: Land use, Land cover, Topography, Remote sensing, GIS

INTRODUCTION

The terms, Land use and land cover are often used interchangeably [Dimyati *et al.*, 1996][1].As per[Longley, 2001][2], "land cover refers to the physical materials on the surface of a given parcel of land, while land use refers to the human activities that takes place on or make use of land, e.g., residential, commercial, industrial etc." [Jensen, 2007][3] in his investigation of urban landscape reflect land use as away by which human beings utilize land, while land cover exists as a natural environmental system. Land use and land cover are important factors in understanding the interactions of the human activities with the environment, and thus it is necessary to be able to