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# TRENDS IN HEAVY RAINFALL OVER SELECTED STATIONS IN INDIA

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**Abstract**

The impact of global warming and climate change has resulted in the increase of both the frequency and intensity of extreme weather events like flash floods, heavy rainfall events and cloud burst etc. The beginning of this century has witnessed such extreme weather events which are becoming more prominent. And hence, this has prompted to investigate the trends in Heavy rainfall over 13 stations during the period from 1902-2009 spread across the Peninsular and Gangetic plain of India. The heavy rainfall data set were subjected for trend analysis. This analysis concludes that stations receiving rainfall (6.5 cm to 12.5 cm) indicate that 62% of the stations reported significant decrease in rainfall. The same behavior is also observed during the monsoon season. The stations that received rainfall (12.5 cm to 25 cm) indicates that majority of them reported significant decreased in rainfall amount. Further, this decrease is attributed to the decrease in the frequency of cyclones and depressions over the Bay of Bengal and land. And the same reason can be attributed to the decrease in heavy rainfall events over the interior India.

## 1. INTRODUCTION

Climate change has become debated topic and scientific findings shows that changes in precipitation are predominant around the globe; particularly in heavy precipitation while some provide clues for a decreasing trend. Climate model generally predict an increase in extreme precipitation events as a result of Greenhouse gases emissions. The impact of global warming and climate change has resulted in the increase of both the frequency and intensity of extreme weather events like flash floods, heavy rainfall and cloud burst etc. The beginning of this century has witnessed such extreme weather events which are becoming more prominent. The knowledge of extreme weather events – heavy rainfall - is vital for the Indian economy as it is rain dependent.

These events would lead to crop failures, floods and droughts, colossal loss of life and property. This has led to the increase in the numbers of hydro meteorological disaster during the past decades. Heavy to heavy rainfall is the major cause of this disaster confined mostly in urban areas because of poor engineering works. And hence it is relevant to study this rainfall viability which is critical for the economy of the country.

The recent extreme heavy rainfall events over Cherrapunjee (15–16$^{th}$ June, 1995), Amini Devi (5–6$^{th}$ May 2004) and Mumbai (26-27$^{th}$ July 2005) prompted to ponder whether there is any significant trend in heavy rainfall events over the Interior parts of the country. Occurrences of heavy rainfall are becoming more and more frequent in the last few decades which are prominent feature of freak weather conditions. Whether these severe weather events are only isolated occurrences like the flash floods of Leh in 2010 or is there any significant changes occurring over the country?

## 2. LITERATURE REVIEW

According to (IPCC 2001; IPCC 2007); regional precipitation has been found erratic in some areas as well as the extreme events appeared to have increased both in number and intensity. Observations reveal that over the past century the earth is warming, but there are significant differences at regional levels. The existence of climatic change has been commonly addressed by the climatologists and meteorologists on spatio-temporal scales- global, regional, and national and at urban/local levels.

The analysis of precipitation trends during the 20th century has attracted the attention of researchers in different regions of the world. Most of the studies related to climate change by researchers have examined the evidences of change in rainfall pattern and extremes (Trenberth, 1999; Zhai *et al*., 1999; Groismann *et al*., 1999; Peterson *et al*., 2002; Klein Tank and Konnen, 2003; Easterling, 2003).

Trends in the number of extreme rainfall days have decreased significantly throughout South Asia and the Western and Central South Pacific but increased in the north of French Polynesia, Fiji and in Australia. The proportion of extreme annual rainfall has increased and the frequency has declined (Manton *et al*, 2001). Observed change in precipitation in Northeast Spain reveals that there is an increased in precipitation in winter/summer with a higher number of extreme events (Ramos and Martinez-Casasnovas, 2006). Also, there is a significant increasing trend in extreme precipitation in Europe as reported by Moberg et al (2006).

Rainfall trend over India has been the subject of scientific investigation on different time scale and many methods of approach have been employed to determine the trends. There is an increase in frequency of extreme daily precipitation events according to the study conducted by Shouraseni Sen Roy *et al*, (2004), where they used standardized regression coefficient technique. Recently, Goswami *et al* 2006, found increasing trend of extreme rain events over India by using trend analysis. Recent studies by Shouraseni Sen Roy, 2009) reveals increasing trend in extreme hourly precipitation over north-western Himalaya, Indo-Gangetic basin however the southern west coast experienced a declining trend. Further, Ghosh *et al* (2009) reported increasing trend in heavy rainfall and decreasing trend in moderate rainfall during summer monsoon rainfall over India.

Thus, it is clear that the rainfall is very an important weather element whose trend analysis would throw light on the performance of monsoon season both spatial and temporal scales. However, trends in heavy rainfall are also equally relevant to investigate. It is also interesting to study the changing rainfall amounts spatio-temporally. Sometimes heavy rainfall events can occur in one day exceeding the monthly normal. Therefore, it is necessary to monitor closely the trends in heavy rainfall across the Deccan Plateau and Gangetic Plain of the country. This has prompted to examine whether the extreme weather events are becoming more frequent over the Interior India and whether the extreme events are region specific? In order to seek answers to the above mentioned queries, it is necessary to examine the annual and monsoon extreme rainfall over the study areas during the 107 years.

## 3. DATA AND METHODOLOGY

The heavy rainfall data for 13 stations was acquired from Indian Meteorological Department (IMD) Pune for the period 1901-2009 as provided in Table 1. The heavy rainfall events are classified as per the IMD norms which are of three types - one data signifying the threshold amount of rainfall ranging from 6.5 cm to 12.5 cm, 12.5 cm to 25 cm and 25 cm to 9999.9 cm. Apart from this data set the frequency of cyclones/ depression and severe cyclones were collected from IMD website www.imd.gov.in. The extreme value has been computed for all the months focusing on monsoon season and annual scales. In order to determine the significance of trend linear regression coefficients and t-test were employed and tested at 0.05 and 0.01. Time series were plotted for the entire periods of record.

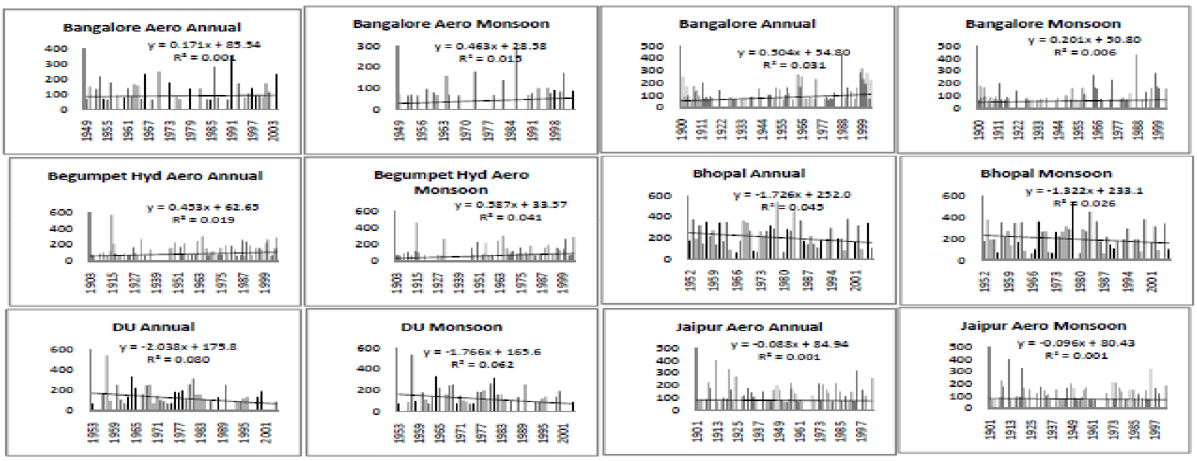
**Table 1: Location and Data range of 13 stations**

| Stations | Data Range | Elevation | Latitude and Longitude |
|---|---|---|---|
| Bangalore Aero | 1949-2004 | 915 m | 13°11′56″N 77°42′20″E |
| Bangalore | 1900-2004 | 920 m | 12°58′ 0″ N 77°34′0″ E |
| Begumpet Aero | 1903-2006 | 531 m | 17°27′11″N 78°28′03″E |
| New Delhi Safdarjung (S) | 1902-2005 | 215 m | 28°35′04″ N 77°12′21″E |
| Pune | 1905-2006 | 560 m | 18°31′13″N 73°51′24″E |
| Bhopal | 1952-2006 | 427 m | 23°15′ N 77°25′ E |
| Delhi University (DU) | 1953-2004 | 216 m | $28^0$ 59' N $77^0$21'36' E |
| Jaipur Aero | 1901-2004 | 385 m | 26°49′27″N 75°48′44″E |
| Mausi Lucknow (LKN) | 1951-2006 | 123 m | 26°45′43″N 80°53′00″E |
| Nagpur Aero | 1943-2005 | 315 m | 21°32′01″N 79°02′50″E |
| Nagpur Meyo Hospital | 1901-2003 | 311 m | 21° 09' N, 79° 09' E |
| Delhi Palam | 1961-2005 | 237 m | $28^0$33'16'' N $77^0$5'58'' E |
| Patna Aero | 1947-2006 | 52 m | 25°35′37″N 85°05′31″E |

## 4 RESULT AND DISCUSSIONS

### 4.1 TRENDS IN EXTREME RAINFALL (6.5 cm - 12.5 cm)

The trends in the heavy rainfall for the study regions are shown in Table 2 and for the significant stations are depicted in Fig 1.



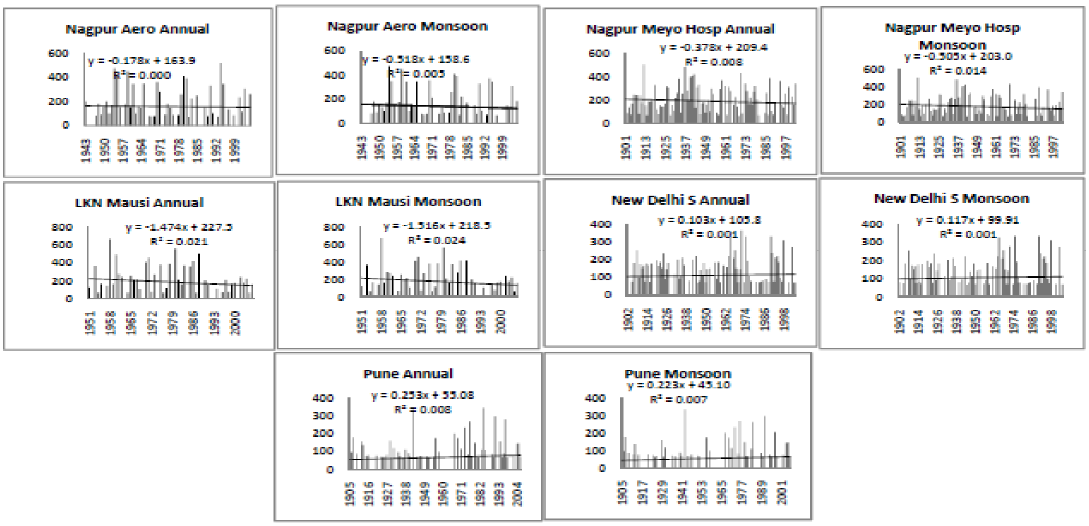



**Figure 1. Trends in Heavy rainfall extremes events (6.5 cm -12.5 cm)**

**Table 2: Trends in Heavy Rainfall Extremes (6.5 cm - 12.5 cm)**

| Stations | Year | $R^2$ | T-value | Significant level |
|---|---|---|---|---|
| **Annual** | | | | |
| Bangalore Aero | 56 | 0.031623 | 1.33 | + |
| Bangalore | 105 | 0.176068 | 4.69 | +** |
| Begumpet Aero | 104 | 0.13784 | 4.04 | +** |
| New Delhi Safdarjung | 104 | 0.031623 | 1.83 | +* |
| Pune | 102 | 0.089443 | 3.13 | +** |
| Bhopal | 55 | 0.212132 | 3.78 | -** |
| Delhi University | 52 | 0.282843 | 4.44 | -** |
| Jaipur Aero | 104 | 0.031623 | 1.83 | -* |
| Mausi Lucknow | 56 | 0.144914 | 3.03 | -** |
| Nagpur Aero | 63 | 0 | 0.00 | - |
| Nagpur Meyo Hospital | 103 | 0.089443 | 3.15 | -** |
| Delhi Palam | 45 | 0 | 0.00 | - |
| Patna Aero | 60 | 0 | 0.00 | - |
| **Monsoon** | | | | |
| Bangalore Aero | 56 | 0.122474 | 2.75 | +** |
| Bangalore | 105 | 0.07746 | 2.94 | +** |
| Begumpet Aero | 104 | 0.202485 | 5.09 | +** |
| New Delhi Safdarjung | 104 | 0.031623 | 1.83 | +* |
| Pune | 102 | 0.083666 | 3.02 | +** |
| Bhopal | 55 | 0.161245 | 3.19 | -** |
| Delhi University | 52 | 0.248998 | 4.07 | -** |
| Jaipur Aero | 104 | 0.031623 | 1.83 | -* |
| Mausi Lucknow | 56 | 0.154919 | 3.15 | -** |
| Nagpur Aero | 63 | 0.070711 | 2.15 | -* |
| Nagpur Meyo Hospital | 103 | 0.118322 | 3.68 | -** |
| Delhi Palam | 45 | 0 | 0.00 | - |
| Patna Aero | 60 | 0 | 0.00 | - |

***Note-Aero-aerodrome, * Indicate 0.05% and ** 0.01% Significant Trend***

From the above table, it can be concluded that for annual, 4 out of 5 stations namely- Bangalore city, Begumpet Aero, New Delhi Safdarjung and Pune show increasing trend significant at 95% and 99% except for Bangalore Aero. For the remaining 8 stations, five are significant - namely Bhopal, Delhi University, Jaipur Aero, Mausi Lucknow and Nagpur Meyo Hospital reported significant decrease in rainfall except at Nagpur Aero, Delhi Palam and Patna Aero. The same behavior is noticed during the monsoon season too. However, the stations namely Delhi Palam and Patna Aero doesn't indicate significant trend during the monsoon season.

The above table indicates that 62% of the stations (8) reported decrease in rainfall whereas only 38% (5) of the stations reported increase in rainfall. So, the analysis concludes that majority of the stations receives less amount of heavy rainfall in annual and monsoon season.

## 4.2 TRENDS IN VERY HEAVY EXTREME RAINFALL (12.5 cm - 25.5 cm and >25 cm)

The trends in the very heavy extreme rainfall for the study regions are shown in Table 3 and for the significant one are depicted in Fig 2.

**Table 3: Trends in Very Heavy Rainfall Extremes (12.5 cm - 25.5 cm and above)**

| Stations | Year | $R^2$ | T-value | Significant level |
|---|---|---|---|---|
| **Annual** | | | | |
| Patna Aero | 61 | 0.070711 | 2.12 | +* |
| Jaipur Aero | 99 | 0.109545 | 3.45 | +** |
| Bhopal | 52 | 0 | 0.00 | - |
| Delhi University | 49 | 0.192354 | 3.35 | -** |
| Maus Lucknow | 54 | 0.118322 | 2.64 | -** |
| Nagpur Meyo Hospital | 101 | 0.148324 | 4.15 | -** |
| New Delhi Safdarjung | 100 | 0 | 0.00 | - |
| **Monsoon** | | | | |
| Patna Aero | 61 | 0.126491 | 2.92 | +** |
| Jaipur Aero | 99 | 0.109545 | 3.45 | +** |
| New Delhi Safdarjung | 100 | 0 | 0.00 | + |
| Bhopal | 52 | 0 | 0.00 | - |
| Delhi University | 49 | 0.148324 | 2.86 | -** |
| Maus Lucknow | 54 | 0.070711 | 1.99 | -* |
| Nagpur Meyo Hospital | 101 | 0.141421 | 4.04 | -** |

***Note-Aero-aerodrome, * Indicate 0.05% and ** 0.01% Significant Trend***

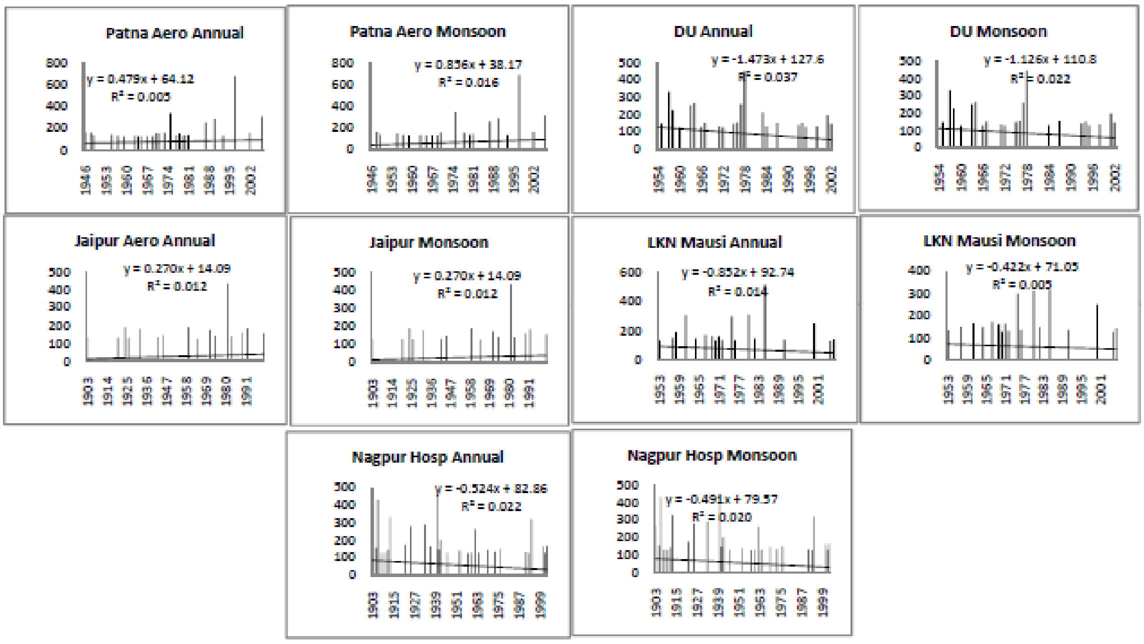



**Figure 2. Trends in Heavy rainfall extremes events (12.5 cm -25.5 cm)**

It is observed from the above table that 2 out of 7 stations namely Patna Aero and Jaipur Aero reported increasing trend at 95% and 99%. While the stations namely Delhi University, Mausi Lucknow and Nagpur Meyo Hospital show significant decrease in rainfall at 99% except for New Delhi Safdarjung and Bhopal. The same trend is also observed for the monsoon rainfall as well. It can be concluded that majority of the stations that is 71% reported decrease in rainfall as compared to increase.

The stations that receive rainfall above 25 cm indicate that none of them reported increasing/decreasing trend. There were few occasions of Very Very heavy rainfall amounts and hence it is not possible to compute the trend. The above study indicates that the interior India receives less amount of rainfall in terms of heavy rainfall to very heavy rainfall.

### 4.3 TRENDS IN HEAVY RAINFALL AND ASSOCIATED SYSTEMS

The above findings reveal that there is a decreasing trend in heavy rainfall amount over the Deccan and Gangetic Plains significantly. However, 30 % of the stations reported increasing trend significantly. The decreasing trends in the study areas were investigated with the help of synoptic circulations. It is a known fact that the heavy rainfall , Very heavy rainfall to Very Very heavy rainfall are caused either by cyclonic circulations, lows, cyclones and depressions, monsoon troughs, north-south troughs, east-west troughs etc. Among the above-mentioned systems, only the trends in cyclones and depressions are used. In order to understand the causative factor for these trends in heavy rainfall the data related to cyclones and depressions were collected from IMD publications during the last 118 years. The frequency of Cyclones and depressions on annual and monsoon seasonal scales are depicted in Fig. 3

.

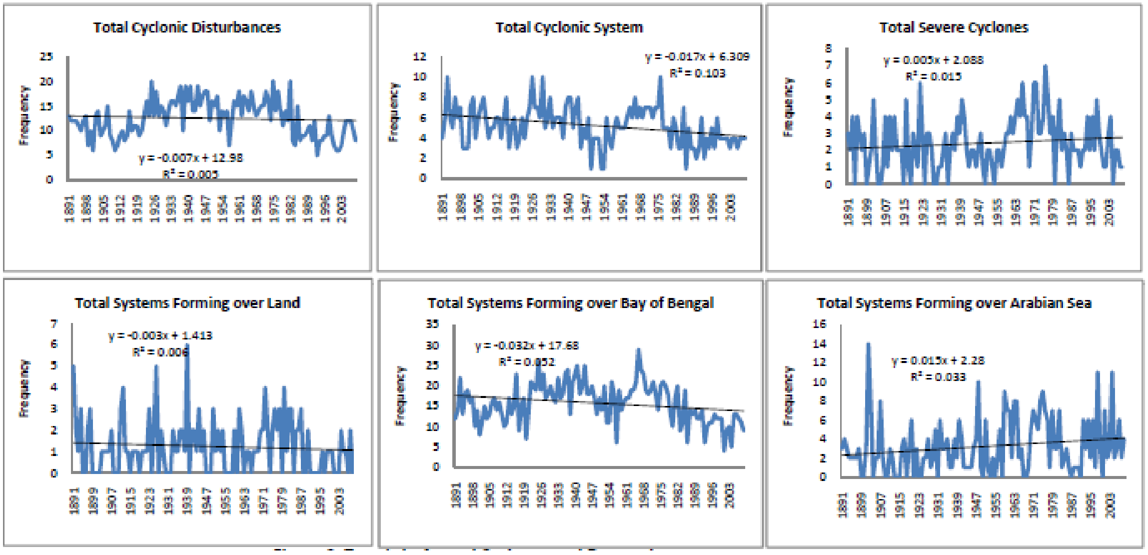



**Figure 3. Trends in Annual Cyclones and Depression**

The figure clearly indicates that the trends in annual cyclonic disturbance, cyclonic system and total system forming over land, Bay of Bengal reported significant decreasing trend except for total cyclonic disturbances. On the other hand, there is an increase in total severe cyclonic storms over Arabian Sea in annual and monsoon season. Further, the synoptic systems forming over land and Bay of Bengal in both the time scale of annual and monsoon season show a decreasing trend significantly.

It is also revealed that from the Fig 4 and 5 total system namely cyclones, depressions and cyclonic storms forming over Bay of Bengal, Arabian Sea and over the land during the monsoon season show decreasing trend significantly.

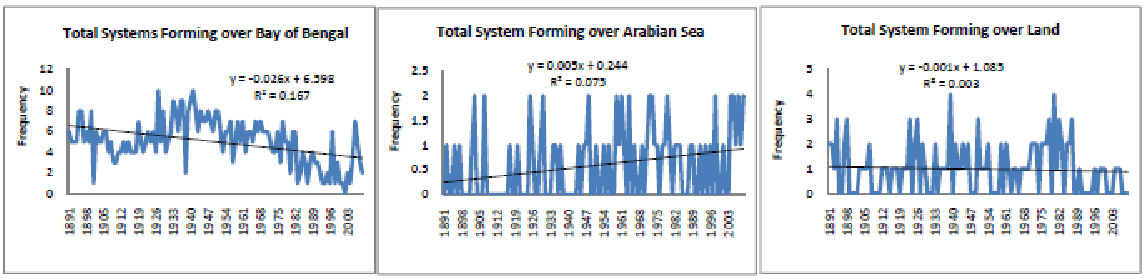



**Figure 4. Trends in Cyclones and Depression During Monsoon season**

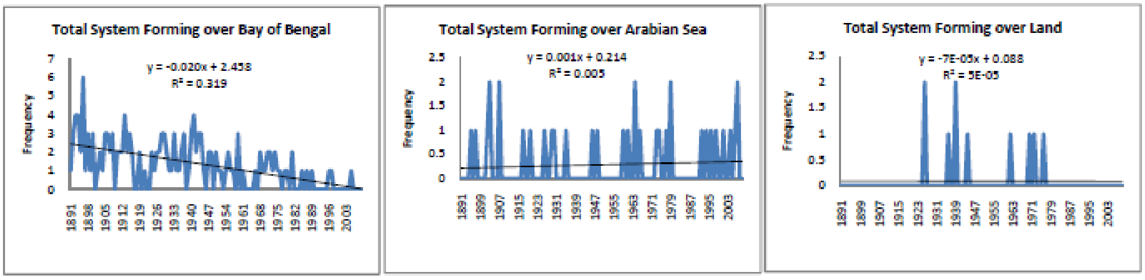



**Figure 5. Trends in Cyclonic Storms During Monsoon season**

This decrease in the system formation might have played a role in decrease in heavy rainfall events over the interior parts of the country. Thus, the study concludes that majority of the stations mostly in northern India rather than Deccan region receives less amount of heavy rainfall.

## 5. SUMMARY AND CONCLUSIONS

- Trend analysis for the heavy rainfall amounts (6.5 cm to 12.5 cm) indicates that four stations- Bangalore city, Begumpet Aero, New Delhi Safdarjung and Pune show increasing trend significant at 95% and 99% during annual. While five stations- Bhopal, Delhi University, Jaipur Aero, Mausi Lucknow and Nagpur Meyo Hospital reported significant decrease in rainfall. The same behavior is noticed during the monsoon season too.
- About 62% of the stations reported decrease in rainfall amounts whereas only 38% reported increase in rainfall. So, the analysis concludes that majority of the stations receives less amount of heavy rainfall in annual and monsoon season.
- Very Heavy rainfall for the stations- Patna and Jaipur Aerodromes- reported increasing trend at 95% and 99%. While the stations namely Delhi University, Mausi Lucknow and Nagpur Meyo Hospital show significant decrease in rainfall at 99%. It can be concluded that majority of the stations that is 71% reported decrease in rainfall amounts as compared to increase.
- The stations that receive rainfall above 25 cm indicate that none of them reported increasing/decreasing trend.
- All the stations reported fewer occasions of very heavy to heavy and hence it is not possible to compute the trend. The above study indicates that the interior India receives less amount of rainfall in terms of heavy rainfall to very heavy rainfall.
- The decrease in heavy to very heavy rainfall amounts can be attributed the decrease in cyclones and depressions forming over Bay of Bengal and land and that during the monsoon season.

## 6. ACKNOWLEDGEMENTS.

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# Empirical-Statistical Approach for Modelling of Mountain Permafrost Distribution in the Central Tian Shan Using Detailed Analysis of Mean Annual Ground Surface Temperatures (MAGST)

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## Abstract
The distribution and thermal state of permafrost is an important aspect of climate change research in the Central Tian Shan. As data availability is scarce, new approaches are needed to model the permafrost distribution in the region. This paper presents an empirical-statistical model using MAGST (Mean Annual Ground Surface Temperatures) as a proxy for permafrost occurrence. GST (Ground Surface Temperatures) was monitored at an hourly interval at 55 representative locations in the 130 km² Gukur catchment. The model incorporates satellite and DEM (Digital Elevation Model) derived data products like PISR (potential incoming solar radiation), NDVI (Normalized Differential Vegetation Index) and altitude. Model output is the simulated MAGST for the whole research area at a 30 m resolution, which is classified into "permafrost presence" (medium certainty/low certainty) and "permafrost absence" (medium certainty/low certainty). More than 62 % of the variance of MAGST is explained by the model parameters. The resulting map gives a detailed assessment of permafrost distribution in this exemplary subcatchcment of the central Tian Shan.

## Introduction
Permafrost is defined as ground where temperatures remain at or below 0 °C for at least two consecutive years (Washburn 1979). Under climate change conditions, the temperature regime and the distribution of mountain permafrost get more and more into the focus of both the public and the scientific community due to its impact on water balance and natural hazards (e.g. Haeberli 2013, Haeberli et al. 2010, Bolch & Marchenko 2006). In contrast to polar lowland permafrost and plateau permafrost (e.g. in Tibet), spatial variability of mountain permafrost is generally very high (Hoelzle et al. 2001). Extensive studies of European mountain permafrost give information on processes like water and air circulation and energy fluxes within the active layer (King 1986, King 2000, Tenthorey 1992, Keller 1994, Hoelzle et al. 1999, Hoelzle et al. 2001, Mittaz 2002). Similar studies have been done in the Tian Shan and other mountain ranges of Central Aisa (Aizen et al. 2002, Gorbunov 2004; Hagg et al. 2007). Within short distances ground temperatures can vary significantly due changes in slope and exposure, subsurface materials, vegetation or snow depth (Gubler et al. 2011, Imbery et al. 2013, Roedder & Kneisel 2012).

In China, research of mountain permafrost got a strong impetus by the international permafrost conference hosted in Beijing in 1993. Later, the construction of the Qinghai-Tibet railway from 2000 to 2006 delivered additional knowledge on permafrost occurrences and dynamics especially of plateau permafrost in Tibet (Wang et al., 2002; Wu et al., 2000, 2004). The "Map of Snow Ice and Frozen Ground in China, 1:4,000,000" (LIGG 1988) and the successive "Map of the Glaciers, Frozen Ground and Desert in China" also in the scale 1 : 4,000,000 (CAREERI 2006) give valuable information on the regional trends concerning glacier and permafrost distribution. A more recent survey is given by Ran et al. (2012). However, the existing small scale maps cannot inform in detail about the large variability of permafrost occurrences that is typical for mountain permafrost. More reliable models are necessary to assess the permafrost distribution for further applications.

Riseborough et al. (2008) give a comprehensive overview of existing permafrost models that have been successfully developed in recent years. While process based models need large amounts of detailed data for computation, statistical models are less demanding. Although giving only an approximate estimate, statistical models are thus more suitable for regional scale modelling and areas where data availability is scarce (Gruber & Hoelzle 2001, Riseborough et al. 2008). This study therefore uses mean annual ground surface temperatures (MAGST) presented by Imbery et al. (2013) to develop an empirical-statistical model for permafrost distribution in the Gukur catchment, Central Tian Shan.

## Study Area

Field investigations to monitor GST for two consecutive years were carried out in the 130 km² Gukur catchment (Figure. 1). This subcatchment is a direct tributary to the Aksu River, which contributes more than 70% to the total runoff of the Tarim River. Altitudes range from about 2,000 m a.s.l. up to 5,986 m a.s.l.. The three main glaciers are known as No. 72, No. 74 and No. 76 according to the Glacier Inventory of China (LIGG 1987). During the Little Ice Age (LIA), glaciers in the region advanced by about 300 – 500 m forming one to four end moraines (Zhao et al. 2010). While being very distinctive at slopes below present hanging glaciers and cirques, LIA end moraines are poorly preserved at the larger valley glaciers (Zhao et al. 2009). The periglacial area therefore consists of steep rock surfaces, exposed blocky moraine deposits of the LIA and widespread grass covered valleys. The large amount of debris on top and surrounding the glaciers - a typical feature for the entire region (Wang et al. 2011) – in combination with a highly continental and arid climate, leads to a close interaction of the glacial and permafrost environment (Harris & Murton. 2005). As a result, glaciers in the study area are surrounded by vast ice-cored moraines and rock glaciers are abundant on slopes exposed to the north. Overall it is hence expected, that a high amount of ice is preserved by permafrost in the Gukur catchment.

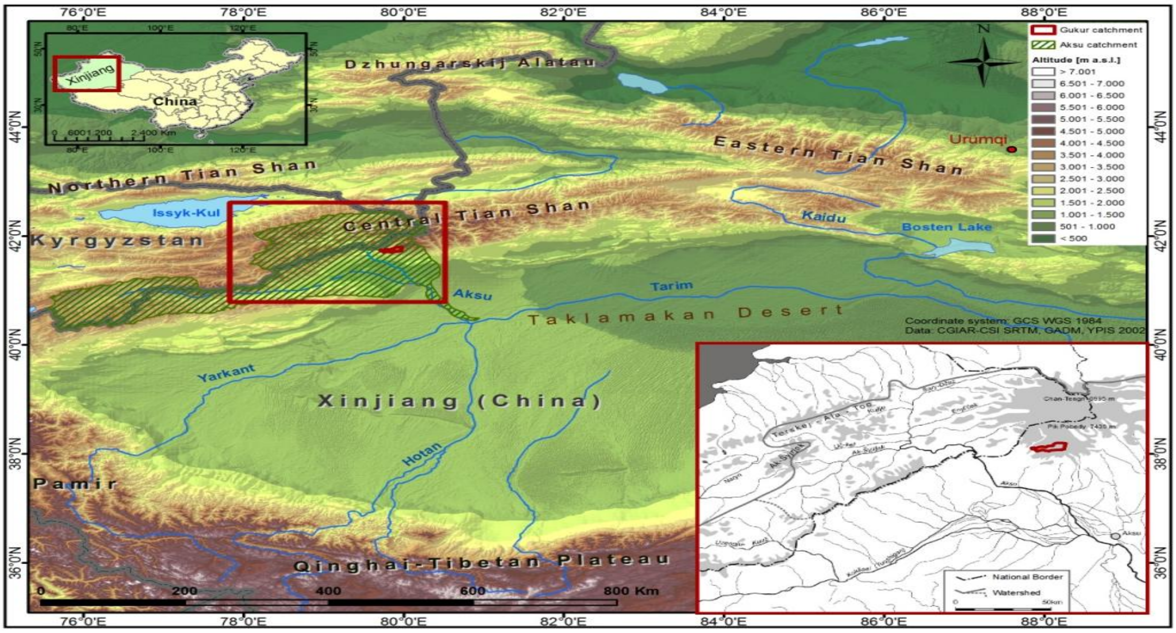

Figure 1: Regional overview and location of the research area (Gukur catchment) within the Aksu catchment, Central Tian Shan.

## Model Design

The statistical modelling of permafrost is based on mean annual ground surface temperatures (MAGST) and identification of relevant field parameters presented by Imbery et al. (2013) in the Gukur catchment. Furthermore remotely sensed and GIS derived parameters from Digital elevation models are tested and incorporated in the model. Each relevant parameter tested for the model will be described briefly.

*Mean Annual Ground Surface Temperatures (MAGST)*

Depending on the accessibility of the terrain, subsurface material and depth of the active layer (ground on top of permafrost, that thaws during summer) direct investigation on permafrost distribution is time consuming and difficult to manage over larger areas. Therefore a proxy for permafrost evidence is needed, that can be extrapolated. Bottom temperature of the winter snow cover (BTS) and MAGST are common indicators for subsurface thermal conditions (e.g. Guadong & Dramis 1992, Gruber & Hoelzle 2001, Cremonese et al. 2011). Making use of the insulating effect of a substantial winter snow cover, BTS is generally used to map the area into zones of "likely permafrost", "possible permafrost" and "no permafrost" (Haeberli 1973, Hoelzle et al. 1993, Gruber & Hoelzle 2001, Brenning et al. 2005). To obtain representative BTS temperatures, remaining constant during midwinter, a continuous snow cover of at least 80 cm is necessary to represent subsurface temperature regimes. In the Central Tian Shan however, drift snow is an important and common factor that results in a thicker snow cover at foot slopes, small depressions and lee positions, while wind exposed locations stay snow free most of the winter (Imbery et al. 2013). Therefore BTS is difficult to use here as an indicator for permafrost in the study area.

MAGST on the other hand is not dependable on a homogenous snow cover. Continuous temperature measurements at an hourly interval secure highly reliable results. Permafrost occurrence is then classified according to Cremonese et al. (2011) by mean annual ground surface temperatures in four categories (permafrost presence: MAGST < −2 °C medium certainty; −2 °C < MAGST < 0 °C low certainty; permafrost absence: 0 °C < MAGST < 2 °C low certainty; MAGST > 2 °C medium certainty).

For continuous simulation of MAGST, a large amount of temperature loggers need to be installed in the catchment to represent the local conditions like altitude, aspect, slope, vegetation and subsurface material. Regression and correlation analysis presented in this paper are based on 55 temperature loggers, recording ground surface temperatures (GST) at an hourly interval from August 16$^{th}$ 2011 to August 15$^{th}$ 2012. A detailed report on experiment design and a description M-Log5W wireless mini data loggers used (GeoPrecision, www.geoprecision.com) is given in Imbery et al. (2013).

*Altitude*

Ground surface temperatures are generally most dominantly influenced by air temperatures. In mountainous regions this factor is expressed less by latitudinal changes as in lowland periglacial areas, but by altitude. Mean annual air temperature (MAAT) decreases by 0.6 °C per 100 m increase in elevation in the region (Zhou et al. 2009). In this study, considerable variations in MAAT can thus be expected at the selected locations due to the altitudinal differences of more than 1,600 m (between 2,476 m and 4,129 m a.s.l.). Therefore, altitude is identified as the site specific factor having the most significant influence on MAGST, with a coefficient of correlation of $r = -0.76$ ($p < 0.001$, $n = 55$). For adequate representation of the elevation in the Gukur catchment a DEM is used with a 30 m grid size, obtained from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer).

*Potential Incoming Solar Radiation (PISR)*

Besides air temperature, solar radiation significantly influences ground surface temperatures. Based on the 30 m ASTER DEM, potential incoming solar radiation is calculated in ArcGIS for the whole year. A wide range of parameters for the computation can be modified to fit the local conditions. While most parameters were left with standard values, parameters like azimuth divisions were adjusted to give credit to the steep and therefore often shaded terrain in mountainous areas.

An attempt to enhance the results by calculating net shortwave radiation was made by Gruber & Hoelzle et al. (2001) by incorporating a summer albedo map. However, the net shortwave radiation model was later on discarded, as no benefit was detectable as compared to the standard model. A summer albedo map is just a snapshot of conditions and does not give credit to the temporal variability of soil moisture or most importantly the snow cover. Due to the importance and high variability of snow distribution and duration in the Gukur catchment as a result of drift snow (Imbery et al. 2013), the integration of an albedo map for correction of the PISR data product was omitted in this study.

*Remote Sensing Data Products*

To further improve the permafrost distribution model, an attempt is made to incorporate the ground cover. Vegetation cover can significantly influence ground surface temperatures and the thermal regime of the subsurface (e.g. Hoelzle 1994). To implement vegetation cover, a quantitative area wide parameter is needed. Therefore multispectral satellite data is used to calculate the normalized differential vegetation index (NDVI). The formula takes advantage of the high spectral reflectance of vegetation in the near-infrared wavelength (NIR) in contrast to a low spectral reflectance in the visible red wavelength (VIS):

$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$

With grassland being the only abundant vegetation in the relevant altitudinal level, NDVI is a simple but highly suitable quantitative indicator for in the entire research area.

Landsat ETM+ not only has the necessary spectral bands (NIR and VIS) but also an adequate resolution of 30 m, fitting perfectly to the 30 m resolution of ASTER DEM and PISR data products. For best representation of the vegetation and the least presence of snow, an image in late summer was chosen. The selected cloud-free scene was taken on the 5$^{th}$ of October 2002 (with ETM+ scan line corrector still functional). Correlation between MAGST and NDVI is very high and significant ($r = 0.45$, $p < 0.001$).

Furthermore duration and thickness of a snow cover is an important factor for the thermal regime of the subsurface (e.g. Bartlett et al. 2004, 2012 Imbery et al. 2013, Roedder & Kneisel). To assess the duration of snow cover area-wide, high temporal resolution of the satellite data is indispensible. MODIS (Moderate-resolution Imaging Spectroradiometer) provides a very high temporal resolution and its bands can be used to detect snow cover very reliable. However, the spatial resolution of 500 m is not suitable for the application in this study, where MAGST can vary within short distances. For this study a spatial resolution of at least 30 m is desirable. Hence, the addition of snow is omitted in this permafrost distribution model due to scale issues, but highly recommended for larger areas like the entire Central Tian Shan.

## Model Results

Applying multiple linear regression analysis, the coefficients obtained predicting MAGST including the parameters altitude, PISR and NDVI are as follows:

$$MAGST = -0.005909 * altitude + 9.065E-07 * PISR + 0.02787 * NDVI + 18.33$$

The resulting multiple coefficient of determination is 0.642. Taking the number of variables and the number of observations and the associated chance into account, the adjusted coefficient of determination ($R^2$) is 0.621.

Testing the model without NDVI, multiple linear regression analysis produces following formula:

$$MAGST = -0.006227 * altitude + 9.418E-07 * PISR + 19.23$$

The calculated multiple $R^2 = 0.6369$ is marginally lower than in the first model, while the adjusted $R^2 = 0.6229$ is slightly higher. Despite the high coefficient of correlation between NDVI and MAGST, variance explained by NDVI is neglectable and insignificant. The reason is shown in Table 1. A high degree of inter-correlation between NDVI and altitude is detected. Thus, no additional input is given by NDVI as it rather resembles the input already apparent in the model through altitude. Vegetation is bound to climate and therefore decreases with altitude. This relationship is furthermore enhanced, as old fine grained moraine deposits give way to less favourable younger and coarse debris in higher altitudes in the Gukur catchment. As a result, the second and simpler model is chosen, omitting the insignificant parameter NDVI due to its high inter-correlation with altitude and in accordance with previous studies on permafrost distribution modelling in the European Alps (Hoelzle 1994, Gruber & Hoelzle 2001).

Table 1: The table presents the coefficients of correlation for the monitored temperatures (MAGST) and the variables altitude, PISR and NDVI. Note the high correlation between NDVI and altitude, while PISR shows no signs of inter-correlation with altitude.

| | MAGST | Altitude | PISR |
|---|---|---|---|
| Altitude | -0.76 | | |
| PISR | 0.20 | 0.07 | |
| NDVI | 0.45 | -0.47 | 0.08 |

**Permafrost distribution and discussion**

The statistical-empirical model simulating continuous MAGST is applied for the whole Gukur catchment research area and categorised into a permafrost distribution map. Figure 2 is a detailed map of the focus area, while Figure 3 gives an overview of the whole catchment and surrounding areas. Monitored MAGST at the individual logger positions indicate the high quality of the model. With an adjusted coefficient of determination of $R^2 = 0.62$ the explained variation of MAGST is very high and significant. Taking into account the resolution of 30 m for the input parameters and the high variability of MAGST within very short distances (Gubler et al. 2011, Imbery et al. 2013), the deviation of just one category is within a tolerable range. For further justification of the permafrost distribution model, the mapped ice-cored moraines and rock glaciers in the Gukur catchment are taken as permafrost indicators. A detailed description of the features is given by Imbery (2011). Rock glaciers and ice cored moraines are important and safe indicators for permafrost in mountainous areas (e.g. King 2000, Haeberli 1985).

The presented permafrost distribution map is a valuable contribution to the overall research effort on permafrost in the Central Tian Shan.

Existing maps (CAREERI 2006, LIGG 1988) give helpful information on the general permafrost environment at a 1:4,000,000 scale. However, to assess the thermal state of the permafrost on a local to regional scale, higher resolution maps are essential. The 30 m resolution map presented in this study is hence indispensable for the assessment of thermal conditions and the stability of ice preserved within the permafrost environment (ice-cored moraines, rock glaciers and ground ice). Considering the rising demand for water in the surrounding arid lowlands, strongly depending on the runoff generated from the cryosphere (glaciers, permafrost and snow) in the Central Tian Shan, this is one of the greatest challenges in the region under climate change conditions.

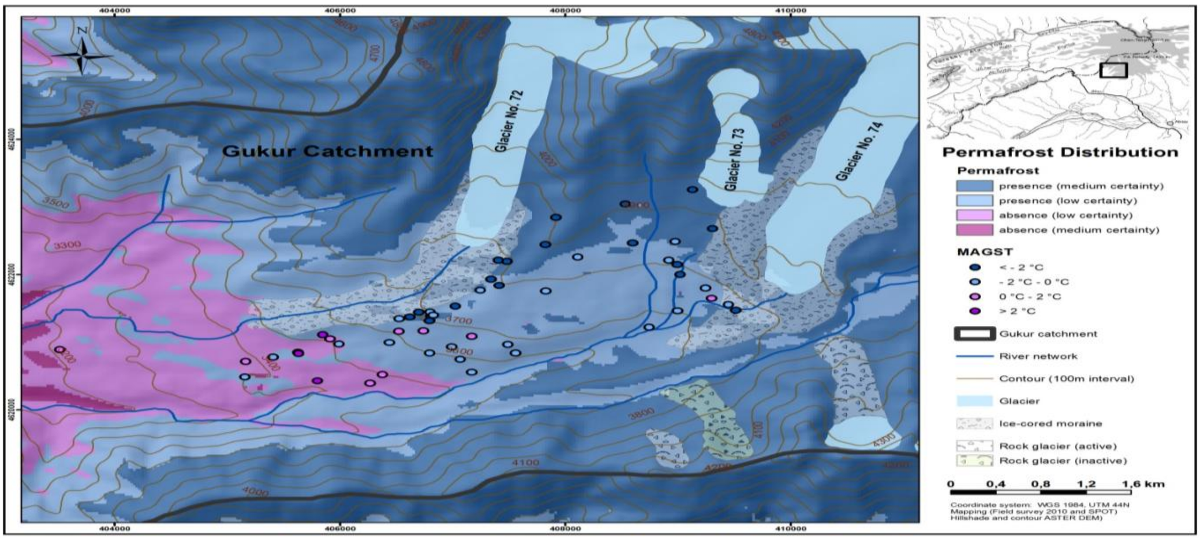


Figure 2: Permafrost distribution map for the focus area, using continuous modelled MAGST as a means of classification into four categories (permafrost presence: MAGST < −2 °C medium certainty; −2 °C < MAGST < 0 °C low certainty; permafrost absence: 0 °C < MAGST < 2 °C low certainty; MAGST > 2 °C medium certainty). Monitored MAGST are included for reference.

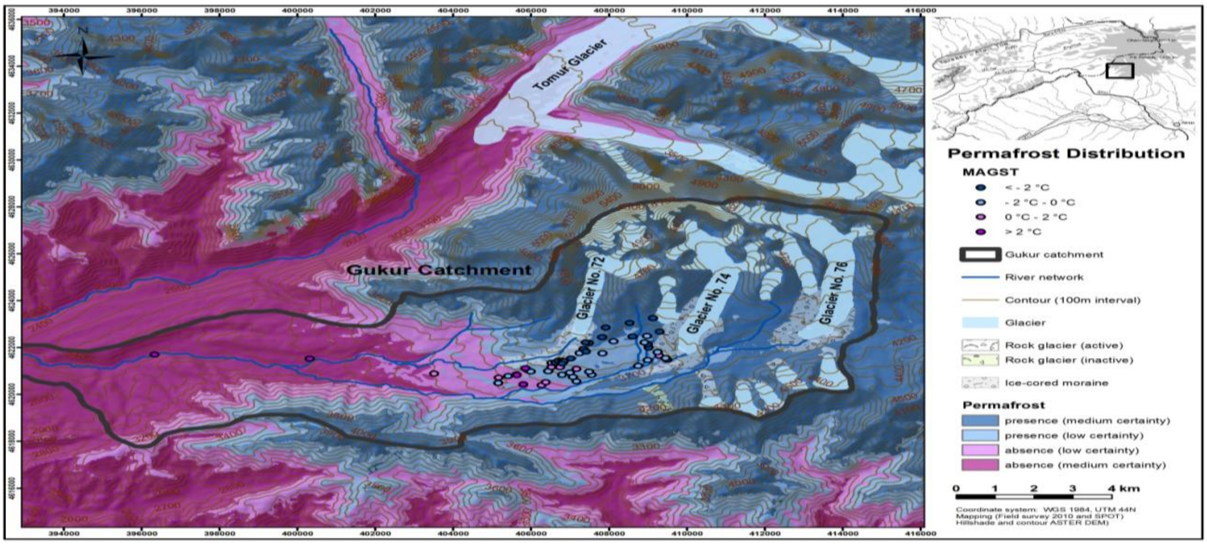


Figure 3: Permafrost distribution map of the Gukur research area, using continuous modelled MAGST as a means of classification into four categories (permafrost presence: MAGST < −2 °C medium certainty; −2 °C < MAGST < 0 °C low certainty; permafrost absence: 0 °C < MAGST < 2 °C low certainty; MAGST > 2 °C medium certainty).

**Outlook:**

Parameters used in the presented model explain more than 62% of the variance of MAGST. Therefore, the empirical-statistical approach proved to be very effective and highly accurate for the regional scale. Attempts have been made to improve the model by incorporating additional parameters (e.g. NDVI). However, parameters in a statistical model are often compound parameters and already include parameters that correlate with it (e.g. altitude and vegetation). Therefore the parameters should be regarded as a complex system.

Within climatically and geological similar conditions, the model can be used for permafrost distribution modelling in the Central Tian Shan. Nonetheless, further validation of the model, using additional measurements of ground surface temperatures for cross-validation and direct identification of permafrost presence or absence in the field are necessary.

Depending on the scale of application, further changes could be made to the model. For a more detailed analysis of e.g. singular slopes, a higher resolution DEM could improve the accuracy of the model as it would take small scale effects into account that are also important for the calculation of PISR (slope, shielding etc.). For application of the model to a larger scale, where resolution is less important, the authors would recommend to incorporate the factor snow cover into the model (e.g. MODIS at a 500 m grid resolution).

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# "RS AND GIS BASED SLOPE STABILITY ANALYSIS USING WEIGHTED SUM METHOD FOR PART OF HIMACHAL HIMALAYAS, INDIA"

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**Abstract:**

Landslides are one of the most common natural hazards in the Himalaya terrain, causing widespread damage to property, infrastructure and human lives, almost every year. Appropriate management measures taken at the right time reduce the risk of potential landslides. This is the rationale behind taking up the research topic on the landslide. The present research work attempts to carry out LHZ studies in the part of Sirmaur district, Himachal Himalaya. It uses Weighted Sum Method of Qualitative Approach for Slope Stability Analysis. The highlight of this work is the creation of Landslide Hazard Zone's map. This research work makes use of Remote Sensing data, Topographical Maps, Published Documents and field survey for preparing spatial data on 7 predictor variables, which are Geological, Geomorphological, Topographical and Anthropogenic in nature. It is assumed that the effects of earthquakes and rainfall are uniform in the study area due to its limited geographic extent. Hence these factors won't be considered for analysis. It demonstrates the use of raster based GIS data for spatial analysis. Thus, the present research work establishes LHZ procedures in a landslide prone area.

## Introduction

Landslides are a major problem in mountainous regions such as the Himalayas, Nilgiri Hills, Western Ghats and Northeastern region in India. Every year landslides cause large damage to infrastructure, property and sometimes loss of life. Large landslides in mountainous areas can result in landslide dams blocking river courses; it causes valley inundation upstream and can be subsequently breached by lake water pressure, thus cause the deadly flash flood or debris flow downstream. Landslide takes place most frequently in monsoon rains, as water is an important factor for initiating landslides. Inherent geological characteristics of the strata and the geometry of slope control the stability of slopes and in turn landslides. Active tectonic movements cause the instability and weaknesses across certain tectonic zones which are prone to landslides and other types of mass movements. Himalaya is one of the major landslide prone regions in India, which experience the landslide events and causes loss of property and human lives almost every year. The region of the present study i.e. Himachal Pradesh has witnessed many destructive landslide events in the past such as Spity valley landslide in September 2009, Landslides at Raison, Dobhi, Alu Ground, Rangri and Manali in February 2011, recurrence of such events cause the disturbances in post disaster relief, rescue, reconstruction of infrastructure. Redevelopment in such areas increases the burden on the state treasury. Mountainous terrains must have some good policies for planned development, highly reliable landslide hazard maps and landslide hazard mitigation strategy. For all these things the most important factor is the identification of potential landslide hazard area based on past events of landslides, geological, geomorphological and topographical conditions. The purpose of the present study is to prepare most reliable Landslide Hazard Zonation map, taking into account the geological, geomorphological, topographical and anthropogenic conditions. It is assumed in this study that the effects of earthquake and rainfall, which are the major triggering factors for landslide, more or less uniform in the study area due to its limited geographic area. Therefore these factors have not taken into consideration for LHZ mapping.

**Objectives**

1) Preparation of thematic maps on the basis of various causal factors of landslides e.g. geological, geomorphological, topographical and anthropogenic.

2) Landslide hazard assessment and its Zonation based on the contributing factors and existing landslides using the weighted sum method.

**Location Map of the Study Area**

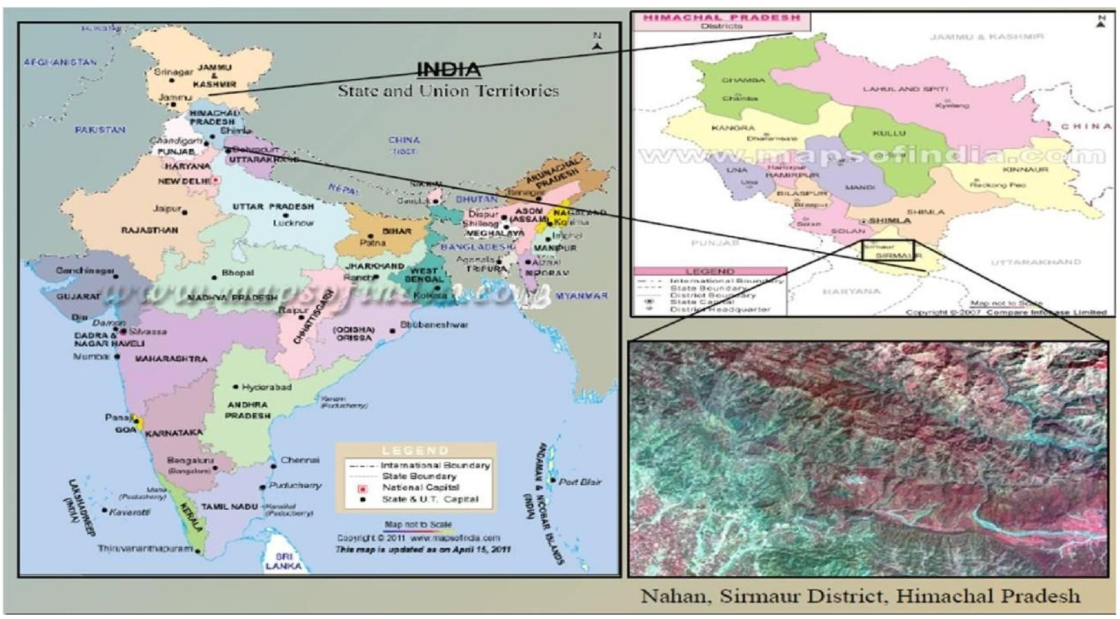


Fig. 1

**Study Area**

The selected study area is a part of Sirmaur district, Himachal Pradesh. It covers an area of 950 $km^2$ and is bounded between latitude $30^0$30’00” and $30^0$40’00”N as well as longitudes $77^0$18’00” and $77^0$33’00”E. The major township in the area is Nahan city, it is the district headquarter of sSirmaur district and very well known as the best designed city. Some major rivers flowing through the area, these are Giri River, its tributaries Jalal River, Jagar ka Khala, Khair ka Khala etc., Markanda River, Bata Nadi. The study is having the two distinct geological regimes; the Shiwaliks and the lesser Himalaya. It also has one of the most important regional geological structure; the Main Boundary Thrust (MBT), passing from southeast to northwest direction.

**Data used:**

Satellite remote sensing data is one of the major datasets used in the present work. Topographical maps of SOI and relevant geological maps from published literature have been referred. The details of the data used are given below:

Table 1 – Data used in the study

| Data | Scale | Source |
|---|---|---|
| IRS P6 LISS III | 23m X 23m | NRSC Data Center, Hyderabad. |
| IRS P6 LISS III | 5.8m X 5.8m | NRSC Data Center, Hyderabad |
| Cartosat 1 PAN | 2.5m X 2.5m | NRSC Data Center, Hyderabad |
| SOI Toposheet | 1: 50000 | Survey of India |
| Rupke's Geological Map | 1: 100000 | Geological Survey of India . |
| ASTER DEM | 30m X 30m | USGS online data center |

**Methodology:**

In this study Weighted Sum method was used to produce landslie susceptibility map for the part of Sirmaur district. Following parameters were used as the cause factors of slope instability and landslides in the study area.

**Lithology:**

One of the important inputs into slope stability mapping is the information as well as the spatial distribution of various lithological units. In the Himalaya, due to the complex post-depositional tectonic disturbances and also due to the ruggedness and inaccessibility of the terrain, mapping of individual lithological units is very difficult. So, it is possible to prepare the lithological map with the help of published geological maps, taking the combination of various lithological units mapped as a single lithostratigraphic unit or individual lithological units mapped under various formations. In the present study, the lithological map has been prepared using the published geological maps (Rupke's Geological Map) pertaining to the study area by grouping or rearranging geological units based on the most prominent or characteristics lithological unit in each formation. The geological units have been designated with the lithological classes according to the description given above.

**Geological Structure:**

The geological structures which are considered in the present study for slope stability analysis, are faults (thrust/normal faults), joints, fractures etc. The regional geological structures like thrust and faults and present in the study area have been mapped by earlier workers. In addition to the conformed thrusts and faults, there are many features such as faults, joints and fractures, which have drawn only from remote sensing data. The traces of features appear as linear to curvilinear entities on satellite images, depending on the topography and attitude of the structure. These are commonly designated as lineaments.

In the present study, the lineament have been interpreted on standard FCC prepared using merged image of IRS P6 LISS IV and CARTOSAT1-PANA images. The geological structures of the study area nsisting of the confirmed thrust/faults and the inferred faults, fractures and joints.

**Slope:**

Surface topography controls flow sources, flow direction and soil moisture concentration is an important factor limiting the density and spatial extent of landslide (Ayalew and Yamagishi, 2005). So it is necessary to use information on elevation, slope, slope aspect, relief etc.

Slope is a parameter that is closely associated with the elevation. It can be defined as the rate of change of elevation over a surface. In tectonically active regions with incising bedrock channels, hill slopes steepened above a threshold angle are rapidly denuded until the slope is brought back down to the threshold angle (Carson and Petley, 1970). Because precipitation affects the slope stability through its control on pore pressure, Car son (1976) proposed that slope angle may adjust to climate through landsliding. This suggests that there is an association between the slope angle and the slope stability. Slope is one of the most important geomorphic factors for shallow mass movement processes (sidle et al., 1985). Gentle slopes are expected to show lesser tendency for slope failure. At the same time steep natural slopes having outcropping bedrock may be more prone to rock falls and similar kinds of slope failure rather than shallow landsliding (Lee and Evangelista, 2005). For the present study, slope has been calculated using the DEM as the input. The slope function available in spatial analyst tool in ArcGIS, ArcMap software has been used for calculating the slope. In the study area, the slope values vary from $0^0$ to $88^0$. The flood pain area and the nearby fluvial terraces show the lowest slope values in the study area. Being one of the significant controlling factors of slope stability, the categorization of this continuous variable should incorporate its sensitivity towards slope failure. This means that a small number of slope classes will overlook the influence of some particular range of slope values. At the same time, a large number of classes will increase the complexity of the statistical analysis. The slope values have been classified into eight classes.

**Slope Aspect:**

The morphological parameter that complements slope is its aspect. Aspect can be defined as the prevailing direction of slope of a surface. It is expressed as the angle between slope direction and the N direction, measured clockwise from N.In multifaceted landscapes, which usually are the case with natural landforms, the solar insolation varies according to the slope aspect and thereby creates varying microclimatic condition in an area. The microclimatic variation influences the soil moisture and erosion potential and hence controls the slope form. The equator facing slopes is hottest and driest while pole facing slopes are cooler and moister (Wilkinson and Humphreys, 2006). In the northern hemisphere, S facing slope receives more direct sunshine and experiences higher evaporation loss from the surface (Thornbury, 2002). The slope aspect also influences the rate of weathering of the rocks by inducing differential effects on the rocks exposed in different aspects and thus indirectly influencing the stability of the slopes.In the study area, the slope aspect has been calculated from the DEM using spatial analyst tool in ArcGIS, ArcMap software. In the present study, the slope aspect values, which range from 0 to $360^0$ have been classified into 8 classes of $45^0$ intervals.

**Drainage:**

In order to incorporate the influence of drainage in the slope stability analysis, it has been decided to utilize the distance to the drainage information. It has been computed on a cell-by-cell basis, using a 25 m grid. For each cell, the shortest distance to the nearest drainage segment has been calculated and this has been given as its value.

**Land Use/Land Cover:**

The land use/land cover condition of the area is another factor which influences the stability of slopes to certain extent. The term land use relates to the human activity associated with a specific piece of land. Land covers relates to the type of feature present on the earth such as forests, water bodies, grass lands etc. The land use characteristics of the area is a reflection of the human interference, which effectively and productively utilizes the land or causes the degradation of the land (Lillesand et al., 2005). The presence of vegetation in the form of dense forests helps to increase the shear strength of the soil due to root-induced cohesion. Land use mapping may also reveal the presence of landslide areas, which usually are susceptible to slope failures in the future. Further, the land use/land cover information will enable the planners and the administration to take appropriate landslide hazard mitigation measures. In the present study it has been decided to carry out the land use/land cover classification using the IRS P6 LISS IV data as the objectives is to get the spatial distribution of the broad land use/land cover categories, rather than going into the very detailed mapping for local supervised classification. Supervised classification using the maximum likelihood procedure has been adopted for the preparation of land use/land cover map.

**Road:**

The construction of roads along the slopes of hilly terrains causes destabilization of the terrain due to multiple factors such as removal of slope support, reduction of the rock mass strength due to the enhancement of the planes of weakness in the rocks or creation of new discontinuities resulting from the blasting etc. the road network in the study area has been taken from the SOI toposheets and are new roads which have constructed after the period of mapping of the toposheets are updated with the merged PANA and LISS IV data. The distance to road has been calculated using a 25m grid and each cell has been assigned a value, which is the distance to the nearest road segment. The grid data of distance to road (figure 4.7) has a maximum value 7565m. The influence of the road cannot extend to distance of the order of 5.5 km in creating slope instability.

**Analysis:**

The main objectives of the present work

are to study the landslide hazard in the study area, to categorize the area into different hazard classes using qualitative methods of LHZ for their accuracy of slope failure susceptibility prediction. Due to the limited geographic extent of the present study area, the variation of the climatic conditions is narrow and the triggering factors, which strongly affect the temporal dimension of slope failures, are assumed to be a uniform influence over the study area. Hence, in the present study, landslide hazard and landslide susceptibility are used for implying the same meaning; the probability of slope failure in the spatial context. The LHZ mapping of the study area, using qualitative methods. This method is strongly dependent on the experience of the surveyors, but it is the only practicable approach for landslides caused by different mechanisms. The layers were weighted with indices due to their importance iteratively and were combined into a landslide susceptibility map. Landslides in the Himalayan terrain have varying controlling factors. It is very difficult to develop a generalized regional model to successfully predict the landslide hazard across the Himalaya. In the present study, Slope Stability Analysis has been attempted using the Weighted Sum Method.

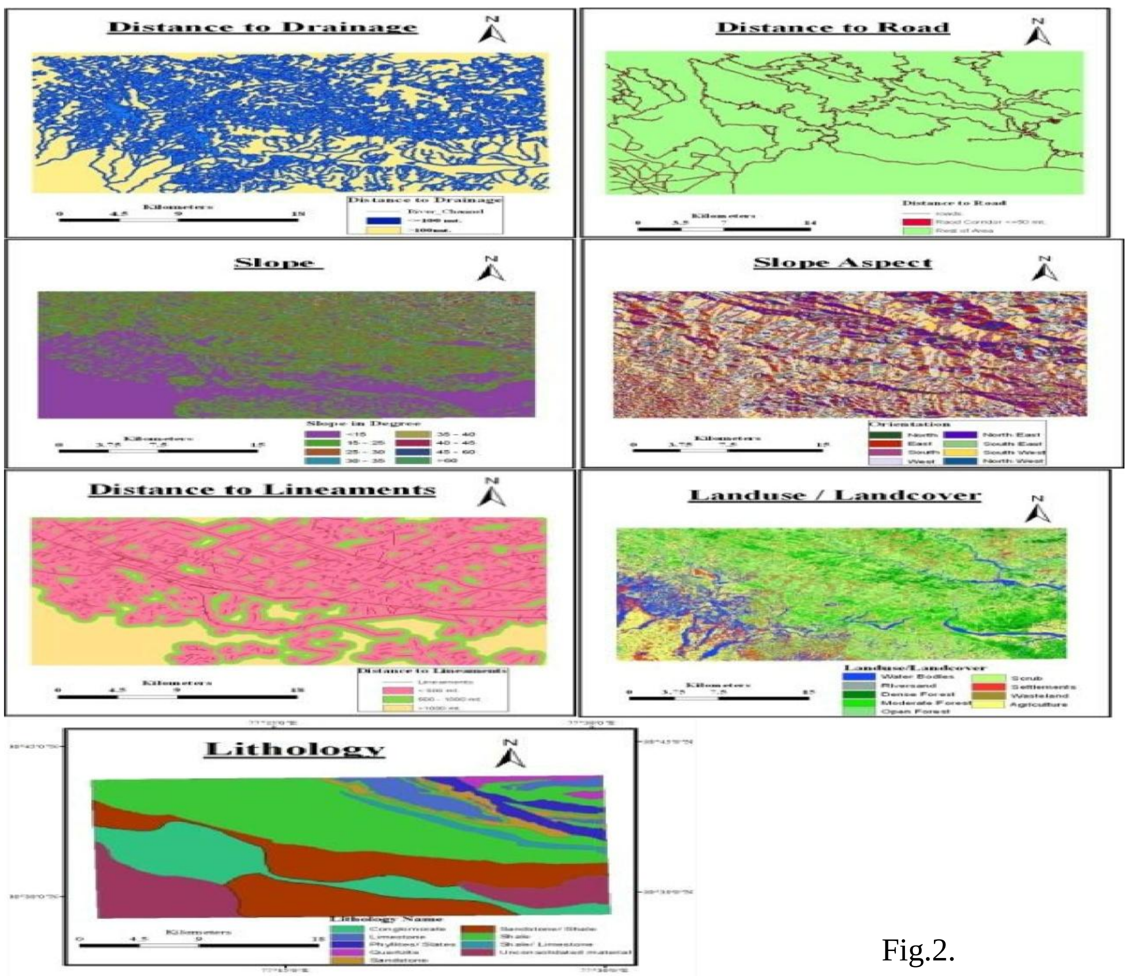


Fig.2.

**Analysis using weighted sum method**

A weight function is a mathematical device used when performing a sum, integral, or average in order to give some elements more "weight" or influence on the result than other elements in the same set. They occur frequently in statistics and analysis, and are closely related to the concept of a measure. Weight functions can be employed in both discrete and continuous settings. In order to prepare a qualitative landslide hazard zonation map weighting and rating system has been adopted in this study. It is based on the relative importance of various causative factors. An ordinal number (0-9) is given to each layer in terms of its relative importance. Similarly, each class of the data layers has been given an ordinal rating from 0 to 9. Table 2 describes the weight and rating given to each data layer and their classes respectively. These weight and rating values have been assigned using expert defined weight and rate for each parameter and each class.

| Sl. no. | Parameters | Rate | Category | Weight | Total |
|---|---|---|---|---|---|
| 1. | Slope | 9 | <$15^0$ | 2 | 18 |
| | | | $15^0$-$25^0$ | 3 | 27 |
| | | | $25^0$-$30^0$ | 5 | 45 |
| | | | $30^0$-$35^0$ | 8 | 72 |
| | | | $35^0$-$40^0$ | 9 | 81 |
| | | | $40^0$-$45^0$ | 8 | 72 |
| | | | $45^0$-$60^0$ | 7 | 63 |
| | | | >$60^0$ | 5 | 45 |
| 2. | Lithology | 8 | Unconsolidated material | 8 | 64 |
| | | | Conglomerate | 6 | 48 |
| | | | Sandstone/Shale | 7 | 56 |
| | | | Sandstone | 7 | 56 |
| | | | Shale | 6 | 48 |
| | | | Limestone | 5 | 40 |
| | | | Phyllites/Slates | 3 | 24 |
| | | | Shale/Limestone | 4 | 32 |
| | | | Quartzite | 2 | 16 |
| 3. | Distance to Lineament | 7 | <500 m | 9 | 63 |
| | | | 500-1000 m | 6 | 42 |
| | | | >=1000 m | 3 | 21 |
| 4. | Distance to Drainage | 6 | <100 m | 4 | 24 |
| | | | >=100 m | 2 | 12 |

| | | | | | |
|---|---|---|---|---|---|
| 5. | Landuse | 5 | Water body | 2 | 10 |
| | | | Riversand | 2 | 10 |
| | | | Dense forest | 2 | 10 |
| | | | Settlement | 3 | 15 |
| | | | Moderate forest | 3 | 15 |
| | | | Agriculture | 3 | 15 |
| | | | Open forest | 5 | 25 |
| | | | Scrub | 6 | 30 |
| | | | wasteland | 8 | 40 |
| 6. | Aspect | 4 | North | 4 | 16 |
| | | | North-East | 5 | 20 |
| | | | East | 9 | 36 |
| | | | South-East | 8 | 32 |
| | | | South | 7 | 28 |
| | | | South-West | 6 | 24 |
| | | | West | 4 | 16 |
| | | | North-West | 5 | 20 |
| 7. | Distance to Road | 3 | Road Corridor (<=50 m) | 4 | 12 |
| | | | Rest of area | 2 | 6 |

(Table 2 - Slope Stability Analysis weighting and rating system adopted in this study)

**Computation**

The classes of different data layers are assigned the corresponding rating value as attribute information in the GIS and an "attributed map" is generated for each data layer. The raster operation capability of ArcGIS 9.3 has been utilized for computation. A weighted Sum tool from an Overlay function in Spatial Analyst has been used to generate the output layer.

Weighted sum = ∑ [layer1 weightage + layer2 weightage+layer3 weightage……..layer n weightage]

One of the objectives of the present study is to prepare the LHZ map of the study area using Weighted Sum method. Therefore a Landslide Hazard Zonation map is prepared showing five zones namely very high hazard, high hazard, moderate hazard, low hazard and very low hazard using the reclassify operation.

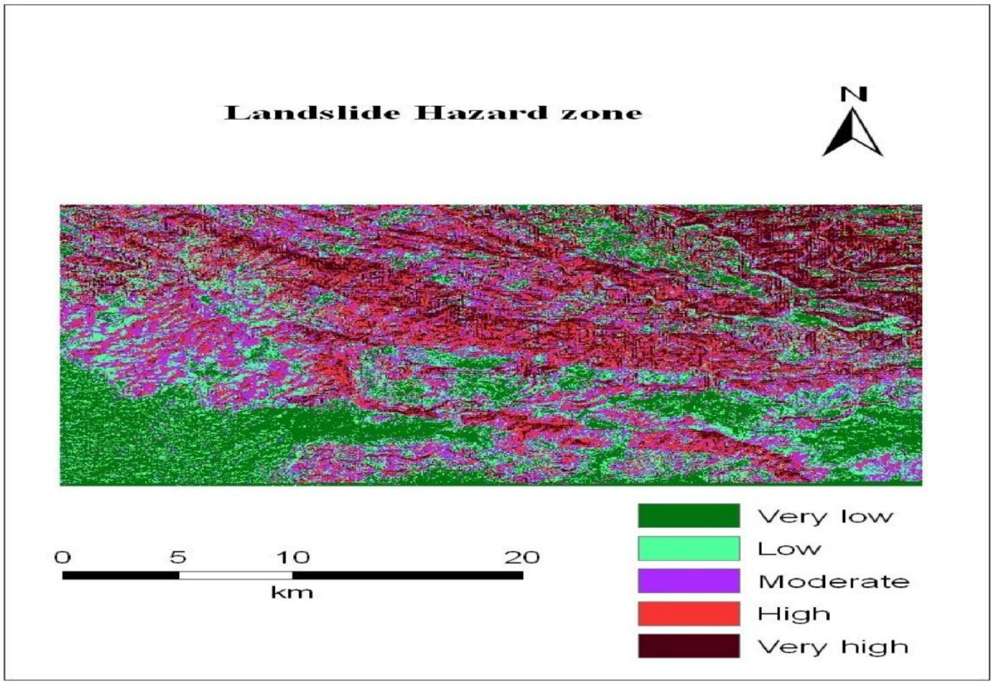


Fig. 3

**Result & Conclusion**

The weighted sum method is basically a qualitative method giving ample scope for incorporating expert knowledge in the hazard mapping process, which is essential to produce reliable LHZ maps. Though qualitative methods introduce some degree of subjectivity in the process, it cannot be considered as a reason for the inferiority of the method. Subjectivity implies mainly poor reproducibility of the output in repeated processes. In fact, the expert knowledge is essential to identify the contributing factors itself in the first place, whether it is for subjective analysis or for quantitative analysis.

The final Hazard zone map showing five classes of the hazard zone. These are namely very low, low, moderate, high, very high hazard zone. It has been identified with the help of the landslide inventory map that a large number of landslide events have occurred in the moderate and high landslide hazard zones and less number of landslides are identified in low and very low landslide hazard zone. Through the present study of slope instability analysis and LHZ mapping using Weighted Sum Method, it has been concluded that the Weighted Sum Method of Qualitative Approach in LHZ mapping is a reliable method. It seems to be very useful for quick and much accurate analysis of LHZ. The weight assigning to the parameters and classes is totally depends on the expert's decision, therefore it is necessary to have deeper knowledge of evidential parameters and their contribution in controlling the slope stability.

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# Morphometric Analysis of Bhima River at Niranarshingpur in Maharashtra: A GIS approach

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**Abstract**

Morphometry is the measurement of form analysis of its landforms. Morphometric analysis is an important aspect to study characteristics of the river basin. The present study is undertaken to determine the drainage characteristics of Bhima river basin in Maharashtra. The total area of the basin is 29,493.97 $km^2$. The Morphometric variables are computed by using Geographic Information system (GIS). Order of the stream is $9^{th}$. The quantitative analysis of various aspects of river basin drainage network characteristics reveals complex Morphometric attributes. The streams of lower order mostly dominate the basin. The development of stream segments in the basin area is more or less affected by rainfall For the Morphometric analysis Geographic information system techniques has been used and Strahler (1964) stream order method used for stream ordering. The drainage density of the basin is 0.075 per km. Lithology of the basin plays important role on erosional processes of the basin. Nira River is 14424.10 square km.

**Introduction:**

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape, dimension of its landforms (Clarke, 1966). The morphometry analysis includes the linear aspects and aerial aspects, in the linear aspects the stream ordering, stream length, stream length ratio, and bifurcation ratio and in the aerial aspect the drainage density, stream frequency, form factor, circulatory ratio, and elongated ratio has been calculated. Morphometric analysis is an important aspect of hydrological and hydrogeological studies (Agarwal et al., 2000). Morphometric analysis will help to quantify and understand the hydrological characters and the results will be useful input for a comprehensive water resource management plan (Jawahar raj et al., 1998; Kumaraswami et al., 1998 and Sreedevi et al., 2001). GIS techniques are now a day used for assessing various terrain and Morphometric parameters of the drainage basins, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information.

The Morphometric analysis of the drainage basin and channel network play a vital role in order to understand the hydro-geological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology and structure etc. The relationship between various drainage parameters and the aforesaid factors are well recognized by Horton, 1945, Strahler, 1957, Melton, 1958, Pakhmode, *et al.*, 2003 and Gangalakunta, *et al.*, 2004. Recently many workers have used remote sensing data and GIS generated more precise data on Morphometric parameters (Srivastava, 1997, Agarwal, 1998, Nag, 1998, Das and Mukherjee, 2005) and concluded that remote sensing has emerged as a powerful tool and useful in analyzing the drainage morphometry. The objective of the present study is to analyze the Morphometric attributes of Bhima river basin.

**Aim and Objectives:**

1. The main objective of the present study is to derive the different drainage aspects of Bhima River basin and to understand the relationship of the drainage networking.
2. To study the quantitative analysis of drainage system.
3. To evaluate linear and areal aspects of morphometric characteristics.

**Study Area:**

The total study area extends from Ujjani Dam up to Man River Confluence extending between 17° 2' 50" N to 18° 4' 26" N latitude and 75° 7' 12"E to 75° 37' 25" E longitude. The River Bhima rises in the Western Ghats at Bhimashankar at an altitude of about 945 m and flows south-eastwards though Maharashtra and Karnataka. It has a total length of 861 km and falls into River Krishna about 26 km North at Raichur at an altitude of 343 m. About 137 km. from its source the Bhima River receives from its right the cabined waters of the River Mula and Mutha from Poona and about 29 km lower the Ghod River joined on its right bank by the Nira River which is also rises in the Western Ghats and then by the run for a length of 74 km. The Bhima River runs along the boundary between Maharashtra and Karnataka. The total catchments area of the River Bhima is 76614 $km^2$. During this long journey many small rivers join to the main river River Kundali, Bhima, Indrayani, Pawana are the major tributaries around Pune, of these River Indrayani, Mula, Mutha and River Pawana flows through Pune and Pimpari Chinchwad city limits. River Chandani, Thamini, Moshi, Bori, Sina, Man, Bhogwati and Nira are the major tributaries in the Solapur district. River Nira and River Bhima confluence at Niranarsingpur in Malshiras Taluka and River Man confluences at Sarkoli, Manglweda Taluka in Solapur district. Study area is selected from Ujjani Dam to the Niranarshingpur, at the river Nira River confluence in the Solapur district. The total length of the study area is 36.66 km. The major flood affected villages are 23 and pilgrim place Niranarshingpur is western bank side of River Bhima. Select locations are highly affected by flood. Many villages and stretches both the bank side of Bhima River, Major changes have observed.

**Materials and Methods:**

The Morphometric analysis of the Bhima River basin was based on topographical maps on a 1: 50,000 scale, and different Morphometric parameters have been generated in GIS environment. Digitization and the stream order were assigned by layer concept. The quantitative analyses of the basin which include stream orders, stream numbers, stream lengths, bifurcation ratios, basin circularity, drainage density, drainage frequency, drainage texture etc., have been analyzed through use of a GIS using Arc Info, which determines the geomorphic stage of development of the area. The drainage network of the basin is analyzed as per laws of Horton (1945) and stream ordering is made after Strahler (1964).

**Morphometric Analysis:**

The measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landform provides the basis of the investigation of maps for a geomorphological survey (Bates and Jackson, 1980). This approach has recently been termed as Morphometry. The area, altitude, volume, slope, profile and texture of landforms comprise principal parameters of investigation. Dury (1952), Christian, Jenning and Tuidale (1957) applied various methods for landform analysis, which could be classified in different ways and their results presented in the form of graphs, maps or statistical indices.

**Linear Aspects of the Drainage Basin:**

**Stream Order:**

The streams of the Bhima river basin have been ranked according to the method described by Strahler (1964). According to Strahler, when two first order streams join, a stream segment of second order is formed; When two second order streams join, a segment of third order is formed, and so on. The study area is a ninth order drainage basin.

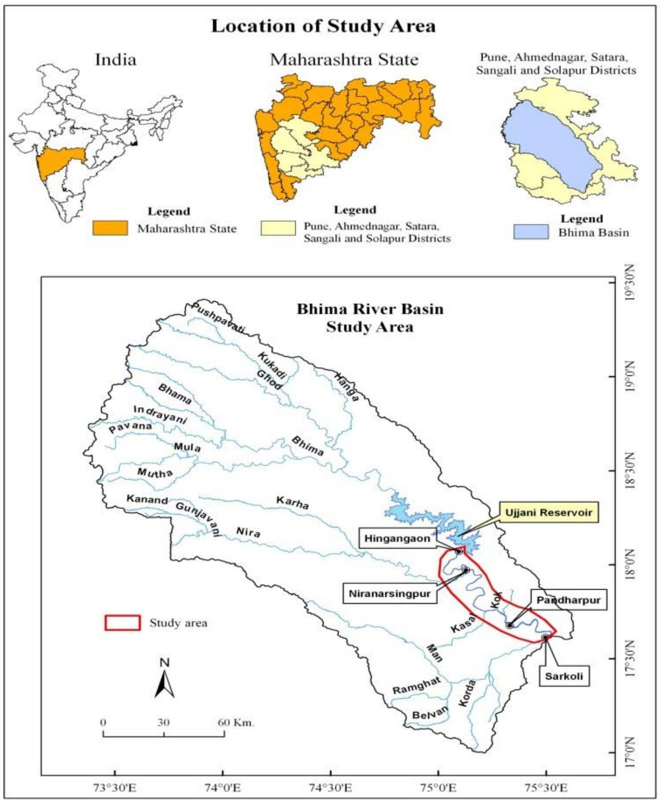


**Fig. 1**

**Stream Number:**

After assigning stream orders, the segments of each order are counted to get the number of segments of the given order (u). The stream lengths of the various segments are measured with the help of GIS software. In the study area, the total stream are present 1, 03, 557 of which 75.44 % are first order streams having 78,123 segments (Table 1). The second order stream segments are 19,442 and account for 18.77 %; Third order stream segments are 4,584 and accounted 4.42 %; Fourth order stream segments are 1,085 and account for 1.04%; Fifth order stream segments are 258 and account for 0.24 %; Sixth order stream segments are 50 and account for 0.048 %; Seventh order stream segment is 10 and account for 0.01 %; eight order stream segments are 4 and account for 0.0038 % and Ninth order stream segment is 1 and account for 0.0009 %.

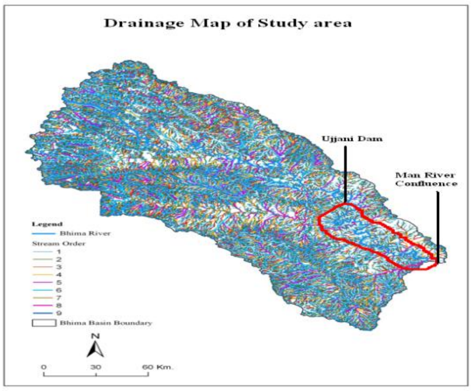


**Fig. 2**

**Bifurcation Ratio (Rb):**

Bifurcation Ratio is the ratio of the number of streams of an order to the number streams of the next higher order (Horton, 1945, Strahler, 1964). In the Bhima basin bifurcation ratio ranges from 2.5 to 5.16 (Table 1). The average bifurcation ratio of area is 4.16. This means that on an average, there are 4.16 times as many channel segments to any given order as of the next higher order. Bifurcation ratios are related to the structural control on the drainage (Nautiyal, 1994; Strahler, 1964; Chow, 1964). A lower Rb range suggests that structure does not exercise a dominant influence on the drainage pattern. Higher Rb indicates some sort of geological control (Agarwal, 1998). If the Rb is low, the basin produces a sharp peak in discharge and if it is high, the basin yields low, but extended peak flow (Agarwal, 1998). In well developed drainage network the bifurcation ratio is generally between 2 to 5 (Horton, 1945; Strahler, 1964).

$$Rb = \frac{Nu}{Nu + 1}$$

**Stream Length (Lu):**

The stream length of various orders has been measured form topographical map. Horton's law (Horton, 1932) of stream length supports the theory that geometrical similarity is preserved generally in the basins of increasing order (Strahler, 1964). The mean length of channel Lu of order U is the ratio of the total length to the number of streams of a given order. Mean length of channel segments of a given order is greater than that of the next lower order but less than that of the next higher order. The logarithm of stream length of each order as a function of order is plotted and yields a set of points lying generally along a straight line.

**Table 1:** Morphometric parameters of Bhima River basin

| Stream Order | No of Streams | No of streams % | Total Length km | Mean Stream Length km | Bifurcation Ratio | Log of No of Streams | Log of total Length |
|---|---|---|---|---|---|---|---|
| 1 | 78123 | 75.44 | 44538.23 | 0.57 | - | 4.89 | 4.65 |
| 2 | 19442 | 18.77 | 14460.31 | 0.74 | 4.01 | 4.28 | 4.16 |
| 3 | 4584 | 4.42 | 7542.96 | 1.65 | 4.24 | 3.66 | 3.87 |
| 4 | 1085 | 1.04 | 3990.00 | 3.68 | 4.22 | 3.03 | 3.60 |
| 5 | 258 | 0.24 | 1774.93 | 6.88 | 4.20 | 2.41 | 3.24 |
| 6 | 50 | 0.048 | 952.52 | 19.05 | 5.16 | 1.69 | 2.97 |
| 7 | 10 | 0.01 | 451.33 | 45.13 | 5.00 | 1.00 | 2.65 |
| 8 | 4 | 0.0038 | 231.17 | 57.79 | 2.50 | 0.60 | 2.36 |
| 9 | 1 | 0.0009 | 292.09 | 292.09 | 4.00 | 0.00 | 2.46 |
| **Total** | **1,03,557** | | | | | | |

**Here,**

$$\textbf{MSL} = \frac{\textbf{Total Length of streams}}{\textbf{Number of streams in this order}}$$

**Aerial Aspects of Drainage Basin:**

**Basin Watershed area in study area:**

| Sr. No | Name of Watershed | Area of Watershed (km$^2$) | Length of Basin (km) |
|---|---|---|---|
| 1 | Ghod | 4,546.17 | 407.12 |
| 2 | Mula-Mutha | 3,897.16 | 363.15 |
| 3 | Nira | 6,531.10 | 496.71 |
| 4 | Man | 4,756.85 | 421.27 |
| 5 | Bhima | 9,696.83 | 836.54 |
| | **Total** | **29,428.11** | **2524.79** |

**Basin Area (Au):**

The area of watershed is 29,493.97 km$^2$. If the basin size is small, it is likely that rainwater will reach the main channel more rapidly than in a larger basin, where the water has much further to travel. Lag time will therefore be shorter in the smaller basin. According to Gregery and Walking (1973), the ‘L’ is the longest length of the basin from the catchment to the point confluence. The length of the River Bhima basin is 142.18 km. Basin area is the direct outcome of the drainage development in a particular basin. It is usually seen that the basin are pear shaped in early stages, but as the cycle advances, the shape tends to become more elongated (Padmaja Rao, 1978). The shape of the basin is significant since it affects the stream discharge characteristics (Strahler, 1969). It has long been accepted that a circular area is more likely to have a shorter lag time and a higher peak flow than an elongated basin. Three dimensionless ratios viz., form factor, circularity ratio and elongation ratio, reflect the basin shapes.

**Form Factor (Rf):**

It is the ratio of a basin area Au (Horton, 1932) to the square of the basin length Lb. For Bhima basin, the form factor is 0.0046.

$$Rf = \frac{Au}{Lb^2} \quad Rf = \frac{29428.11}{(2524.79)^2} \quad Rf = \frac{29428.11}{6374564.54} \quad Rf = 0.0046$$

A form factor nearer to zero indicates a highly elongated shape and the value that is closer to 1 indicates circular shape. The basins with high form factor value have high peak flow for short duration whereas elongated basin with low form factor will have a flatter peak flow of longer duration. Flood flows in elongated basins are easier to manage than that of the circular basins (Nautiyal, 1994). The Bhima basin, being elongated in shape, has an Rf of 0.0046.

**Circularity Ratio (Rc):**

Circularity Ratio is defined as the ratio of basin area (Au) to the area of circle (Ac) having the same perimeter (Pr) as the basin (Miller, 1953). It is influenced more by the length, frequency and gradient of streams of various orders rather than slope conditions and drainage pattern of the basins. For Bhima basin, the ratio is 3.51.

**Elongation Ratio (Re)**

It is the ratio of the diameter of a circle of the same area as the basin to the maximum length of the basin (Schumm's, 1956). For the study area, the elongation ratio is 0.032. Values range from 0.6 to 0.8 is generally associated with strong relief and steep ground slopes. There is no strong relief.

**Drainage Density (Dd):**

The Drainage Density (Dd) is defined as the length of streams per unit area. It is obtained by dividing the cumulative stream length by the basin area (Horton, 1932). For the Bhima basin the overall drainage density is 0.075 per km. In general, high Dd is characteristic of regions having nonresistant or impermeable subsurface materials, sparse vegetation and mountainous relief; Whereas low Dd indicates regions of highly resistant rock or highly permeable subsoil materials under dense vegetative cover, where the relief is low. In the study area, the hilly region to west shows high Dd, while it is very low in the area close to the coastal plain.

**Stream Frequency (Fs):**

Stream frequency of the basin may be defined as the ratio of the total numbers of segments cumulated for all orders with a basin to the basin area (Horton, 1945). The Fs of the whole basin is 3.51streams/$km^2$. High drainage density and stream frequency indicate larger run off from a basin.

**Drainage Texture (T):**

The drainage texture may be defined as the relative spacing of drainage lines. The drainage density and drainage frequency have been collectively defined as drainage texture.

It can be expressed by the equation (Smith, 1950),

**T** = **D**d X **F**s.

Based on the values of T it is classified as (Smith, 1950)

0-4 – Coarse
4-10 – Intermediate
10-15 – Fine
>15 – Ultra Fine (bad land topography)

For Bhima basin the drainage texture is 0.263 indicating the massive and resistant rocks cause coarse texture.

**Results and Discussion:**

The total drainage area of Bhima river basin is 29,428.11 $km^2$. The details of stream characteristics confirm with Horton's (1932) "law of stream numbers" which states that the number of streams of different orders in a given drainage basin tends closely to approximately an inverse geometric ratio. It also confirms with Horton's (1932) the "law of stream length" which states that the average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio.

**Conclusion:**

The study reveals that drainage area of the basin is passing through an early mature stage to old age stage of the fluvial geomorphic cycle. Lower order streams mostly dominate the basin. The development of the stream segments in the basin area is more or less affected by rainfall. It is noticed that stream segments up to third order traverse part of the high altitudinal zones which are characterized by steep slopes while the fourth, fifth and sixth stream segments occur in comparatively flat lands. The average bifurcation ratio of 4.16 reveal that drainage network in study area is well developed stage. The drainage basin size analysis reveals that the flooding may be lesser.

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# GEOMORPHOLOGIC CHARACTERIZATION OF FOOT HILLS OF ARUNACHAL PRADESH USING REMOTE SENSING AND GIS TECHNIQUES

**Varsha Patnaik**

**Abstract:**

Remote sensing and GIS have been increasingly used for geomorphological studies due to synoptic view and precise spatio-temporal data and image of earth surface features. RS GIS has been used to physiography and relief of the foothills of Papum Pare district of Arunachal Pradesh. The main earth surface parameter is slope, a derivative of height and distance is responsible for development and evolution of hillslope facets. Various geomorphic units have been delineated using satellite image in conjunction with DEM, aspect, drainage in the foot hills of Papum Pare District of Arunachal Pradesh. Drainage density reflects intensity of erosion in the area with uncohesive earth materials of Siwaliks and high intensity rainfall. Overall analysis indicates the rock types and structure especially in the Siwalik region control the Geomorphological characteristics of each identified Geomorphological units.

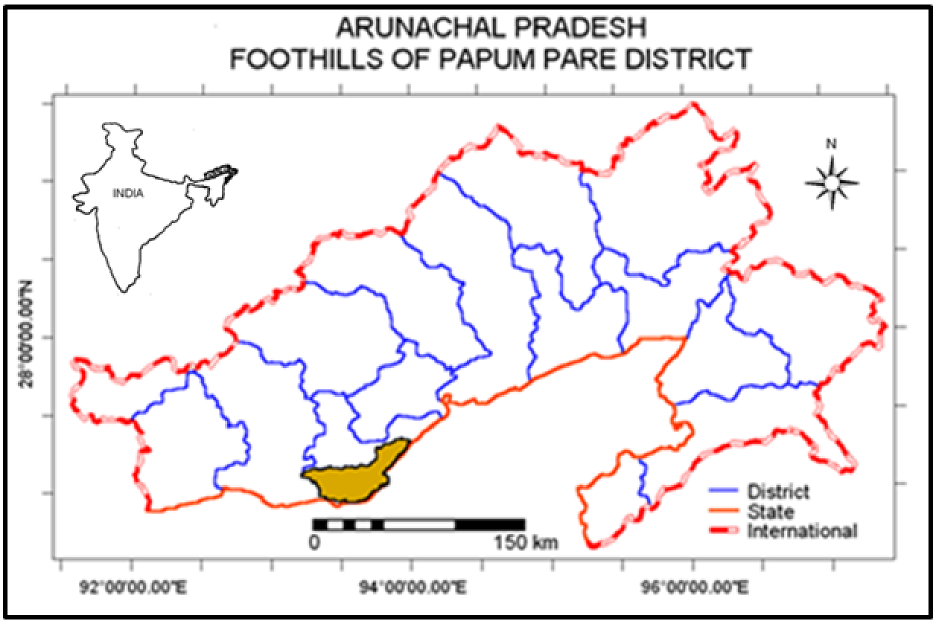
## Introduction:

The developments on terrain analysis using GIS is being introduced recently and becoming more popular in Geomorphological studies. Further the development of remote sensing and availability of satellite image are providing more and precise spatio-temporal data for any area and thus helped in identifying geomorphic changes through time and space. Besides these, GPS has added another dimension in studying location and significance of earth surface features. All these advanced sources of information are deemed fit to help in studying influence of Geomorphological factors in any respect. Such advancement and incorporation of different technologies have provided opportunities for better understanding the theme and preparation of different target maps. The RS GIS capabilities have been utilised in the present study to understand the physiography and relief of the foothills of Papum Pare district of Arunachal Pradesh.

## Location:

Papum Pare district has fifteen circles having total area of 2875 sq. km. The altitude ranges from below 100 m to 1300 m. Sagalee, Parang, Leporiang and Mengio circles are high hilly areas (between 1000 to 3000 m above m.s.l.) and the slope slowly lowers down towards the Assam state between which the foothills comes. The present study area includes the foothills of Papum pare district which falls under Taraso, Balijan, Banderdewa, Gumto, Doimukh administrative Circles and southern parts of Naharlagun, Itanagar and Kimin Circles with an area of 1411.58 sq. km. of the total geographical area of the district. It lies between 26º 45' N to 27º 30' N latitude and 93 º 00’ E to 94 º 00’ E longitudes. It is bounded by Lower Subansiri district in the north-east, East Kameng district in the west and Assam state in the south.

Figure 1: Location




**Literature Review:**

Literature review has been made to reflect the salient aspects and development of the study. Different scholars from earlier days have carried out extensive studies on slopes and profiles till now. One of the pioneering works in the field of slope morphometry is that of A. Tylor (1875). In a paper far in advance of its time, he gave a valley side profile surveyed in detail; he plotted binomial curves that showed a close fit with observed slope form and he supposed that slopes are eroded into this curve because it is the 'form of greatest stability…. It is the form which gives the nearest possible approach to uniform motion of water on its surface.'

Hill slopes are the part of the landscape included between the crest of hills and their drainage lines. Chorley (1964) has given four difficulties associated with the study of slopes: their complexity of form, the multivariate nature of processes, the doctrinaire attitude of most researches, and the feedback nature of the problem. Many processes rather than a single one eg, lithology, surface and sub surface, flow of water, mass movements and base level are responsible for the forms of hill slopes, and in addition the evidence suggests that changes occur on slopes much more slowly than in stream channels (Leopold, et.al, 1964).

In mountainous areas orographic effects are pronounced with greater precipitation and rainfall also generally decreases eastward across the region (Abrahams, 1986). The coincidence of major storms, extensive logging or development on steep slopes, and major earthquakes could trigger major episodes of landsliding in the region. A rapid landslide poses the greatest hazard to life because they can destroy buildings or damage roads with little warning. Kockelman (1985) had outlined some techniques for reducing landslide like remapping of bedrock geology, preparation of regional slope- stability maps, mapping of soils overlying the landslides, land- use planners for the implementation of hazard-reduction programs and to engineers who serve as advisors to local or state governments.'

Slopes are the angular inclinations of terrain between hill tops (crests) and valley bottoms, resulting from the combinations of many causative factors like geological structure, climate, vegetation cover, drainage texture and frequency, dissection index, relative reliefs (and of course denudation processes, including weathering, mass wasting and mass movements of rock wastes, erosion and transportation of eroded materials down slope) etc. are significant geomorphic attributes in the study of landforms of a drainage basin.' Thus, slope is the upward or downward inclination of surface between hills and valleys and form most significant aspect of landscape assemblages (Singh & Srivastava, 1977). At the base level, foothills are originated because of active denudation mainly by rain wash, rill and gully erosion. These are minor slopes formed due to accumulation of debris/scree coming down from the hill slope as a result of mass movement of rock wastes (Chorley, 1985).

**Geology:**

According to Pilgrim (1910) and Pascoe (1919) the Siwalik formation is made of the river deposition. This river was extending along the foothills and called as 'Indo-brahm'. Siwaliks are 'fore deep' deposits. Streams flowing from the mountains in the north supplied huge amount of sediments to the foothills. Upper tertiary sequence has been grouped into three rock strategraphic units which are from bottom to top Dafla, Subansiri and Kimin formations roughly corresponding to the lower, middle and upper Siwalik of the central and western Himalaya.

Kimin formation is formed of alternate soft current bedded sandstone; siltstone, clay and gravel. Thickness of conglomerate ranges in between 3 m to 30 m. with clasts of pebble to boulder size. In the lower horizons the pebbles have an orientation parallel to the bedding. Upper horizons are having the random orientation. The clast material is composed of gneiss, quartzite, schist and vein quartzite. The sandstone are coarse grained loosely consolidated and having current bedding. Colour varies from gray, blue gray to orange brown. Carbonized wood fragments of the length ranging in between few cm to 2 m are seen during fieldwork.

Subansiri formation includes soft massive sandstone and commonly known as salt pepper sandstone. The sandstone is bluish gray in color, medium to coarse grained, massive, soft and poorly micaceous. On weathering they turn yellow brown in color. The rocks are current bedded and thickness ranging from a few cm to 3 m. Occasionally, they are pebbly with pebbles of purple and gray quartzite. They also contain carbonized and silicified wood fragments. In the study area these rocks are exposed along the ridge of Simna Parbat hills. This range is forming an anticline and in its north and south Kimin formation is present.

Dafla formation covers the altemative beddings of indurated sandstone and shale. These sandstones are light gray to brown in color and poorly micaceous. The clays are greenish grey in color, exhibit spheroidal weathering and thickness ranges from 1 to 5 cm. Greenish gray to dark gray thin shale bands normally form the base of these shales.

**Temperature:**

In general the rise of elevation decreases temperature; hence lower altitudinal areas have higher temperature, in the study area. Highest average temperature is 36º C (July), 32.5º C (July), 35º C (August), 36.4º C (July) and lowest temperature are 7º C (January), 9.7º C (December), 6.8º C (January), 8.5º C (January) at Itanagar center in the year 2002, 2003, 2004 and 2005, respectively.

**Rainfall**

The distribution of rainfall depends on slope aspects, altitude and alignment of ridges. The windward side receives more rainfall. In the study area, the maximum rainfall occurs in the months of September (823.7 mm), June (682.3 mm), July (797.2 mm), August (731.1 mm) and lowest rainfall are in the months of January (12.3 mm), January (22.3 mm), December (60.6 mm), December (0.6 mm) in the year 2002, 2003 2004 and 2005, respectively

**Soil**

In the study area, new alluvium is found which consists of recently deposited silt and sand and is rich in organic content and if it is less sandy it is very fertile and suitable for agriculture, this soil is generally rich in phosphate, potash, calcium, nitrogenous material and organic substances and is less acidic and not saline. The main problem is that, during heavy rainfall these soils are easily washed out before formation. The alluvial soil is sandy in the immediate riverbanks, loamy at some distance from the riverbeds and clayey in areas of greater distance from the river.

**Data Base And Methodology**

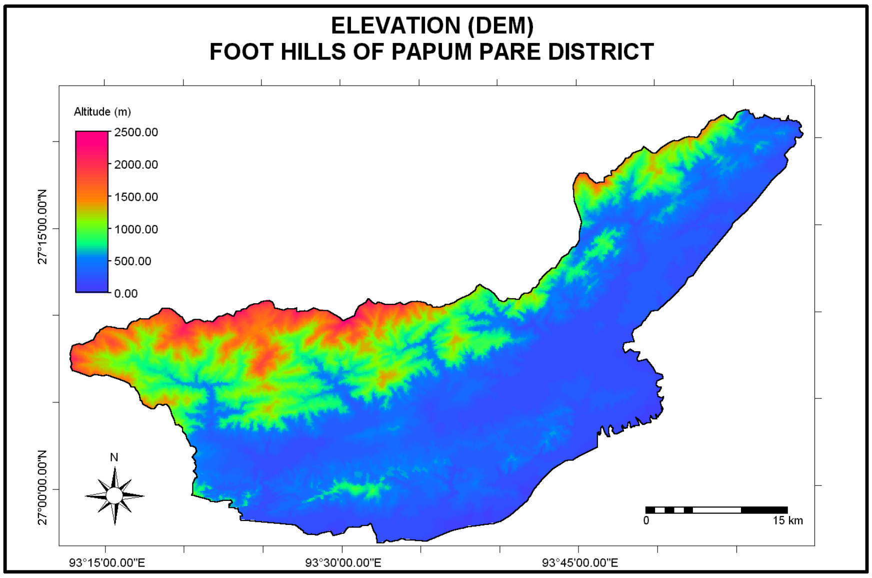
The study has been carried out using toposheets of SoI at 1:50000 scale, digital satellite data (LISS III) as source of spatial data base. Basic and preliminary information about different landforms have been collected from the topographical maps. Detailed field work has been done by taking traverse along the roads and rivers. The boundaries of different landforms units were delimited and salient erosional and depositional geomorphic features of each unit were identified. Various thematic maps have been prepared, for example, relief maps, drainage maps, slope maps and profiles, etc. An appropriate base map, contour map and drainage map would be prepared by using SOI topographical map. DEM, altitude map, aspect map, slope map, drainage density map (for morphometric analysis) have been prepared by using GIS method, ILWIS software from toposheets.

**Relief And Slope Analysis**

**Digital Elevation Model (Dem):**

Digital Elevation with a cell size of 100 m has been prepared for the study area using ILWIS software. The contour with an interval of 20 m has been taken as input. This DEM shows gradual altitudinal variation. The upper or the northern sides have higher elevation while the lower elevation prevails towards the southern side. The altitude ranges from 80 m to above 2275 m. Figure 2 and Table no.1 clearly shows that maximum area is covered by the lower elevations from 200 m to 500 m of about 60% of the total area.

Figure 2: Digital Elevation Model




**Altitude Zone:**

For a clear observation of the altitude zone of the area, a bar graph is prepared. Longer the bar of the altitude class higher the area covered by that altitudinal zone. Thus, figure no.3 shows that maximum area is under the elevation of 300 m to 500 m above sea level.

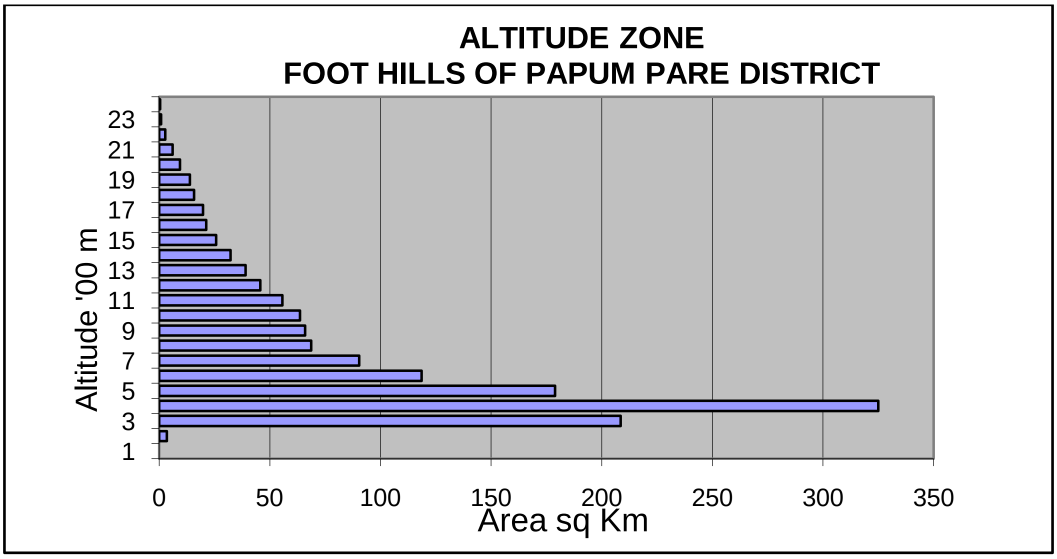
Table no. 1 **Altitude Zone and Area**

| ALTITUDE | AREA Km |
|---|---|
| 80 | 0.00 |
| 100 | 3.48 |
| 200 | 208.53 |
| 300 | 324.97 |
| 400 | 178.97 |
| 500 | 118.57 |
| 600 | 90.42 |
| 700 | 68.74 |
| 800 | 65.96 |

| ALTITUDE | AREA Km |
|---|---|
| 1200 | 39.08 |
| 1300 | 32.23 |
| 1400 | 25.77 |
| 1500 | 21.19 |
| 1600 | 19.86 |
| 1700 | 15.74 |
| 1800 | 13.82 |
| 1900 | 9.33 |
| 2000 | 6.08 |

| | | | |
|---|---|---|---|
| 900 | 63.60 | 2100 | 2.70 |
| 1000 | 55.68 | 2200 | 0.84 |
| 1100 | 45.65 | 2275 | 0.37 |

Figure no. 3: Altitude Zone




**Slope Analysis:**

There are different methods suggested by many earth scientist for the study of average slope. But here by using ILWIS software, the contour lines are digitized at 1:50 000 scale with 20 m interval. Plan slope is calculated using interpolation technique and further classified into six slope categories such as flat, plain, moderate, steep, very steep and precipitous. Table no 2 and Figure no. 4 clearly indicates the six categories of slope with their area and broad classification.

Figure No. 4 Slope

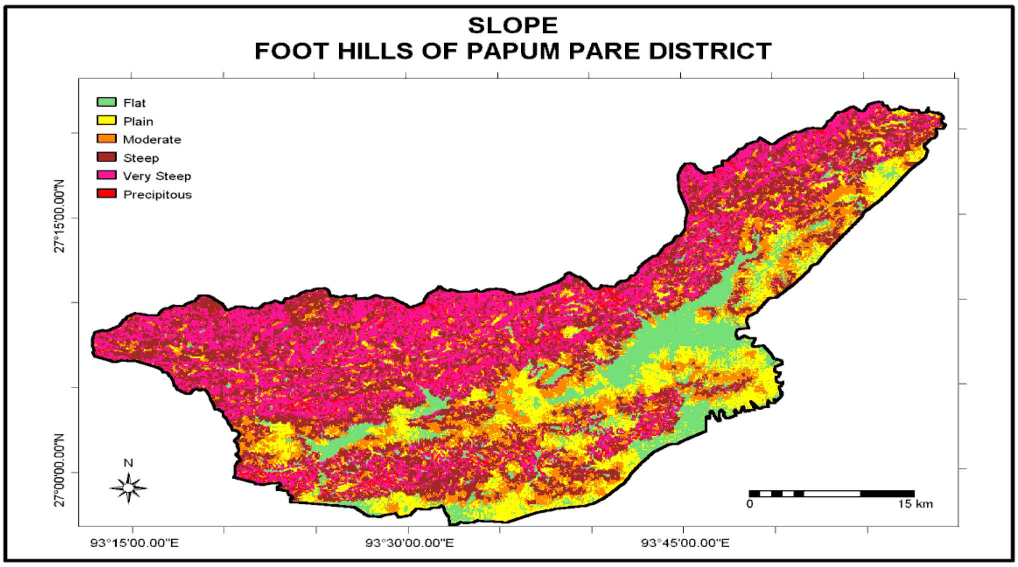



**Table no. 2: Average Slope**

| Sl. No. | Slope Classes | Slope category | Area (in sq.km) | Area (in%) | Cumulative area (in%) |
|---|---|---|---|---|---|
| 1 | Below 2º | Flat | 181.80 | 12.88 | 12.88 |
| 2 | 2º-5º | Plain | 199.92 | 14.16 | 27.04 |
| 3 | 5º-10º | Moderate | 208.16 | 14.75 | 41.79 |
| 4 | 10º-25º | Steep | 426.47 | 30.21 | 72.00 |
| 5 | 25º-45º | Very steep | 358.32 | 25.38 | 97.38 |
| 6 | 45º and above | Precipitous | 36.91 | 2.62 | 100.00 |

**Aspect:**

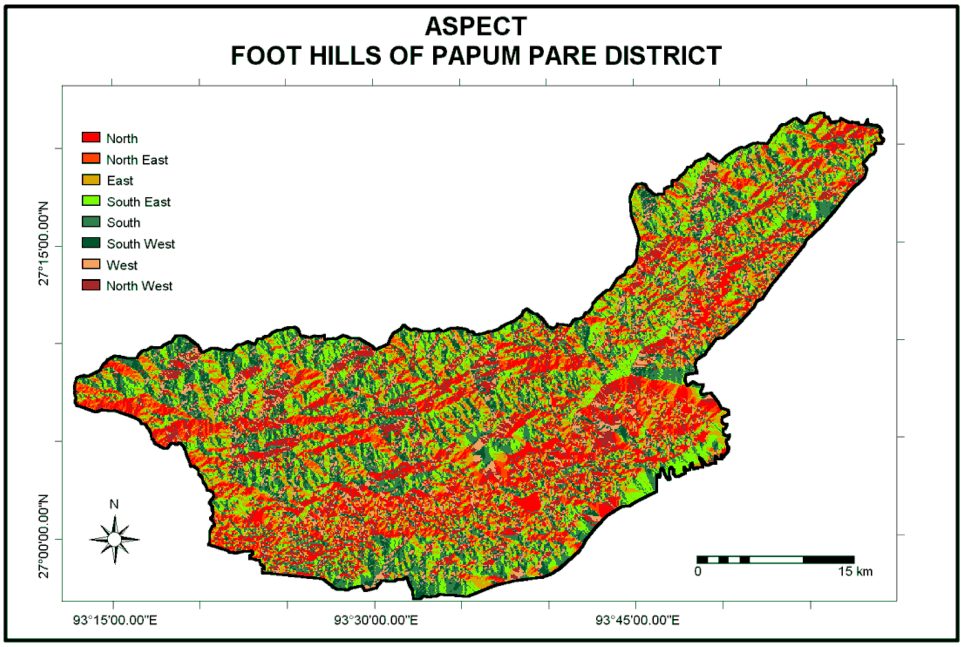
The ground slope facing the sun receives more insolation because the sun's rays reach the surface more or less straight an hence sun facing ground surfaces record higher temperature than the leeward slopes where sun's rays reach more obliquely. Thus, sunshine plays an important role in the growth of settlement and cultivation. Number of sunny days, duration of sunshine and its intensity plays a determining role. So aspect study of the area is an integral part of the study. The aspect analysis shows the presence of sunlight called as *ubec*. The possibility of vegetation cover is also found to be more in the sunny side of the terrain. Topography affects the absorbance of solar energy in a given landscape. In the northern hemisphere, south facing slopes are more perpendicular to the sun's rays and are generally warmer and thereby commonly lower in moisture than their northern facing contour part. Thus the sunny side of the aspect supports dense vegetation cover as well as agriculture.

Aspect map (figure no 2.6) and Table no. 2.3 shows that from south east to south i.e. from 112.5º to 202.5º, there is more chance of vegetation cover, agriculture and settlement, followed by north direction i.e. from 337.5º to 22.5º.

Table no. 3 Aspect

| Sl. No. | Degree | Category | Area (in sq.km.) | Area (in %) | Cumulative Area (in %) |
|---|---|---|---|---|---|
| 1 | 337.5-22.5 | North | 210.89 | 14.94 | 14.94 |
| 2 | 22.5-67.5 | North east | 133.88 | 9.48 | 24.42 |
| 3 | 67.5-112.5 | East | 181.10 | 12.83 | 37.25 |
| 4 | 112.5-157.5 | South east | 236.47 | 16.75 | 54.00 |
| 5 | 157.5-202.5 | South | 236.73 | 16.77 | 70.77 |
| 6 | 202.5-247.5 | South west | 151.67 | 10.74 | 81.51 |
| 7 | 247.5-292.5 | West | 131.88 | 9.35 | 90.86 |
| 8 | 292.5-337.5 | North west | 128.96 | 9.14 | 100.00 |

Figure: 5: Aspect



**GEOMORPHIC UNITS AND ASSOCIATED LANDFORMS:**

On the basis of detail study of the satellite images, altitude zone, hypsometric integral, physiography, slope, aspect maps and a limited fieldwork an attempt has been made to delineate the study area into homogenous geomorphic units for which different units are identified

**ALLUVIAL PLAIN** –Alluvial plains are formed when the transporting capacity of the streams decrease enormously at the foothill zones while they leave the mountains and enter the plain topography because of substantial decrease in their velocity consequent upon decrease in channel gradient and finally deposited some materials consisting of finer to coarser and big sized materials of the foothill zone. In this unit the height is between 70 m to 100 m, relative relief is from 0 to 100 m and slope ranges from level to 7º respectively.

**PIEDMONT** –Before reaching to the plain the tributaries of Papum, Pam, Buraii, Pachin, Niorch and Dikrong Rivers are making fan like formation of alluvial deposit. This area is called piedmont because all the individual fan boundaries are intermingled and it is very difficult to differentiate. This unit is made of mainly boulders, cobbles, pebbles, gravels, sand and silt. The height of this unit is between 100 m to 300 m, relative relief is from 20 to 100 m and slope ranges between 7º to 14º respectively.

**HIGHLY DISSECTED LOW HILLS** –Drainage density is very high in this area and a small stream is also having a gully type channels. This unit has weaker rocks due to which erosion is very high. It comprises of conglomerates and loose sandstones. The height of this unit is between 100 m to 300 m, relative relief is between 100 m to 200 m and slope is from 14º to 21º.

**LOW RELIEF RUGGED HILLS** – An area having uneven topography, high drainage density, dendritic drainage pattern, gentle gradient streams and gullies with wide open V-shaped valleys is named as low relief rugged hills. It comprises of poorly consolidated alternate sand, clay and conglomerate. This area is found to be more or less like bed land topography. Small streams also have a wide valley and watersheds in between are narrow. This area is extending in the north of Simna Parbat anticline. Probably the area comprises synclinal limb. In this unit the height is between 600 m to 1000 m, relative relief is from 100 m to 400 m and slope is from 14º to 29º respectively.

**STRUCTURAL HILLS** –The area which showing banded texture, straight ridge lines and a combination of parallel, rectangular and trellis drainage pattern is designated as structural hills. It is further divided into two zones i.e. low relief structural hills and high relief structural hills on the basis of altitude. In the low relief structural hills flat iron an scarps type of features are found and in the high relief structural hills rapids are found. In the low relief Structural hills the height ranges between 100 m to 600 m, relative relief is 200 m to 500 m and slope is from 21º to 28º respectively. In the high relief Structural hills, the height is between 1000 m to 1200 m, relative relief is between 200 m to 500 m and slope is between 21º to 35º respectively.

**DENUDATIONAL HILL** –This area appears more subdued and denudated so this is called as denudational hills. This area is older in age than the Siwalik so ridge lines are not so sharp as in the Siwalik lithology. Dendritic and radial type of drainage patterns are found in this area. this unit lies in the north of the study area. this unit has height between 1200 m to 2380 m, relative relief between 100 m to 800 m and slope is from 21º to 43º respectively.

During the Himalayan formation the tectonic activities form structural dislocation and deformation due to which various landforms are formed. Some of the major landforms are as follows –

**HOGBACK** –The escarpments or ridges having symmetrical slopes on both sides are called hogback ridges or simply Hogbacks. Hogbacks are formed due to faulting and thrusting which indicates the inner lying structural disturbances. A sudden break in topography due to higher side slope or anti –dip slope than the dip slope. In the study area it is generally followed by the lineaments.

**GORGE** –Very deep and narrow valleys having very steep valley side slopes say wall –like steep valley sides are called Gorges. In the study area small streams passing through the uppermost deposits i.e. loose sand and clay stone (Kimin formation and Post Siwalik deposits) comprise deep gorges. The depth of gorges in some places found upto 15 m. This kind of observation can be explained only proper understanding of the structural control on it. This kind of topography may be observed along the foothills and Jote-Basarnala-Yadang valley. On the basis of these observations it appears that upliftment during the recent years might have been higher.

**RIVER TERRACE** –The narrow flat surfaces on either side of the valley floor are called river terraces which represent the level of former valley floors and the remnants of former flood plains. River terraces are generally formed due to dissection of fluvial sediments of flood plains deposited along a valley floor. River terraces are found in a corridor along the Dikrong and Pachin River. The thickness of the terraces varies from point to point. The forming material includes sand, sand with pebbles, sand with earthy clay, loose sand with very small pebbles, big boulders with sand and pebbles. The shape of these pebbles varies from elongated, semi-rounded, sub rounded to sub angular and made of quartzite, gneiss, schist and few of slate. In general the maximum pebbles are made of quartzite. Four level terraces are identified along Itanagar-Jote-Basarnala and Yadang.

**CHANNEL BAR** –Channel bars are formed due to the change in the gradient on the way of river channel. Channel bars are found in this area due to the tectonic activeness of foothill thrust. Channel bars are observed along the Buraii, Papum, Pachin and Dikrong Rivers.

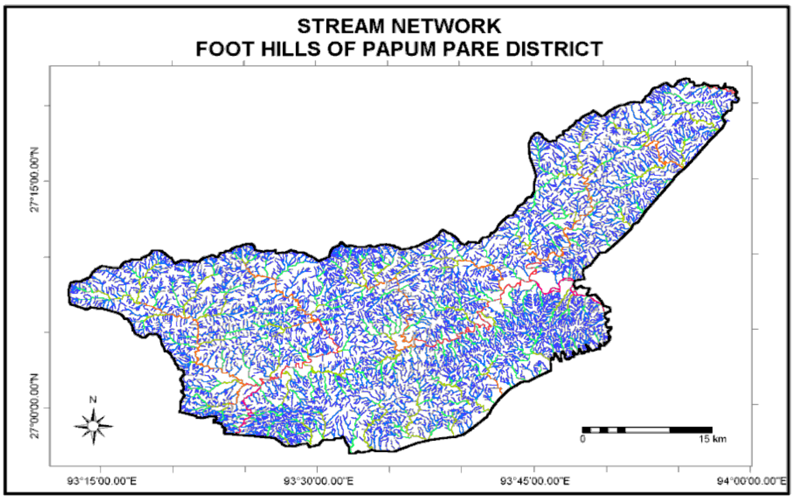
**VALLEY FILLS** –The valley fills are in different pockets scattered over the Pachin and Papum river basins. A large amount of sediment brought by the streams descending from the highly dissected low hills. These valley fills are comparatively plain areas best suited for agricultural purposes.

## DRAINAGE ANALYSIS

### DRAINAGE NETWORK

In the study area, the main river is Dikrong, which flows from north-west to south east and joined by its various tributaries. The main tributaries are Papum, Pam, Pachin, Senkhi, Singra, etc. These rivers are mostly seasonal in nature. The drainage network is following the regional sloped in the direction of north, south east to south and well adjusted to geological structure, joining the river Brahmaputra near Ramghat. In the present study the streams of river basin of the circle have been ranked according to Strahler's stream ordering system. Thus, the Dikrong River, which is the trunk stream of the study area, is of the 7th order. Its tributaries are of lower orders (figure no.6)

Figure No. 6 Drainage Network




**Drainage Density**

Drainage density of the area has been derived using digitized drainage map at 1:50000 scale and segment density technique available in ILWIS, with cell size of 500 m.

Dd = ∑L / A

Where, Dd = Drainage density

∑L = Total length of stream in the grid/cell

A = Total area of the cell

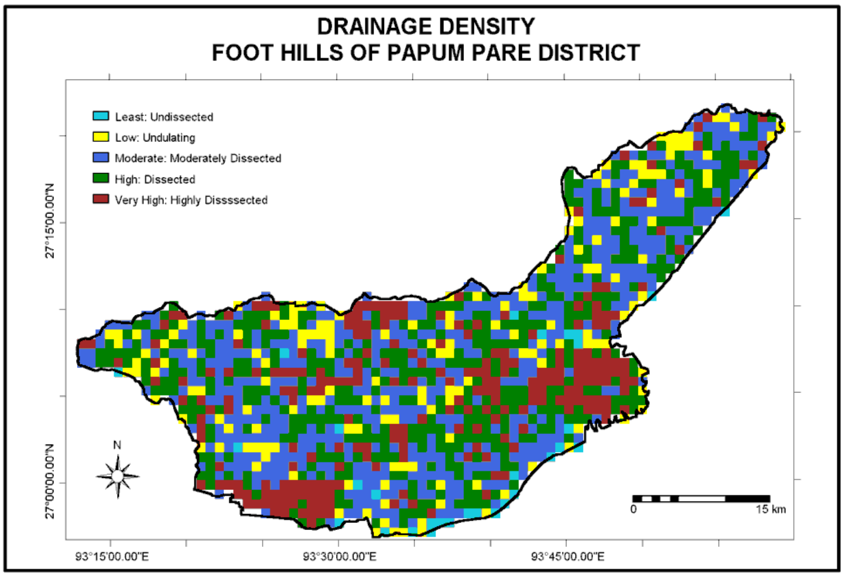
Selecting a suitable class interval, five indices of dissection ranges i.e. Undissected, Undulating, Moderately dissected, Dissected and Highly dissected were formulated (Table 4)

Table no. 4 Drainage Density

| Sl. no. | Drainage Class (in m/grid) | Category | Area (in sq. km.) | Area (in %) | Cumulative area (in %) |
|---|---|---|---|---|---|
| 1 | Below 1000 | Undissected | 31 | 2.13 | 2.13 |
| 2 | 1000-2000 | Undulating | 168 | 11.94 | 14.07 |
| 3 | 2000-3000 | Moderately dissected | 519 | 36.75 | 50.82 |
| 4 | 3000-4000 | Dissected | 439 | 31.20 | 82.02 |

| | | | | | |
|---|---|---|---|---|---|
| 5 | Above 4000 | Highly Dissected | 254 | 17.98 | 100.00 |
| | | Total Area | 1411 | | |

Figure 7: Drainage Density




## Summary and Conclusion:

Regional variation in slopes in the area is associated with tectonic movement with high degree of denudational activity besides other factors such as weathering, process of erosion, transportation. Average relief in different categories expresses the intensity of relief, which can be determined per unit area. In the study area maximum area is under the lower altitudinal zone, a little area is under the higher altitudinal zone and the moderate intensity almost scattered around the central portion of the area.

The slope, aspect and physiography map of the area expresses the amount of slope and nature of the surface slope. The highest relative relief is found in the northern and north western parts, showing structural hills of slightly dissected topography. Moderate relative relief is scattered in the eastern, western and central part of the area with dissected topography. The lowest relative relief is in the southern part of the area with highly dissected topography. This may be due to the higher elevation area has made up of hard rocks and the lower elevation are of softer rocks.

Five categories such as undissected, undulating, moderately dissected; dissected and highly dissected types of drainage density are defined from the length of stream with reference to its intervening spaces which vary in degrees. It coincides with rate of erosion and degradation land in the area. An attempt has been made to classify landforms on the basis of comparison of the results of different morphological techniques applied to the study area. Some of the geomorphic units are alluvial plain, piedmont, highly dissected low hills, low relief rugged hills, structural hills, denudational hill and the associated landforms are hogbacks, gorges, landslides, river terraces, drainage, boulders, channel bars, river meanders, fault scarp, valley fills, etc.

Overall analysis indicates the rock types and structure especially in the Siwalik region control the Geomorphological characteristics of each identified Geomorphological units. In the satellite image dissection pattern is clearly distinct and highly influenced by the litho logy of the area. Major impact of structure or drainage pattern especially in between Main Boundary Fault and Tipi Thrust can be delineated from topographical maps, satellite images, and FCCs.

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# GEOSPATIAL MODELING FOR WATERSHED PRIORITIZATION IN DAHI BLOCK, DHAR DISTRICT, MADHYA PRADESH.

P.S.Dhinwa and Madhavi Pore

## Abstract

Watershed prioritization and management requires scientific knowledge of resource information, expected sediment yield and priority class of watersheds for conservation planning. Satellite data is ideally suited to derive spatial and temporal information of watershed cover types which can be inputs to sediment yield models and watershed prioritization schemes. Prediction of surface run off and sediment yield from any catchment is a complex phenomenon which affected by various factors, e.g. Climate of catchment, its morphometry, soil properties, land use/land cover, irrigation and management practices affect the sediment yield from catchment. In this case study of Dahi Block, Dhar district soil erosion due to the runoff is most important cause of land degradation. An endeavor is made here to prioritise Dahi block, Dhar district (M.P.) based on geospatial data and by using surface run off and sediment yield models so that conservation measures can be planned and executed.

## Introduction:

The established procedure for watershed development planning in India is a top down approach by way of schemes to address specific problems and opportunities. These schemes are mandated by state and central government, and implemented by the sectorial institutions in a district. Existing decision methods are traditional, manual and biased in identifying the watershed sites for different schemes. Generally, base unit for these schemes is watershed, being a complete hydrological/topographical unit. Each scheme has a set of policies that are defined by legislation. Under these watershed management schemes, planners at district/sub-district level need to identify the priority watershed/ sub watersheds for preferential treatment/ land use plans. Run off is that portion of rainfall which moves down to the stream, channel, river or ocean as surface or subsurface flow. “If the farmer can intelligently harvest the runoff from his field, store in a pond and recycle it for life saving or supplementary irrigation to crops, it will be possible to boost up his crop production and thus obtain good returns (Dhruva Narayana, 1993)”.

There are many reasons to develop a non-point source pollution prioritization system to determine which watershed requires the most attention. Once priority problems watersheds have been determined, an approach for directing specific actions is needed, i.e., targeting the specific areas of greatest potential erosion which can contribute to water quality degradation. Once targeted areas are identified, an optimizing management system can be used to examine trade – offs of the potential impacts from the implementation of various best management options. The BMP’s could be selected to minimize off – farm degradation of water quality and the farmers economic criteria.

**Objective:**

The primary aim of the this study is to carry out watershed prioritization based on surface run off and sediment yield models in Dahi Block, Dhar district (M.P.).

# Study Area:

The study area, Dahi block of Kukshi taluka is located in south-west part of Dhar district, Madhya Pradesh. It lies between 22° 00’ and 22°15’ N Latitude and 74°30’ and 74°45’ E Longitude. The south and western boundaries of study area are marked by rivers Narmada and Hatni respectively. Total geographic area of this watershed is 470.46 sq. km. The major part of the study area is covered by Deccan traps of Lower Eocene to Upper Cretaceous Era. The study area is spread over two major geomorphic divisions, namely Vindhyachal range and Narmada valley. Physiographically Dahi block is characterized with High hills, inter hill uplands, Interfluves, Valleys and River terraces. The mean annual precipitation of the area is 395.86 mm with high degree of annual variability. The drainage density is moderate with predominantly dendritic to subdendritic drainage pattern

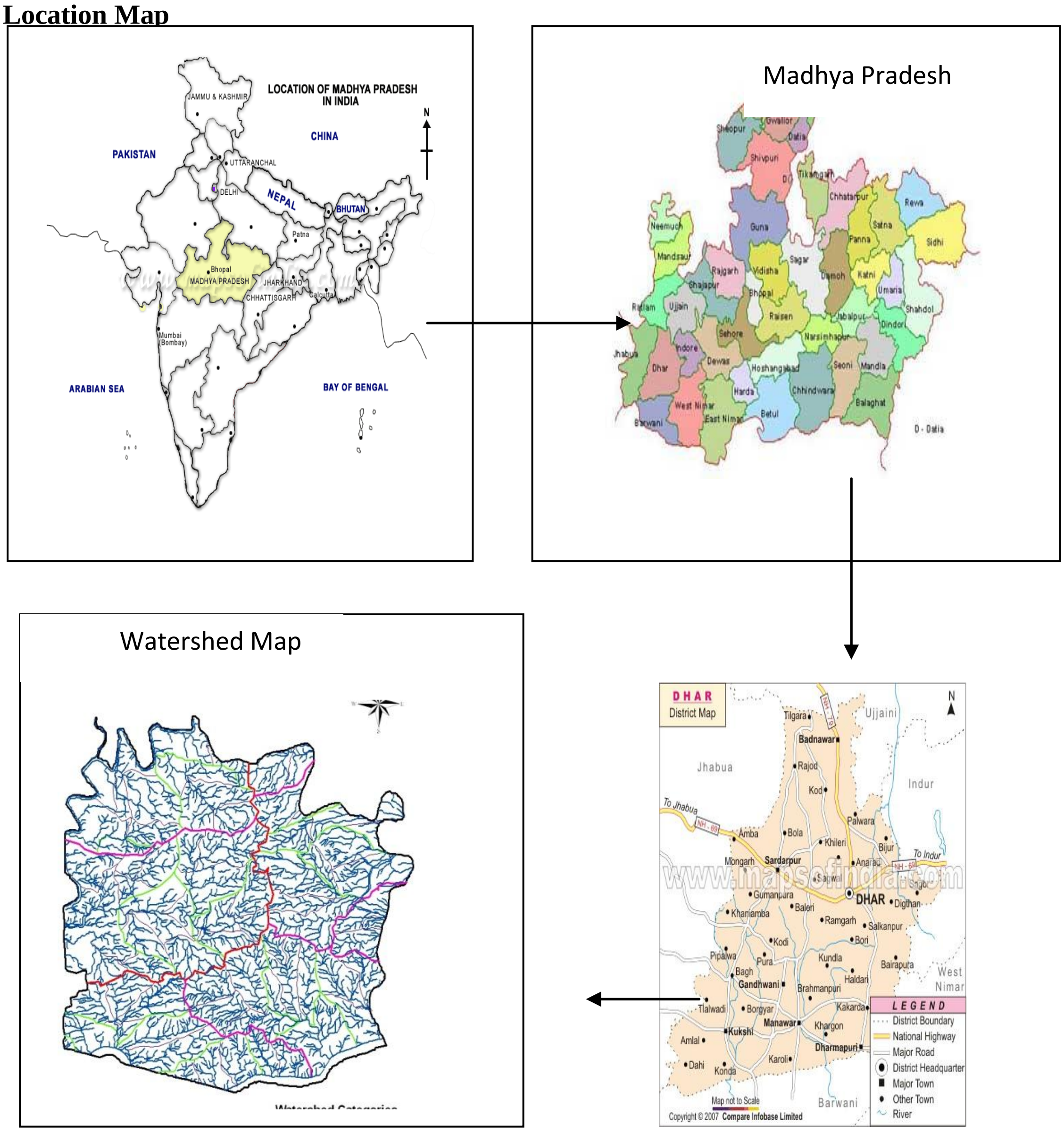
**Data Used**

IRS 1D multi-date satellite data, ancillary information and collateral data have been used for preparing thematic maps to be used for prioritizing watersheds in Dahi Block Dhar district (M.P.) as given in Table 1.

**Table 1. Data Used**

| | Satellite-ID | Sensor | Date of Acquisition |
|---|---|---|---|
| Satellite Data | IRS-P6 | LISS-III | 24.10.2007 |
| | IRS-P6 | LISS-III | 28.01.2008 |
| | IRS-P6 | LISS-III | 09.05.2007 |
| Ancillary Information | 46 J/12 Toposheet (1:50,000 scale) | | |
| Collateral Data | Daily Rainfall Data of Dahi Block<br>Soil Texture and Soil Depth Maps, Cadastral Map | | |

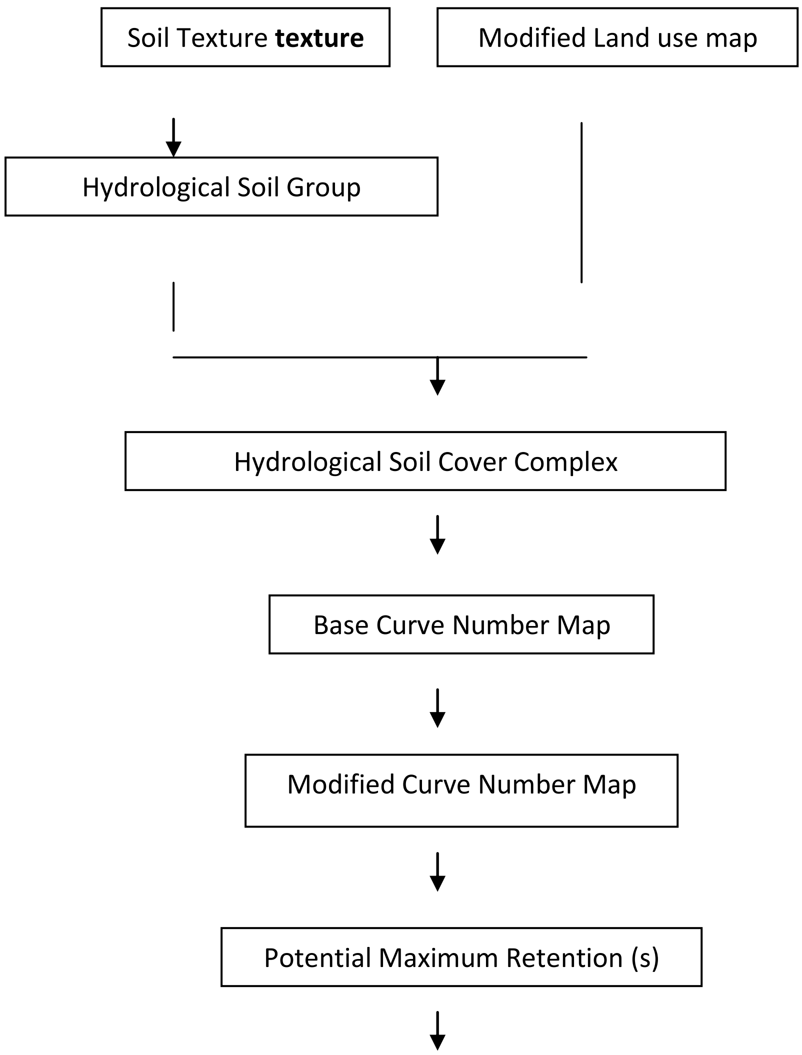
**Fig. 1 Location Map**



## Methodology:

Various thematic maps, e.g. Land use/ cover, ground water prospect and slope were prepared through the use of multidate satellite data, ancillary information and collateral data as referred in Table 1. Later on, spatial database is created for these themes in GIS environment and subsequently this coverage's are unionized and integrated in GIS environment for creating special themes for calculation of run off and estimation of soil loss. For run off estimation, Land use/ land cover and soil maps were integrated and final run off was predicted by using SCS model as shown in Fig.1. Run off was calculated per micro-watershed wise. For soil loss calculation, Land use/ land cover, soil, slope and hydro geomorphology maps were integrated and soil loss was predicted by using Sediment Yield Index Model as shown in Fig. 2. Seasonal and month wise Run off of the study area was calculated for the year 2007.

**1. Curve Number Method**



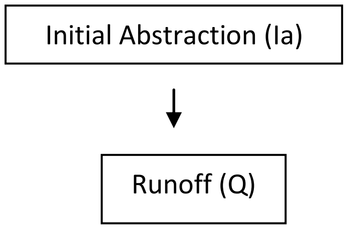



**Fig. 2 Flow Chart of Runoff Estimation**

**Procedure adopted for estimation of direct runoff**

1. Generation of NDVI (Normalized Difference Vegetation Index) map.
2. Calculating poor, fair and good condition for crop and forest.
3. Modification of Land Use map in giving poor, fair and good categories.
4. Preparation of hydrological soil group (HSG) map using soil texture.
5. Preparation of hydrological soil cover complex (HSCC) map combining HSG map and modified Land Use map.
6. Preparation of the base Curve Number (CN) map.
7. Preparation of daily rainfall maps using rainfall depth data.
8. Preparation of Antecedent Moisture Condition map using rainfall maps.
9. Modification of base curve number map for AMC I and AMC III condition.
10. Preparation of modified Curve Number (CN) map.
11. Calculation of maximum retention
12. Calculation of initial abstraction (Ia)
13. Calculation of daily runoff.

Final rainfall-runoff relation used in the SCS method of estimating direct runoff from storm rainfall is,

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)}$$

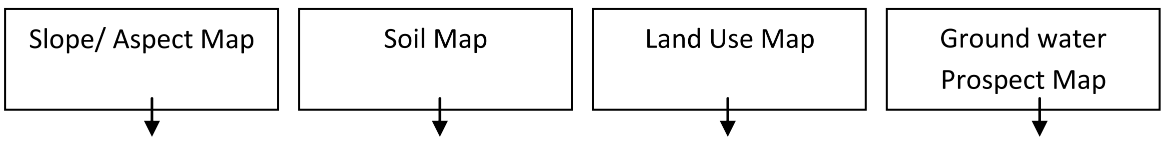
Where,

Q = Runoff in mm

P = Precipitation in mm (P > Q)

S = Potential maximum retention in (mm)

**2. Integration of thematic maps and Sediment Yield Model (SYI)**



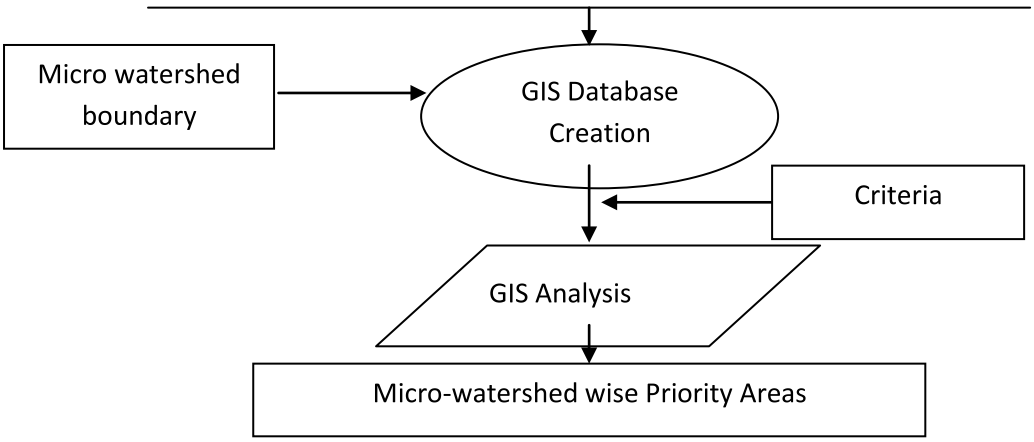



**Fig. 3 Flow Chart for Micro-watershed Prioritization**

HLP (Homogenous Land Parcel Unit) is homogeneous at specific level of details and is obtained by integration of the above characteristics i.e. HLP is derived from integration of slope, soil, land use and ground water prospect maps.

To derive HLP following inputs were used.

i) Elevation contour – from SOI topographical map with contour interval 20m at 1:50,000 scale

ii) Soil – Soil map prepared by giving soil depth attributes to the cadastral map of selected study area.

iii) Ground water prospect map derived from prepared hydrogeomorphological map of selected study area.

iii) Land use map at level-III using remote sensing data of the selected study area.

## Results and Discussion

Various thematic maps, e.g. Land use/ cover, ground water prospect, slope and soil depth were prepared through the use of multidate satellite data, ancillary information and collateral data. Later on, spatial database is created for these themes in GIS environment and subsequently these coverages are unionized and integrated in GIS environment for creating special themes for calculation of run off and estimation of soil loss. Runoff Calculated using SCS CN method. For soil loss calculation, Land use/ land cover, soil, slope and hydro geomorphology maps were integrated and soil loss was predicted by using Sediment Yield Index Model.

Several studies have been carried out to develop methodology for prioritizing watershed using remotely sensed data and through GIS. "Advances have been made in the development of discrete input output models of the rainfall run off processes (Guang Te Wang and Yuan, 1990)". Many models, Rational Method, Cook Method, Khosla's Model and Curve Number Methods of run off estimation have been attempted by various authorities for watershed prioritization. For the present case study, Curve Number Method has been attempted. A number of sediment yield models, both empirical and conceptual, are in practice to address wide ranging soil and water management problems. Many models, Douglas Sediment Yield Equation, Musgrave Equation, Sediment Yield Predictive Equation, Universal Soil Loss Equation and sediment Yield Index Equation of soil loss estimation have been attempted by various authorities for watershed prioritization. "The watershed that contains the largest amount of impervious area has the largest amount of storm runoff (Brown, 1988)". Most conservation planning for erosion control, however use empirical models to estimate average annual soil loss. "The accelerated soil erosion in the catchments of multipurpose dam reservoirs and transport of eroded material through the drainage network give rise to series of problems (Karale et al, 1989)". "Investigation into such empirical models reveals that most of these models require input parameter in terms of spatial information of land use, soils, slope, drainage density, besides run off and rainfall intensity (Chakraborti, 1991)". The sediment Yield Equation model developed by All India Soil and Land Use Survey, Government of India, New Delhi (1977) for estimation of soil loss has been used in this study. The run off estimation has been done by Curve Number Method. The details for Curve Number Method are as follows-

## Estimation of runoff

### Curve Number Method

Curve Number Method was developed by Ogrosky and Mockus (1957) for determining peak rate of run off for small watersheds by synthesizing information about characteristics, physiographic factors and soil cover data. "Runoff is the water in a river or stream that is derived from precipitation (Barry et. Al, 1988)". In the present study, the model Soil Conservation Service (SCS), established by United States of Agriculture is used to study the hydrologic response of the watershed to precipitation in order to prioritize watershed for adopting suitable water conservation measures. This method is used to estimate direct runoff volume from the rainfall depths. This method takes into account the parameters characterizing a watershed such as land use, hydrological soil cover and antecedent moisture condition for predicting yield from the watershed. The Land Use/ Land Cover map that was generated based on IRS-P6 LISS III images was used as one of the inputs. There are 15 categories in Land Use/ Land Cover ,i.e., Built up - Villages(Rural), Agriculture - Kharif, Rabi, Double crop and Fallow, Wasteland – Land with scrub, Land with out scrub, Barren Rocky / Stony Waste, Mining(Industrial waste), Forest – Dense forest, open forest, scrub forest, forest blank, crop land in forest and water bodies. All these land use/ land cover classes have been modified into three classes of poor, fair and good based on good crop, good canopy of forest/ Land with scrub given in a modified land use/ land cover map. A NDVI map was prepared for the images using NIR-R/ NIR+R band. NDVI images for forest and agriculture were prepared. Then by using mean and standard deviation values under agriculture and forest poor, fair and good conditions were calculated as follows:

| | | | | |
|---|---|---|---|---|
| NDVI | >= | μ + 6 | | Good Condition |
| μ + 6 | > | NDVI | > μ - 6 | Fair Condition |
| NDVI | <= | μ - 6 | | Poor Condition |
| Where, μ | = | Mean | | |
| 6 | = | Standard deviation | | |

**Table 2. Modified land use/land cover classification system.**

| Sl. No. | Level II | Level III | Hydrological crop condition |
|---|---|---|---|
| 1. | Built-up | Village (Rural) | |
| 2. | Agriculture | a. Kharif | Poor Agriculture |
| | | b. Double crop | Fair Agriculture |
| | | c. Cropland in forest | Good Agriculture |

| | | | |
|---|---|---|---|
| 3. | Fallow | a. Rabi | Fallow |
| | | b. Fallow land | |
| 4. | Forest | a. Dense Forest | Good Forest |
| | | b. Open Forest | Poor Forest |
| | | c. Scrub Forest | Fair Forest |
| | | d. Forest Blank | |
| 5. | Wasteland | a. Land with scrub | Good Wasteland |
| | | b. Land without scrub | Fair Wasteland |
| | | c. Barren rocky/stony waste | Poor Wasteland |
| | | d. Mining outcrop | |
| 6. | Water bodies | Streams/Reservoirs | |

Antecedent soil moisture is known to have significant effect on both volume and rate of runoff. This factor is duly considered by classifying moisture content in the soil into 3 antecedent moisture conditions. Antecedent moisture condition is five days moisture or wetness condition of the soil before occurrence of storm and hence, this is determined by the total in the 5 day period preceding a storm. To calculate AMC of a particular day, the cumulative rainfall values of the prior five days is calculated and decided with the help of table 3.

**Table 3. Classification of antecedent moisture classes (AMC) for the SCS method of rainfall abstractions.**

| AMC Group | Total 5 – day Antecedent Moisture Condition (Rainfall in mm) | |
|---|---|---|
| | Dormant Season | Growing Season |
| I | Less than 12.5 | Less than 35 |

| | | |
|---|---|---|
| II | 12.5 – 27.5 | 35 -52.5 |
| III | Over 27.5 | Over 52.5 |

Example: If the cumulative rainfall for the prior five days calculated is 50 mm in the growing season then it is grouped into the AMC group-II.

Soil properties influences the generation of runoff from rainfall and they must be considered in the method of runoff estimation. The properties of the soil which influences the runoff are effective depth, clay in the surface layer, average clay in the profile, infiltration, permeability, soil texture etc. Soil map was prepared using soil texture information. Soil classification system developed by Soil Conservation Service (SCS) has been followed while classifying soil into different hydrological soil group, i.e., moderately low run off, moderately high run off and high run off. Hydrological soil group map was integrated with modified Land Use/ Land Cover to get Hydrological Soil Cover Complex Map (HSCC). Run off numbers were assigned to the Hydrological Soil Cover Complex Map considering average antecedent moisture condition. For assigning of curve numbers for different combinations of HSCC table was used as given in table 4 and shown in Fig.4.

The average curve number i.e. normal antecedent moisture condition (AMC-II) values of the selected study area was redesigned to the actual antecedent moisture condition i.e. dry conditions (AMC I) or wet conditions(AMC III) with the help of base curve number map. The following two equations used for CN (I) and CN (III) with respect to (AMC I) and (AMC III) respectively.

$$CN(I) = \frac{4.2 * CN(II)}{10 - 0.058CN(II)}$$

$$CN(III) = \frac{23 * CN(III)}{10 + 0.13CN(II)}$$

Potential maximum retention (s) was calculated for all the three antecedent moisture conditions using ARC/INFO GIS. The formula used for the calculation of potential maximum retention is as follows.

$$S = (25400/CN) - 254$$

Initial abstraction is calculated for the study area depending upon the antecedent moisture conditions using ARC/INFO GIS. Vanderspan, Bali J.S. and Yadav Y.P. (1990) suggested “various initial abstractions (Ia) to be used in the SCS rainfall runoff relationship”. The formula used for the calculation of the initial abstraction (Ia) for Indian condition is as follows.

Black soil region AMC II and AMC III, Ia = 0.1S

Black soil region AMC I, Ia = 0.3S

All other regions Ia = 0.3S

Where ‘S’ is the potential maximum retention, ‘Ia’ is the initial abstraction. Study area comes under the category ‘All other regions’. So the following formula was used.

$$Ia = 0.3S$$

Calculation of runoff on daily basis

The values of the s and Ia have been put into the following equation to get the runoff values on daily basis. For the selected study area, the runoff was calculated in mm since precipitation was given in mm.

$$Q = \frac{(P - Ia)^2}{(P - Ia + S)}$$

Ia = 03S

Then formula becomes

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)}$$

After calculating runoff on daily basis it was calculated event wise. Fig. 4 shows Total run off for the year 2007.

**Table 4. Run off Curve Number for Hydrological Soil Cover Complex**

| Land use cover | Treatment of Practice | Hydrological condition | Hydrological soil groups | | | |
|---|---|---|---|---|---|---|
| | | | **A** | **B** | **C** | **D** |
| Fallow | Straight Row | Poor | 77 | 86 | 91 | 94 |
| Row crop | Straight Row | Poor | 72 | 81 | 88 | 91 |
| | Straight Row | Fair | 67 | 78 | 85 | 89 |
| | Straight Row | Good | 65 | 76 | 84 | 88 |
| Pasture or Range or waste land | | Poor | 68 | 79 | 86 | 89 |
| | | Fair | 49 | 69 | 79 | 84 |
| | | Good | 39 | 61 | 74 | 80 |
| Woodlands (farm wood lots or forest) | | Poor | 45 | 66 | 77 | 83 |
| | | Fair | 36 | 60 | 73 | 79 |
| | | Good | 25 | 55 | 70 | 77 |
| Farmsteads | | | 59 | 74 | 82 | 86 |
| Roads (dirt) | | | 72 | 82 | 87 | 89 |
| (settlement) | | | 74 | 84 | 90 | 92 |

**Soil Loss Estimation**

The sediment yield equation was used for estimating soil loss from each micro - watershed. To derive HLP map from the above four inputs fig (layouts) criterion analysis was carried out. The criteria used in this case were areas less than 1.5 sq. km., after union were deleted/dissolved and some categorical generalization was done considering the location and extent of units/polygons and the scale of mapping. As a first step, Slope and Soil coverages were intersected. Secondly, Land use was intersected with derived layer of slope soil map. In the final step, the ground water prospect map was intersected with slop soil land use map to derive HLP map. Later on weightages were assigned to HLP combinations as specified in Table 5 and shown in Fig. 6. Soil erosion takes place at all the places but the intensity of erosion is different at different places. It is not possible to take measures for minimizing soil erosion at all the places at the same time due to constraints of money and technical man power. Hence, areas which are eroding more in time and space are to be conserved first. In this study, an effort is made to identify priority areas for soil conservation by using empirical formula developed by All India Soil and Land Use Survey organization, Government of India, New Delhi. The following sediment yield equation has been used for estimation of Soil loss.

$$SYI = \frac{Aei * Wei * D * 100}{Aw}$$

| | | | |
|---|---|---|---|
| Where | SYI | = | Sediment Yield Index |
| | Aei | = | Area of homogeneous land parcel unit |
| | Aw | = | Area of micro-watershed |
| | Wei | = | Weightage of erosion intensity, and |
| | D | = | Delivery ratio |

On the basis of SYI, the watersheds are categorized into very high, high, medium, low priorities for taking up soil conservation measures. In Dahi block 2715 ha of area in under low category, 855 ha. under moderate category, 2769 ha. under high category and 1379 ha. Under very high priority category as given in Table 6 and shown in Fig. 5

**Table 5. Following table delineate different combinations of HLP and their weightages**.

| Sl. No | HLP Combinations | SYI Calcode | Weightagess |
|---|---|---|---|
| 1 | Gentle slope categories and Deep soil categories and whole agriculture from Land use. | 10 | 1 |
| 2 | Gentle slope categories and Shallow soils and whole agriculture from Land use. | 20 | 3 |
| 3 | Gentle slope categories and Shallow soils and open forest, scrub forest and land with scrub | 30 | 5 |
| 4 | Steep slope categories and deep soil and whole agriculture | 40 | 5 |
| 5 | Steep slope categories and deep soil and open forest, scrub forest and land with scrub | 50 | 4 |
| 6 | Steep slope categories and deep soil and forest blank | 60 | 4 |
| 7 | Steep slope categories and shallow soil and whole agriculture | 70 | 8 |
| 8 | Steep slope categories and shallow soil and open forest, scrub forest and land with scrub | 80 | 8 |
| 9 | Steep slope categories and shallow soil and forest blank | 90 | 8 |
| 10 | Gentle slope categories and deep soil and open forest, scrub forest and land with scrub | 100 | 2 |
| 11 | Gentle slope categories and deep soil and forest blank and land without scrub | 110 | 2 |
| 12 | Gentle slope categories and shallow | 120 | 5 |

| | | | |
|---|---|---|---|
| | soil and land without scrub | | |
| 13 | Steep slope categories and whole soil categories and land without scrub | 130 | 5 |
| 14 | Gentle slope categories and shallow soil and forest blank | 140 | 5 |
| 15 | Water body in land use | 99 | 0 |
| 16 | Dense forest | 77 | 1 |
| 17 | Barren rocky/stony waste | 88 | 2 |
| 18 | Gentle slope categories and mining outcrop | 661 | 4 |
| 19 | Steep slope categories and mining outcrop | 662 | 9 |
| 20 | Village (rural) | 55 | 0 |

**Table 6. Priority areas soil conservation**

| Priority Class | Area (ha) |
|---|---|
| Low | 27151.21 |
| Moderate | 855.8062 |
| High | 2769.017 |
| Very High | 1379.374 |

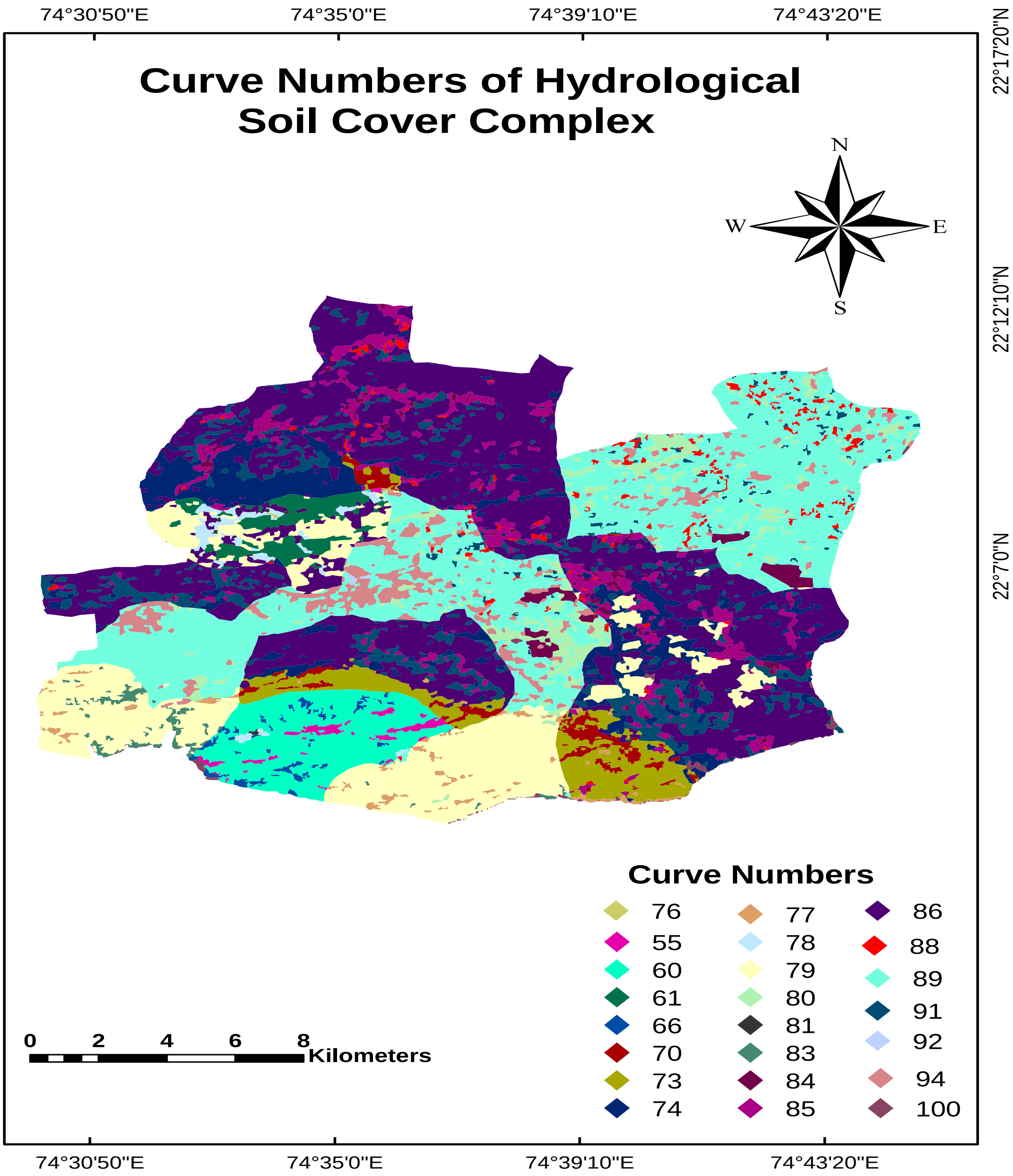



**Fig. 4 Curve Number Map of Hydrological Soil Cover complex Map**

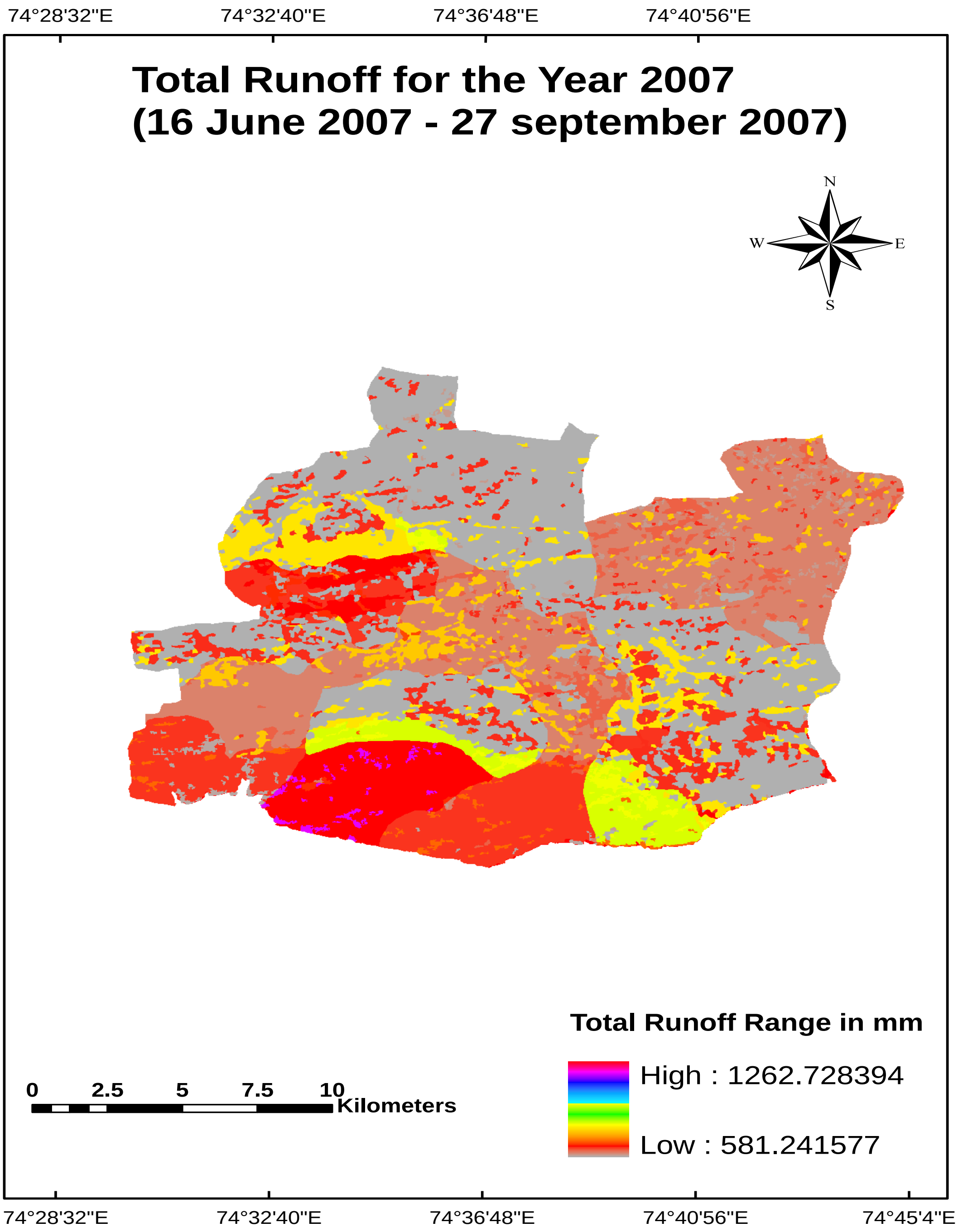



**Fig. 5 Total Runoff Map for the Year 2007**

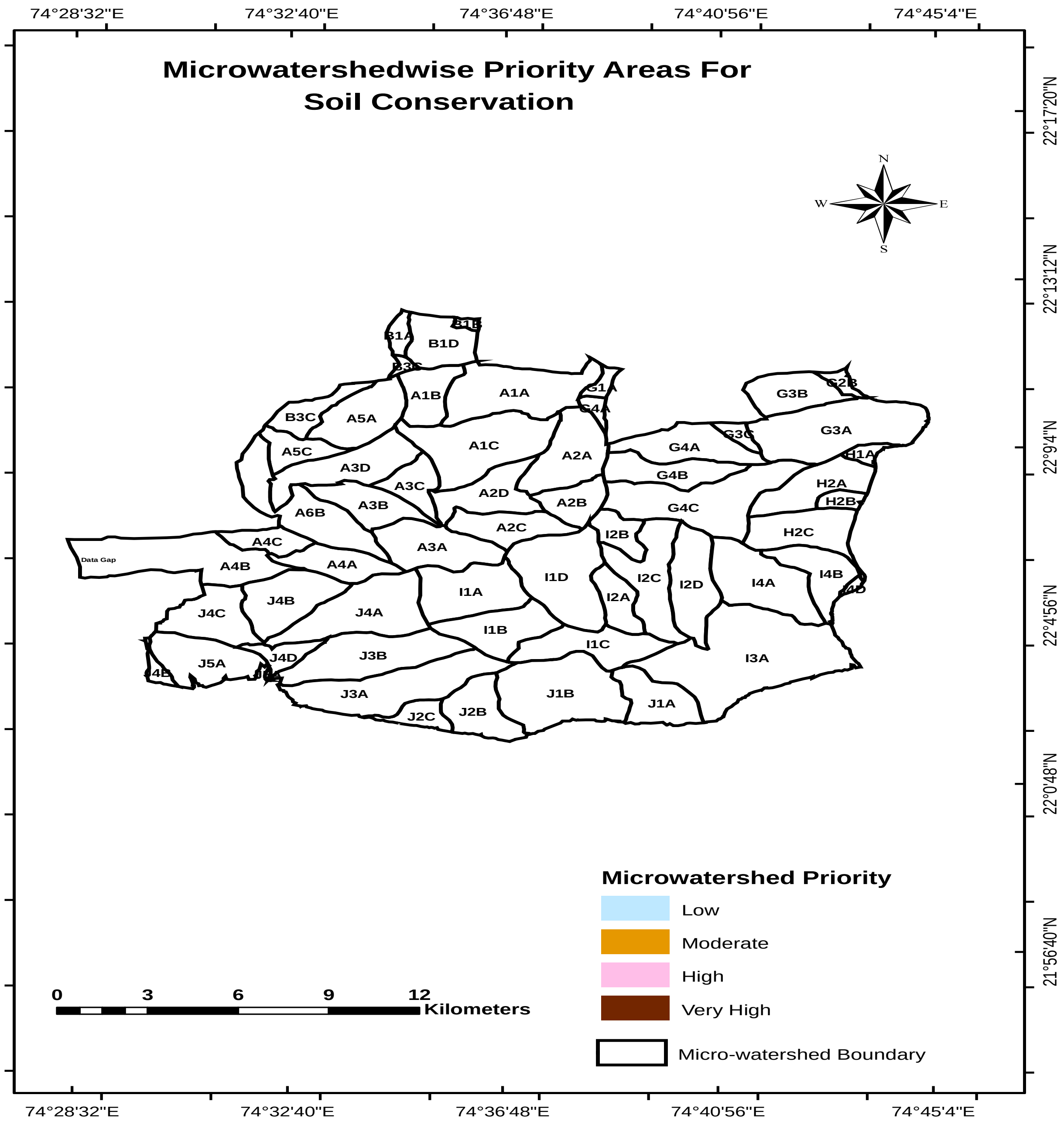



**Fig. 6 Micro-watershed wise Priority areas for Soil Conservation**

## Conclusion

Watershed prioritization of selected study area of Dahi Block was carried out through estimating runoff and sediment yield using Soil Conservation Service model and Sediment Yield Index model.

Geographic Information System (GIS) is proved to be a useful tool in spatial data base creation, for making data compatible from one format to another and retrieval of data as per requirements. Since input data is geographic in nature, GIS found to be a potential tool while carrying out criteria based spatial analysis towards optimal management of natural resources. It is found that natural phenomenon such as hydrologic response of selected area of watershed to precipitation and its proneness to water erosion can be best simulated through GIS. SCS CN model and SYI model used for the estimation of runoff and soil loss respectively, have several advantages. They require few and easily available parameters, sensitive to changing land use condition/practices and easy to use by employing GIS techniques. Using GIS, it is possible to handle spatial and non-spatial data and it is important in run off and sediment data handling. SCS CN model is very useful for prediction of run off. Sediment Yield Index gives priority areas for soil conservation. The analysis reveals that In Dahi block 2715 ha of area in under low category, 855 ha. under moderate category, 2769 ha. under high category and 1379 ha. under very high priority category of prioritization.

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# Sustainable Water Supply Management in Bangalore City Karnataka, South India

**Dr.D.Rajasekaran**

## Abstract

Bangalore, the capital of Karnataka, is an important social, economic, cultural, administrative, educational and political centre of State known for *Garden city* and wide. A phenomenal growth of population together with massive immigration from rural areas and neighboring states to urban center results in change in urban Structure. This has resulted in widening gap between available resources and their demand in urban areas. Urbanization is considered as an indicator of development but at the same time it is creator/producer/generator of many problems among them the most important is water problem. Therefore, there is urgent need to take necessary measures to create enabling measures to cope with. Bangalore has a well-planned water supply and sewage system, which is designed to meet the incremental demands of its population. Many citizen-centric measures have been initiated by the Bangalore Water Supply & Sewerage Board (BWSSB) to improve the efficiency and to enhance the capacity for providing better quality of services to meet the growing demands of its citizens. Although there is no over-all deficit like situation in Bangalore as far as water supply and sewage facility is concerned, definitely there is a question of inadequate access to the facility by disadvantage and poor groups on one hand and rapid rise of water demand on the other, making it imperative to look into the governing process of BWSSB. This paper presents an evaluation of the overall performance of BWSSB not only depends on an effective determined by the strength of the structural and functional components like water management capacity, accountability pattern, and sustainability and consumer orientation. These aspects provide us insights into the current status of amenability capacity, adaptive to innovation, openness to changing needs and requirements and promote responsiveness.

## Introduction:

Population plays a major role in the urban growth. Increase in population and land transformation goes hand in hand. It is one of the most important factors of land transformation with extensive history dating back to millions of years back. This conversion has not stopped till date rather got accelerated and diversified resulting in multitude of problems.

Bangalore, the capital of Karnataka, is an important social, economic, cultural, administrative, educational and political centre of State known for *Garden city* and wide. A phenomenal growth of population together with massive immigration from rural areas and neighboring states to urban center results in change in urban Structure. This has resulted in widening gap between available resources and their demand in urban areas. Urbanization is considered as an indicator of development but at the same time it is creator/producer/generator of many problems, among them the most important is water problem.

Bangalore has a well-planned water supply and sewage system, which is designed to meet the incremental demands of its population. Many citizen-centric measures have been initiated by the Bangalore Water Supply & Sewerage Board (BWSSB) to improve the efficiency and to enhance the capacity for providing better quality of services to meet the growing demands of its citizens. Although there is no over-all deficit like situation in Bangalore as far as water supply and sewage facility is concerned, definitely there is a question of inadequate access to the facility by disadvantage and poor groups on one hand and rapid rise of water demand on the other, making it imperative to look into the governing process of BWSSB.

The pace of urbanization is rather fast in the State. With most of its land under cultivation Karnataka has fast urbanization rate due to the increasing tendency of the population to move towards urban areas. The urban population is 5.68 millions in 2001 instead of 4.13 million in1991. With the rapid increase in size of population existing urban structure of Bangalore City is not able to accommodate the increasing population and results in growth water scarcity and faulty drainage system.

**Study area:**

Bangalore, a tiny village in 12th century grew through times to become one of the fastest growing cities in the world in the 21st century. It has a history of 469 years. This capital city of Karnataka is the fifth largest city in the country and has population about 5.7 million. It was the 16th biggest country in 1941 and grew to become the eighth largest country in the very next decade. Its geographical location in the heart of South India and its salubrious climate (maximum temperature of $33^{o}$ C to lowest minimum of $14^{o}$ C) has contributed to its growth and importance. The city is 949 meters (3,113 feet) above mean see level and at $12^{o}$ $58^{|}$ to $13^{o}$ $0^{|}$ North Latitude and $77^{o}$ $37^{|}$ to $78^{o}$ $18^{|}$ East Longitude. It covers an area of about 2190 Sq. Kms. The swift growth of Bangalore that stands as Silicon Valley of India in today's computer ramp has grown on the extent of valuable and productive agricultural land. It observed that the population of the population of Bangalore city stands at 5.7 million as per 2001census records, and continuing with this growth rate, the city's population is expected to reach around 11 and 22 million in 2021 and 2041 respectively.

Industrialization of Bangalore city is rapid since 1951 where the employment opportunity increased. Large-scale construction activities, educational opportunities, medical facilities, business and industrial activities etc are available in Bangalore has attracted large number of migrants. The number of literate population has also increased and is ever increasing. Though these increases make us happy, there are also increases in sky scrapers, vertical developments of residential units.

**Objective:** For the sustainable water supply management in Bangalore City it is necessary to follow certain objectives are as follows:

- Growths of Bangalore City form its origin to till date.
- Integrated approach for the development of water supply.
- To investigate adequacy of water supply for domestic purpose in Bangalore City.
- To prepare and implement plans and schemes for supply of water for domestic purposes within the Bangalore City to the required standards.
- To prepare and implement plans and schemes for proper supply of water in Bangalore City in future.

**Methodology:**

In the present study of sustainable water supply management in Bangalore City, data from secondary as well as primary sources like Bangalore District Census Hand Book, data from Bangalore Water Supply and Sewerage Board (BWSSB), Handbook of Statistics from various decades 1991-92 & 1992-93, 1993-94 & 1994-95, 1995- 96 & 1996-97, 1997-98& 1998-99, and Annual Reports: 2002-2003, BWSSB, Bangalore. And data of Ban galore Metropolitan Area (BMA) covered area has been collected and analyzed. As the study is qualitative in nature simple tables and suitable maps have been generated. Since Bangalore City is a dynamic metropolis there are a series of popular articles published in leading dailies from which information has been elicited.

**Urban Growth:**

The population of Bangalore city stands at 5.7 million as per 2001 census records, and continuing with this growth rate, the city's population is expected to reach around 11 and 22 million in 2021 and 2041 respectively. With the Information Technology (IT) boom, Bangalore is one of the fastest growing cities in India and Asia. With the emerging Bio-Technology (BT) boom, Bangalore's population growth may be even faster in the forth-coming decades. Bangalore is booming with other growth which is evident from its nicknames viz. "India's Silicon Valley", "Fashion Capital of India", "The Pub City of India", and so on. All these factors contribute to the growth of population of city. The table 1 below shows the growth trends.

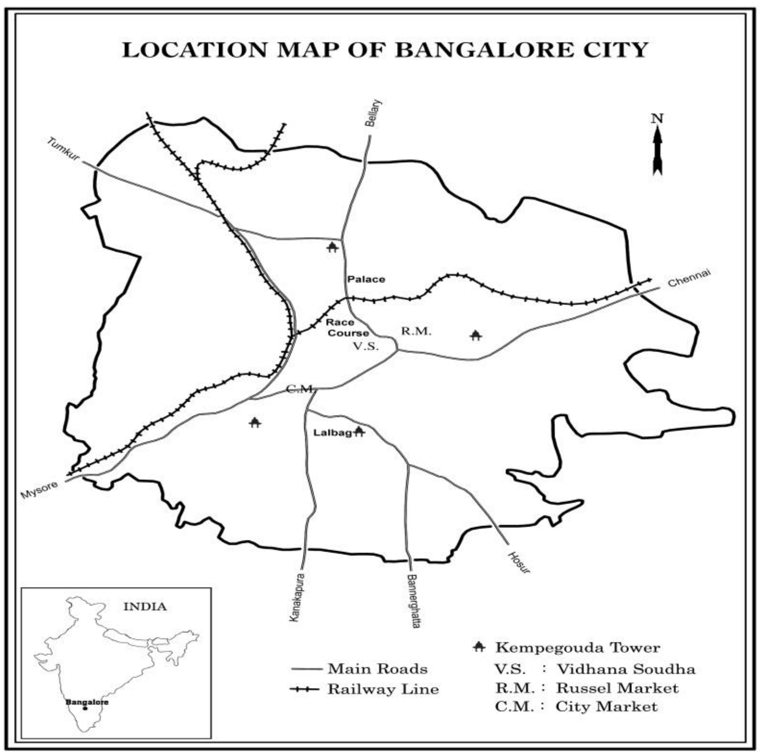
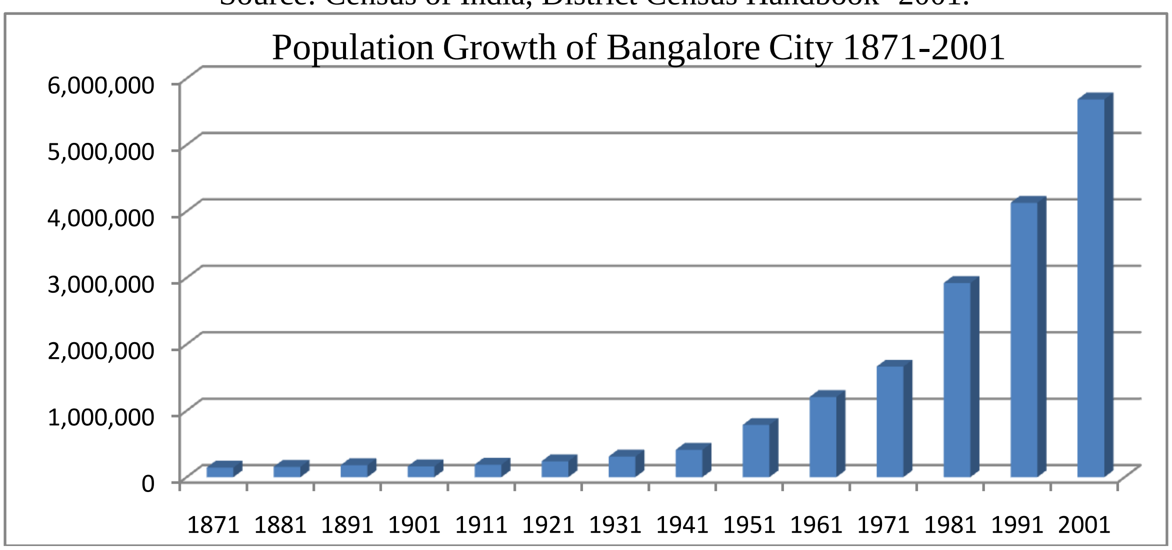



**Table 1: Population Growth of Bangalore City 1871-2001**

| Year | Area (in km2) | Population | Sex Ratio | Density | Decadal Variation in % |
|---|---|---|---|---|---|
| 1871 | NA | 144,479 | NA | NA | -- |
| 1881 | NA | 155,857 | 1,128 | NA | 7.88 |
| 1891 | NA | 180,366 | 981 | NA | 15.73 |
| 1901 | NA | 163,091 | 962 | NA | -9.58 |
| 1911 | 60.35 | 189,485 | 938 | NA | 16.18 |
| 1921 | NA | 240,054 | 893 | NA | 26.69 |
| 1931 | NA | 309,785 | 903 | NA | 29.05 |
| 1941 | NA | 410,967 | 900 | NA | 32.66 |
| 1951 | NA | 786,343 | 883 | NA | 91.34 |
| 1961 | 501.21 | 1,206,961 | 874 | 2,408 | 53.49 |
| 1971 | 177.30 | 1,664,208 | 875 | 9,386 | 37.88 |
| 1981 | 365.65 | 2,921,751 | 896 | 7,991 | 75.56 |
| 1991 | 445.91 | 4,130,288 | 902 | 9,263 | 41.36 |
| 2001 | 531.00 | 5,686,844 | 906 | 10,710 | 37.69 |

Source: Census of India, District Census Handbook -2001.




The spatial extent of Bangalore City in the year 1971 was about 177.30 sq.km. this increased to 365.65 Sq.Km. in 1981 and 445.91

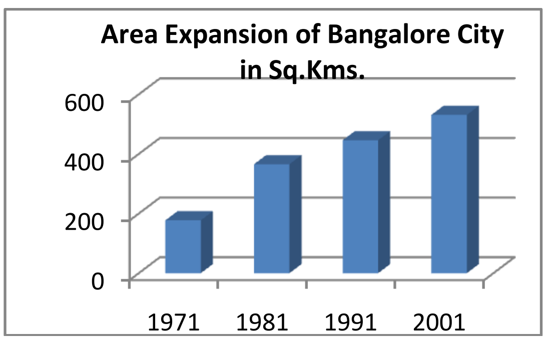
Sq.Km. in 1991 to 531.00 Sq.Km. in 2001 respectively. As it is evident from the census figures (Table 1) urbanization in 1971-81due to expansion of urban area, we can see the real emergence of city
outgrowths. Of course this includes factory type of urbanized areas plus the enormous outgrowth of urbanized fringe villages with new layouts with or without civic amenities. Where the latter is a kind of phenomenon that exists in these newer urbanized areas even at all India level (B.K.Ray1993). In the year 1981 the Bangalore City along with its outgrowths has a population of 2.9 million, which increased to 4.1 million to 5.6 million in 1991 and 2001 respectively. It attributes fastest growth in aerial expansion of Bangalore City.

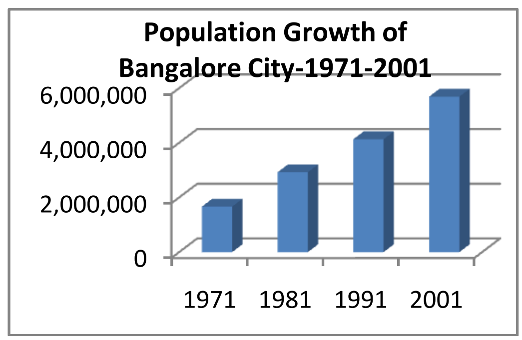
The urban aerial expansion of Bangalore city has shown remarkable growth in recent years. Table 2 shows temporal dynamics of urban sprawl of Bangalore City.

**Table 2: Urban Sprawl of Bangalore City in the recent decades**

| Year | Area Sq.Km. | % Growth/year | Population | % Growth/year |
|---|---|---|---|---|
| 1971 | 177.30 | - | 1,664,208 | 37.88 |
| 1981 | 365.65 | 27.35 | 2,921,751 | 75.56 |
| 1991 | 445.91 | 22.43 | 4,130,288 | 41.36 |
| 2001 | 531.00 | 18.83 | 5,686,844 | 37.69 |

Source: Compiled from population Statistics– Kendriya Sadana Koramangala, Bangalore.




**Land use pattern of Bangalore City:**

The other major effect of urban growth is the change in land use pattern of Bangalore City. In the year 1983 the total land area was 20283.18 hectares, which increased to 28400 hectares in 1990 to 42432 hectares in 2001, further it will be increased to 56462 hectares in 2011. The map below shows the growth of Bangalore from 1537 – 2001. And the table 3 below shows land-use classification of Bangalore City 1983-2011.

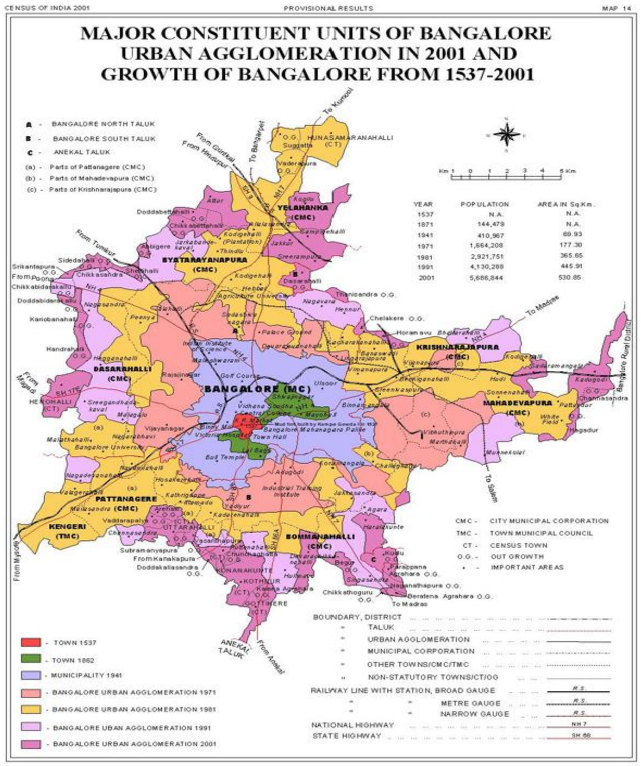
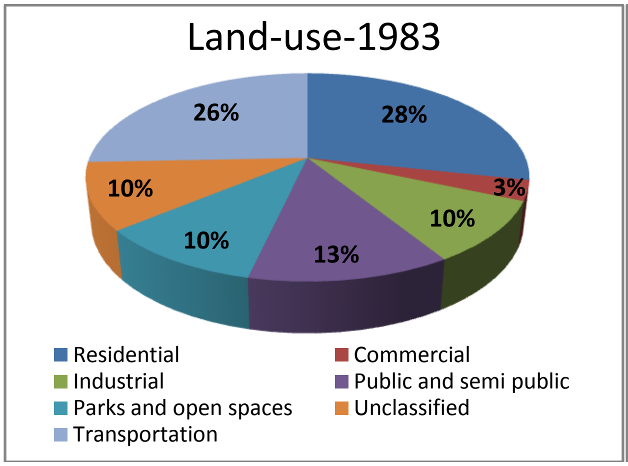
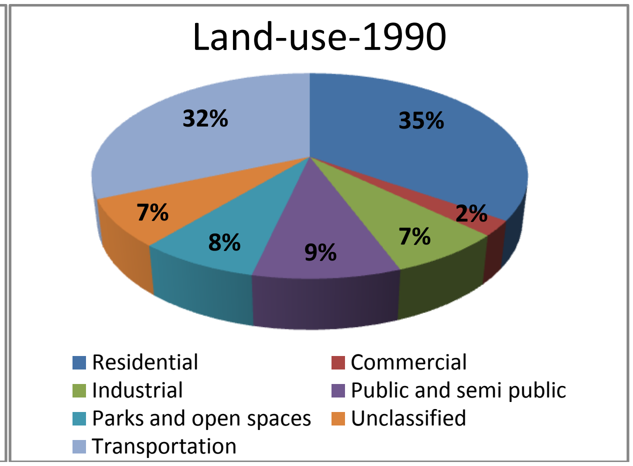


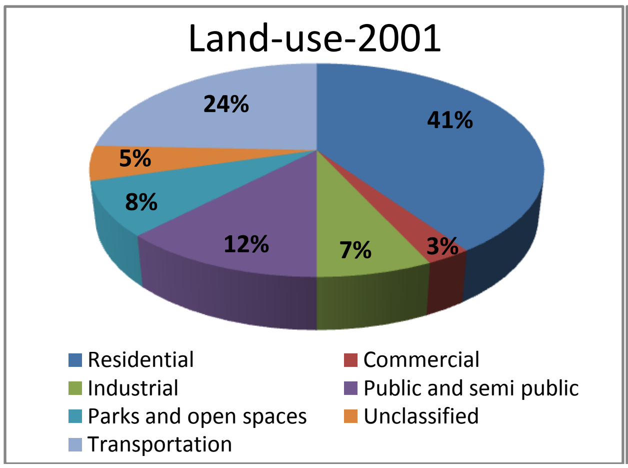

**Table 3: Trends in land use in Bangalore City 1983-2001 and 2011**

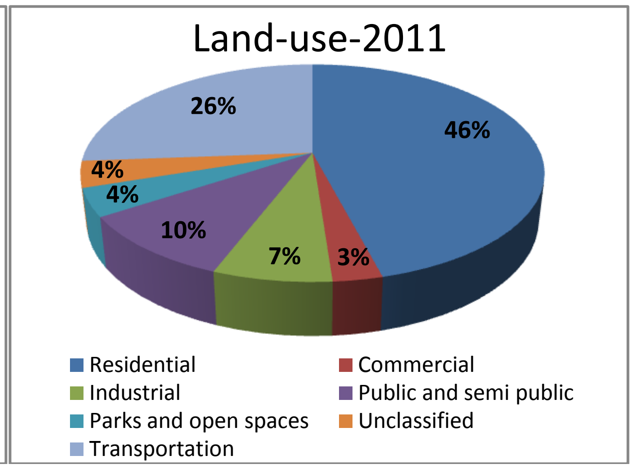
| **Land-use** | **Area (Ha) (1983)** | **%** | **Area (Ha) (1990)** | **%** | **Area (Ha) 2001** | **%** | **Area (Ha) 2011** | **%** |
|---|---|---|---|---|---|---|---|---|
| Residential | 5777.65 | 28.48 | 9877.65 | 34.88 | 17123 | 40.61 | 24369 | 45.94 |
| Commercial | 634.07 | 3.14 | 675.07 | 2.38 | 1159 | 2.85 | 1643 | 2.91 |
| Industrial | 1956.61 | 9.75 | 2038.61 | 7.18 | 2941 | 6.95 | 3844 | 6.98 |
| Public and semi public | 2533.64 | 12.60 | 2615.64 | 9.21 | 5201 | 12.25 | 4908 | 9.89 |
| Parks and open spaces | 2050.16 | 10.41 | 2132.16 | 7.67 | 3520 | 8.25 | 7788 | 4.17 |
| Unclassified | 2114.24 | 10.42 | 2114.24 | 7.45 | 2164 | 5.32 | 2213 | 3.92 |
| **Transportation** | **5216.81** | **25.82** | **8946.63** | **31.60** | **10321** | **24.3** | **11697** | **26.19** |
| **Total** | **20283.18** | **100** | **28400** | **100** | **42432** | **100** | **56462** | **100** |

Source: Data Collected and Compiled from BMP Master Plan.




The land-use for residential purpose was 28.48% 1983 which increased to 34.88% in 1990, to 40.61% in 2001 and it is likely to increase around 45.94% in 2011. This increase will be due to formation of new residential layout in outgrowth of Bangalore. Similarly land-use for commercial purpose was 2.38% in 1990, increased to 2.85% in 2001, and more or less it is going to be around 3% only. Land-use for industrial purpose will also remain around 7%. Whereas the land-use for Public and Semi Public was 12.60% in 1983, reduced to 9.21% in 1990 and it increased to 12.25% in 2001. But it is going reduce to further by 9.89% in 2011. This will be attributed to Public and Semi Public (soft ware sector) already established in the last decade. The land-use for parks and open space was around 10.41% in1983, reduced to 7.67% in 1990 and 8.25% in 2001. It is going to be around only 4.17% in 2011- all due to the upcoming Bangalore Metro and widening of roads in around Bangalore City. Whereas the land-use for unclassified sector was 10.42% in 1983, reduced to 7.45% in 1990 and further declined to 5.32% in 2001, and it is further going to reduce to 3.92% in2011, due to urban developmental activities of the city. The land-use for transportation was 25.82% in 1983, 31.60% in 1990. It reduced to 24.3% in 2001 and it is further going to increase by around 26.19% in 2011.

**Formation of Bangalore Water Supply & Sewerage Board (BWSSB):**

The BWSSB is relatively old institution. The Board was constituted in 1964. Previously the formation of the Board, the task of providing water supply to the city was with the Bangalore City Corporation in the cantonment area and by Karnataka Public Works Department (KPWD) as the city area. From 1961 onwards the entire distribution system except the head works was transferred to BCC (Ban galore City Corporation) for its maintenance. In a number of states, statutory Water Supply and Sewerage Boards are created to with a main objective of introducing commercialization in the water supply and sanitation sector management and bring more accountability. In fact it was at the instance of World Bank that came first hand appraisal of the project insisted upon the need for creating an autonomous Board with water and sewerage authority, which would handle with greater financial and operational autonomy, as well as emphasis on accountability to its citizens. Accordingly, it was also accepted that this move would help towards cost recovery through user fees, which could avoid political interference and generate a substantial proportion of the resources needed to augment bulk water supply.

**Current Trends Bangalore Water Supply & Sewerage Board (BWSSB):**

The people of Bangalore were supplied unfiltered water for a long time in the Karanjee system from number of tanks viz ., Dharmambudi, Sampangi, Sankey, Ulsoor etc. in addition to tanks, local wells and ponds constituting the water sources. The first scheme to provide protected water supply to Ban galore was under taken under 'Chamarajendra Water Works' in the year 1894 was initiated by Sir K. Sheshadri Iyer, the then Dewan of Mysore. The source of supply was Hessarghatta (The Hessarghatta lake is situated at a distance of 18 kms to the North West of the City) Lake on the river Arkavathy River. Due to drying up of the river and increase in demand 'The Chamarajasagar Reservoir' at T.G Halli across the river Arkavathi was constructed and was put into service in 1933. After the formation of the board (the 'Board' or BWSSB), the total supply of water from Hessarghatta and C.R.S reservoir which was initially 6 MLD (million liters per day) and 27 MLD was gradually increased to 22.5 MLD and 143.00 MLD by increasing the storage capacity of the reservoirs. Keeping the view the increasing demand of water, growth of the city and long-term requirements of water supply a comprehensive scheme was mooted. For the first time tapping River Cauvery was considered, the government during April 1964 accepted and Cauvery Water Supply Scheme (CWSS) I stage project was launched in 1974. And subsequently CWSS II stage was also commissioned in 1982 (together 270 MLD). To cope up with the ever-increasing population and demands the CWSS III stage was taken up during 1985-86 (to generate additional quantity of 270 MLD of water). The standard level of water supply was 140 liters per capita per day could not be served to the increasing citizens of Ban galore from 41.30 lakhs during 1991 to nearly 60 lakhs during 2004. The BWSSB therefore formulated CWSS-IV Stage Phase I scheme to maintain the level of supply of 140 LPCD (litres per capita per day) and bring an additional 270 MLD of water at an estimated cost of Rs 1072 crores, and CWSS-IV Stage Phase II to bring in additional 500 MLD of water from T.K Halli to Ban galore at an estimated cost of Rs.2000 crores. The source-wise water supply, drinking water potential and capital investment is indicated in the table (see table 4).

**Table 4: Source of Water Supply in Bangalore City**

| Source of Water Supply | Established in the Year | Distance (In kms) | Potential (In crores) | Investment (In crores) | Average Unit Cost per thousand liters after completing of project |
|---|---|---|---|---|---|
| **1. Arkavathy** | 1896 | 18 | 22.5 | NA | 0.45 |
| a) Hessarghatta | 1933 | 28 | 143.0 | NA | |
| b) T.G Hally | | | | | |
| **2. Cauvery** | | | | | |
| a) Stage- I | 1974 | 98 | 135.0 | 35 | 1.70 |
| b) Stage-II | 1982 | 98 | 135.0 | 80 | 2.70 |
| c) Stage-III | 1993 | 98 | 270.0 | 240 | 4.63 |
| d) Stage-IV | | | | | |
| Phase – I | 2001-03 | 98 | 270.0 | 1072 estimated | - |
| Phase – II | 2003 | 98 | 500.0 | 2400 estimated | - |
| Phase - III | 2005 (Will be commencing | 98 | | | |

Source: Handbook of Statistics (BWSSB), 1997-98 and 1998-99

The above details clear shows that the capital investment across the river Arkavathi was less than the capital investment on the CWSS I, II, III and IV Stage projects which was undertaken recently which involved increased cost of materials and labor charges. Again, it can be observed from the table that capital investment in CWSS I, II and III & IV varies by two folds to bring the same quantity of water. Even the average cost of water, which was Rs. 1.70 per thousand liters, increased to Rs. 4.63, when Stage-III project was completed. Though there is ample scope for development of water resources in Bangalore (Ban galore is one of the few cities in India, which has assured drinking water supply system for the last 100 years). But the cost of bringing additional water to Ban galore in the near future would sharply rise in the cost of construction of projects and their maintenance. Moreover, presently the Board is running under deficit budget, and the expansion of metropolitan region may make it difficult to obtain the land for laying the pipelines for transport and distribution due to the rise in capital costs of land.

The quantum of water available at present from all the four sources together is 705.50 million liters per day. But due to failure of monsoon in the Arkavathi river, the entire potential is not been utilized which considerably varies from year to year which is indicated in the table (see table 4). The table clearly indicates that as against the potential availability of water the per capita availability of water is less. This is far below the national standard recommended by CPHEEO: - (*The Standard Norm recommended by CPHEEO is 150-200 LPCD for a city of the size of Bangalore)*. As Bangalore Metropolitan Area (BMA) is increasing considerably *(The present Metropolitan Area comprises of 595 sq kms.)* augmenting the existing water supply system of Bangalore City becomes imperative. Due to the different pattern of consumption by the various socio-economic groups of urban population and conservation measures, the water demand for the city hence is much lower than the projected demand (Sastry).

On the basis of population projections from 2001, 2010, 2015, 2021 and 2036 A.D the requirement of water, probable demand and supply and the resultant shortage for respective years are also calculated which are presented below (see table 5):

**Table 5: Population projection-demand and supply of water in Bangalore City**

| Year | Population (lakhs) | Water Demand (MLD) | Water Supply (MLD) | Shortfall (MLD) |
|---|---|---|---|---|
| 2001 | 53.79 | 870 | 540 | 330 |
| 2010 | 75.00 | 1125 | 900 | 225 |
| 2015 | 88.00 | 1500 | 1470 | 300 |
| 2021 | 100.00 | 1800 | 1470 | 330 |
| 2036 | 125.00 | 2500 | 1470 | 1030 |

The BWSSB, ready with many plans on paper, is certain that the water demand will only rise this year. For, Bangalore has no major river and the existing tributaries are all polluted. As the Board chairman himself puts it, Bangalore needs 1,125 mld (million liters per day) but only 900 mld of water is being supplied now. There is demand for an additional 225 mld. In 2002, there were only 3,10,000 water connections in the City, which almost doubled to 6,23,000 by 2010. As many as 35,000 new connections were added annually.

With the Centre's approval, the State Government had earmarked 14.52 tmc ft of Cauvery water for drinking water to Bangalore. Out of this, 6.5 tmc ft has been utilized in the III stage and 8 tmc ft for the IV stage II phase Cauvery water distribution. As things stand, river Cauvery continues to be virtually the only source of water for the City. Only three per cent of the total water supply is sourced from the Tippagondanahalli (TG Halli) reservoir. Despite its capacity to meet a larger requirement, the reservoir has no defence against the industries and housing developments.

**BWSSB Agenda in Bangalore City:**

To address the current water shortage and the looming threat of the near future, BWSSB has now come up with an array of long-term and short term projects. This, the Board believes, will help the City meet the water demand over the next 50 years. An expert committee set up by the State Government, with former BWSSB Chairman, B N Thyagaraja as chairman, will work on these proposals. Protection of indigenous water resources is high on Thyagaraja's agenda. “River Arakavathi, which originates from Nandi Hills and river Kumudavathi from Shivaganga needs immediate attention by protecting and rejuvenating them for our water conservation. The Government must take stringent action against sand mining and unauthorised irrigation pump sets which is hampering the river catchment area," Thyagaraja says.Since Bangalore is landlocked and does not have any major river, its development would be restricted, warns Thyagaraja. For that not to happen, the Government had to wake up, for instance, to stop the indiscriminate sinking of borewells. Unlike in Tamil Nadu, which has adequate regulations, Karnataka does not have any law protecting the ground water.

The acute water crisis of 2011 was primarily because of this groundwater depletion. In many areas such as K R Puram and Mahadevapura, the groundwater has depleted to such alarming levels that not a drop could be found even at a depth of 1,000 ft. Incidentally, there are about 4,000 borewells dug by BWSSB and another 1,000 drilled by the BBMP.

**<u>Long-term plans</u>:**

A dam with a capacity of 45 TMC near Mekedatu is a major part of BWSSB's long-term strategy to address the City's water shortage. Both the Karnataka and the Tamil Nadu governments along with the Centre are to be partners in this mega project. Also on the agenda is a hydro power plant and to build a huge reservoir at the gauge-point where surplus water will be let out to Tamil Nadu. The plan is to pump three to four tmc of water to Thorekadana Halli (TK Halli) which can be supplied to the City from 70 kms.

The ambitious-sounding project to draw water from river Krishna is another biggie on the BWSSB list. The Board has plans to draw 12 tmc ft of water from Alamatti dam from a distance of 400 kms to be supplied to the City. However, this project has just been proposed as the expert committee is yet to meet to discuss the subject.

Expert panel chairman Thyagaraja has also suggested certain projects, which may not go well with the environmentalists. The proposal to draw 12 tmc ft of water in Gorur dam across river Hemavathi over a distance of 200 kms, would mean that has to pass through the Western Ghats. There are also other contentious proposals such as the one to divert a part of water of west-flowing rivers such as Nethravathi and Kumaradhana to the east, for irrigation, industrial and drinking purposes. Water could be drawn from Nethravathi too for irrigation purpose through a canal form Tumkur.

**<u>Short-term plans:</u>**

Curbing water leakage, which currently stands at a staggering 38 per cent, is one of BWSSB's immediate plans. Out of the 900 MLD water being pumped from river Cauvery, nearly 342 mld is being wasted through leakages, recorded as 'unaccounted for water' (UFW).Comprehensive plans are being drawn up to reduce the UFW. Replacing the old corroded pipelines in many areas of the City is one measure to reduce leakages. There are also 'leakage repair gangs' appointed to attend to complaints reported through the BWSSB Call centre line. With amendment to the BWSSB Act on water theft and unauthorized sanitary connections, the Board is set to intensify its inspection of these connections. Stringent action is planned against anyone found guilty of water pilferage. The maximum punishment can go up to three years of imprisonment and a penalty of Rs 5000. BWSSB is also planning to increase the number of Sewage Treatment Plants (STPs) and to distribute the treated water to the industrial areas. Thyagaraja has suggested a revival of the existing reservoir at Byramangala near Bidadi, where treated water from Vrishabhavathi valley flows.

The treated water can then be stored in the reservoir and used for irrigation purpose.

The surplus of treated water from Bellandur and Varthur Lakes flows to a valley into Tamil Nadu. BWSSB has proposed a reservoir to cap the water before it enters Tamil Nadu. Getting the treated water back to the City is the plan.

**Depletion of water sources in Bangalore City:**

The consequences of urban development are increased peak discharge and frequency of floods. As land is converted from fields or woodlands to roads and parking lots, it loses its ability to absorb rainwater. Conversion of water bodies to residential layouts has compounded the problem by removing the interconnectivities in an undulating terrain. Encroachments of natural drains, alteration of topography are the prime reasons for frequent flooding even during normal rainfall post 2000. The urbanization process in Bangalore has resulted in loss of aquatic ecosystems by 79 per cent during 1973-2010 in the erstwhile Bangalore City limits and 75 per cent decline in vegetation.

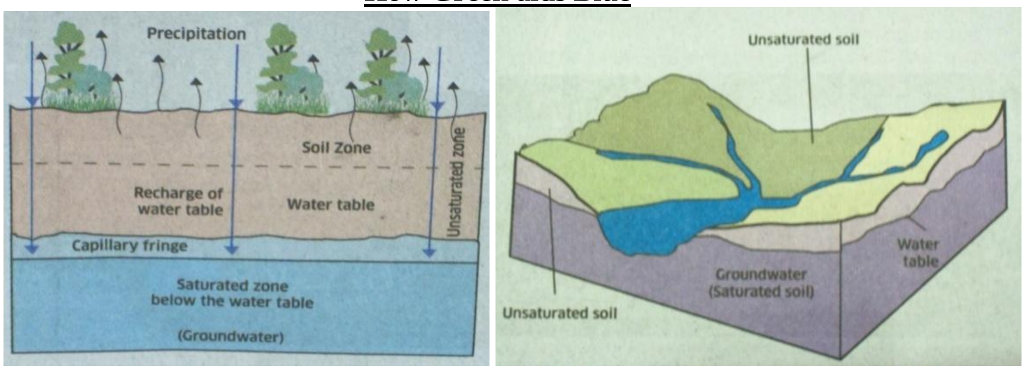
In areas like K R Puram and Mahadevapura, the groundwater has depleted to such alarming levels that not a drop could be found even at a depth of 1,000 ft. That changed quickly with the formation of new layouts in the region, leading to the drastic decline in the groundwater table. The good lake which once was home to hundreds of migratory birds is now dry, despite the 'rejuvenation' by the State Government in the year 2000. The residents around Thindlu are now facing a severe water crisis with the water level having dipped below 700 feet.

The situation faced by the residents of Koramangala Games Village is not much different. The vegetation has been removed and replaced with concrete structures of stadium and apartments that has prevented rainwater seepage. As a result, the water table has gone down by 600 feet and the residents are feeling the heat of water scarcity. It is evident from these examples that vegetation plays a significant role in recharging the groundwater table and the City's growing built-up area is the reason for the depletion of water sources.

**Trees can raise groundwater table in Bangalore City:**

Experts at the Indian Institute of Science (IISc) cite several examples about how vegetation rich areas like its campus have seen an increase in water table. "Land cover is important in deciding water availability. Vegetation allows percolation and enriches the water table," "Recharging groundwater requires 30-40 per cent of open space with vegetation. The vegetation makes soil pervious and helps in percolation." The vegetation holds the water filling in the saturated zone first, then the second layer above saturated zone known as widow zone, is filled up. The runoff seen in the monsoon is a phenomenon which happens only when both the layers are filled. Citing the examples of K R Puram, Whitefield and ITPL regions, experts notes that these places have lost vegetation drastically. Increased vegetation is the solution to depleted ground water table. But the best results would come if the vegetation is of native species. The study had found that the native species with their root structures percolates water much more than foreign species. "The native plant species have low rate of transpiration and high rate of recharge".

**How Green aids Blue**




**Conclusion:**

The Bangalore Water Supply and Sewerage Board is not devoid of governance reforms to rejuvenate its performance levels, as such a number of initiative have been taken to induce the substantive phase of institutional reform which aims at transforming BWSSB in terms of performance impact, and facilitative roles. The, BWSSB which is finding it difficult to meet the rising demand for water, has sunk five to 10 borewells in each wards. Besides the additional water tankers to supply Cauvery water free of cost in the coming days to areas that have no BWSSB connection. And frequent inspection on water theft and try to reduce leakages to manage water supply in Bangalore City.

**Suggestion and measures to adopt future water demand in Bangalore City:**

- Drawing water from existing sources such as Arkavathi and Cauvery.
- Harnessing underground water potential recharging and protecting existing lakes.
- Reduce of waste water for non-potable purposes after tertiary treatment.
- Rain water harvesting a scientific way.
- Linking of peninsular rivers such as Mahanadi, Godavari, Krishna and Cauvery.
- Diversion of Nethravathi water to Cauvery catchment.
- Awareness among public about the importance of water conservation.

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