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Case Study **Open Access**

Impact of Temporal Variation in Land Use on Surface Run Off: A Case Study of Cochin City, Kerala, India

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Abstract The process of urbanization is unplanned and is at a faster rate in developing countries like India. Urbanization is the process of land use alteration. The growth of urban areas results in significant changes in the physical properties of the land surface. The consequence is increased in area of impervious surface resulting in enhanced surface runoff. Increased surface runoff would eventually result in alteration of the prevailing hydrologic system. The present study is an attempt to quantify the impact of land use changes due to urbanization on surface runoff and thereby to study the emerging challenges it impart on the water management and sustainable development. The study area is Cochin, one of the fast developing second tier metros in India. We estimated the seasonal and yearly runoff volume for the study area using SCS-CN method. In this method, land use as well as soil data were used to estimate the runoff volume. The land use changes for the study area were prepared from Survey of India topographic map as well as satellite data. Recent land use map was generated using high resolution Quick Bird image. Runoff depth and volume was calculated for various land use categories using daily rainfall data for the past three decades. An attempt was also made to study the impact of high resolution land use classification on the run off volume. The significant finding from the study is the observation of approximately 24% increase in the average runoff volume over last forty years. This increase in the runoff volume can be attributed to the considerable increase in less permeable area. The built up area increased at the cost of land that falls mostly in the category of vegetation. Approximately one fourth of the study area comprises of water body. The study shows that over the last four decades, the water body got shrunk due to reclamation during the process of vigorous urbanization. The study thus facilitates to identify significant changes in the temporal characteristics of runoff that may lead to major disturbances in the prevailing hydrologic system.

Keywords *Surface Runoff; Cochin; Land Use; Temporal Variation; Urbanization*

1. Introduction

Urbanization can be defined as a process of artificial land use alteration with time. Temporal dimension of urbanization is usually quantified by a design period, defined as a period of time in which reliable forecast of urban changes can be made. It usually ranges between 15 and 25 years. Conversion of natural surfaces to less- or non-pervious artificial surfaces is responsible for increases in both the storm water runoff rates and the total runoff volumes resulting in a decline in the natural water storage capacity of the soil. Natural storage in a watershed is being made available by the effects of infiltration, vegetation wetting, and interception as well as depression storage. An often neglected fact is the change of natural water storage as a consequence of urbanization. Urbanization causes significant changes to the temporal characteristics of runoff from an area, such as shortening the runoff travel time resulting in flash floods. The risk of flooding is defined as a function of both the probability of a flood happening and its impact. In urban areas, the impact can be very high because the areas affected are densely populated and contain vital infrastructure. Imperviousness is the most critical indicator for analyzing urbanization impacts on the water environment. The proportion of impermeable ground is increasing as people build patios and pave over front gardens. Higher levels of impervious surfaces result in a higher volume of runoff with higher peak discharge, shorter travel time, and more severe pollutant loadings. Various climate models predict that heavier showers and hotter summers are expected in the future and this will put more pressure on urban drainage. Increase in surface runoff results in alteration of the prevailing hydrologic system. The present study focuses on the quantification of the changes in land use pattern and its impact on the surface runoff which in turn has a direct impact on the hydrologic system of the study area.

Berthier et al. (2006) explained that the hydrological behavior of urban areas can no longer be restricted to the runoff of rainwater on impervious surfaces, which constitutes the dominant flow component for design purposes. Ragab et al. (2003), exemplify that urban surfaces, such as road pavements and parking lots, are not completely impervious, and observed that 6–9% of total annual rainfall on a paved street infiltrates and that 21–24% of it evaporates. Several studies were carried out in India to improve the runoff models using SCS-CN method for different watershed in many parts of the country. Among the various studies few of the recent studies used Curve Number (CN) method to derive runoff volume as listed here. Geetha et al. (2008) derived a conceptual model based on SCS-CN concept for long-term hydrologic simulation. The model was capable to derive a better match to the observed runoff as well capable to find out the dormant or dominant process involved in the runoff. Patil et al. (2008) estimated the surface Runoff using Curve Number techniques (ISRE-CN) and developed a model using the in-built macro programming language Visual Basic for Applications (VBA) of ArcGIS® tool to estimate the surface runoff by adopting one the most widely used NRCS-CN technique and its three derivatives. In the present study, runoff volume was calculated based on the land use pattern as derived for the year 1965 from topographic sheet, for 2005 and 2010 from Quick bird satellite images.

2. Materials and Methods

2.1. Study Area

The study area is Cochin City otherwise known as Kochi Corporation, which lies between 9˚55´N and 10˚04´N Latitude and 76˚14´E and 76˚20´E Longitude. The Cochin city comprises of Mattanchery, Fort Cochin, part of the main land Ernakulum and a group of islands. Arabian Sea and Vembanad Lake envelops the city all along the western boundary. The City is divided into two blocks by the Cochin backwater (Azhi), as Vypeen Kara on the northern side and Fort Cochin on the southern sides. Major rivers such as Periyar and Muvattupuzha drains to the Vembanad Lake at Cochin. Much of the area lies at sea level and is ‘plain’ land having natural facilities of drainage in the form of backwaters, canals and rivers. Geologically, recent sediments cover major part of the study area.

Charnockites as well as gneiss are sparsely distributed in the study area. The entire western part is covered by recent sediments. Since much of the area is low lying plain, flooding is a recurring natural calamity. Salt water intrusions destabilizing the existing fresh water table and shortage of portable drinking water during peak summer are added troubles encountered in the study area. Since, Arabian Sea and Vembanad Lake surrounds the western boundary of the city, the runoff travel time is very less. In spite of the fact that the study area receives a very heavy rainfall during the monsoon, the area faces shortage of portable drinking water during peak summer. One of the reasons could be attributed to the short span of travel time needed for the surface runoff water to reach the Ocean. In such a situation new development that increases the percentage of impermeable surface can cause more problems regarding drinking water shortage.

2.2. Methodology

Runoff is the flow of water that occurs when the excess portion of precipitation (rainfall or snow) flows over land surfaces toward larger bodies of water. A runoff event can occur only when rainfall satisfy the immediate demands of infiltration, evaporation, interception, surface storage, and surface detention and/or channel detention. The runoff curve number (CN) is an empirical parameter used in hydrology for predicting runoff. The curve number is known as “SCS runoff curve number” and the runoff method developed using SCS CN is developed by the USDA Natural Resource Conservation Service (SCS, 1985). This empirical model is based on the potential of the soil to absorb a certain amount of moisture termed as potential storage S (millimeters or inches). Potential storage ‘S’ is related to 'curve number 'CN which is a characteristic of the soil type, land use and the initial degree of saturation known as the antecedent moisture condition based on field observations. Although the method is designed for a single storm event, it can be scaled to find average annual runoff values.

The runoff equation is

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad \text{Eq: 1}$$

Where, *Q* is runoff; *P* is rainfall and *S* is the potential maximum soil moisture retention after runoff begins. I_a is the initial abstraction or the amount of water before runoff, such as infiltration, or rainfall interception by vegetation; and it is generally assumed that $I_a = 0.2S$ *(SCS, 1985)*

The runoff curve number, *CN*, is then related *(SCS, 1985)*

$$S = \frac{1000}{CN} - 10 \qquad \text{Eq: 2}$$

CN has a range from 30 to 100 with lower number indicating low runoff potential while larger numbers indicating higher runoff potential. In the present study, modified SCS-CN method was used considering the Indian scenario.

Soil is considered as an important factor in the SCS-CN method because of the fact that the infiltration rate of different type of soil is different. The effect of urbanization on runoff is elevated in watersheds with sandy and gravel rich soils having high infiltration rates compared to watersheds predominantly of silts and clays having low infiltration rates. Urbanization can result in mixing or removal of native soil profiles or can result in landfill materials from other areas. Hence, any alteration in a soil profile can significantly change the infiltration characteristics leading to changes in runoff.

Hydrological soil groups (Figure 2) were assigned to the study area based on comparison of the characteristics of unclassified soil profiles with profiles of soils already placed into hydrologic soil groups. Most of the groupings are based on the premise that soils found within a climatic region that are similar in depth to a restrictive layer or water table, transmission rate of water, texture, structure, and degree of swelling when saturated, will have similar runoff responses. The slope of the soil surface is not considered when assigning hydrologic soil groups.

In order to derive the CN, Antecedent Moisture Condition (AMC) should be determined. AMC is defined as the moisture content present in the soil just before or at the beginning of the rainfall-runoff event under consideration. Initial abstraction and infiltration for a particular rainfall event is governed by AMC. Three types of AMC (I, II and III) are recognized by SCS for consideration in all practical applications as given in Table 1.

The major factors that determine CN are the hydrologic soil group (HSG), land use and AMC conditions. The CN value was calculated for antecedent moisture condition AMC II. The conversion of CNII to other two AMC conditions can be made through the following correlation equations. The AMC condition of the study area for the year 2005 is pictorially represented in Figure 1.

Table 1: *AMC Condition*

AMC Type	Total Rain Fall in Previous 5 Days	Actual Surface Condition
I	Less than 36 mm	Soil is apparently dry but not to wilting point
II	36 to 53 mm	Soil moist but not saturated
III	More than 53 mm	Saturated soil

For AMC I

$$\frac{CN_{II}}{2.281 - 0.01281\,CN_{II}} \qquad \text{Eq: 3}$$

For AMC III

$$\frac{CN_{II}}{0.427 + 0.00573\,CN_{II}} \qquad \text{Eq: 4}$$

In the present study, runoff was calculated not for a particular watershed; instead runoff was calculated based on the land use pattern. In an urbanized area, the primary factor that influences the runoff is land use changes. In a growing or expanding city, many major changes occur to the land use and this result in an increased volume of surface runoff. If proper, storm water management practices are not adopted, this may result in frequent flash floods and it can also result in depletion in ground water.

Land use pattern of the study area for the year 2005 as well as 2010 was generated from Quick bird multispectral image. The spatial resolution of Quick bird multispectral satellite imagery is 2.4-2.8m. At this resolution, details such as buildings and other infrastructure are easily visible. The imagery can be imported into remote sensing image processing software, as well as into GIS packages for analysis. The mapping was done at a scale of 1:4000, classifying the different land use categories into various classes such as Industrial, commercial, residential, mixed crops, water bodies etc. The Survey of India topographic sheet of scale 1:50000 were used to prepare the land use map of the area for the year 1965. Due to the low resolution of topographic sheet compared to the satellite image, only major land use classes were mapped for 1965.

The daily rainfall data of the study area for a 30 year period from 1980 to 2010 was collected from Indian meteorological department. The daily rainfall data is necessary to calculate the antecedent moisture condition for the rainfall event under consideration. Antecedent moisture condition is determined by considering the 5 day rainfall prior to the day under consideration.

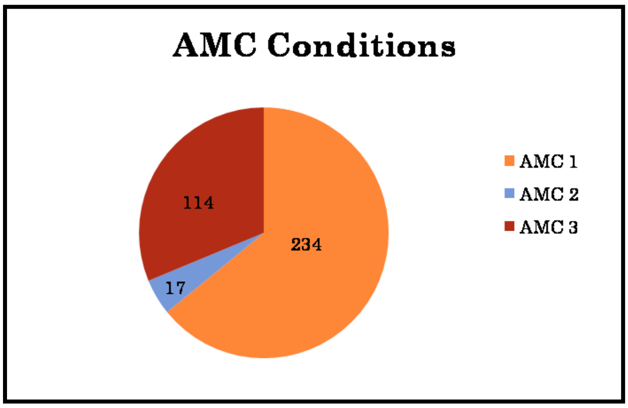

Figure 1: *AMC Conditions of the Study Area (for 2005)*

3. Results and Discussion

The study area is highly urbanized. The area mainly consists of residential, commercial and industrial areas which cover majority of the area. Some of the other prominent land use classes in the area are mixed crops and coconut plantations. The land use pattern showed a significant change from 1965 to 2005 and again from 2005 to 2010. The land use in 2005 and 2010 where classified into 13 categories mainly residential, commercial, industrial, and road network among built-up areas as well as mixed crops, coconut plantation, mangroves and fallow land among non-built-up areas. Due to the comparatively lower scale information available on topographic sheet, the land use was classified into 6 categories namely residential, mixed crops, paddy, water body and open space.

The change detection in land use was achieved by overlaying the land use maps of 1965 (Figure 3), 2005 (Figure 4) and 2010 (Figure 5). The categories into which the various land use classes changes into and the corresponding areas were identified. The areas occupied by different land use classes in 2005, 2010 and 1965 were calculated, which is a direct indication of the changes in pervious and impervious areas over the years, and its impact on runoff volume. Rapid urbanization in the area is particularly evident from the increase in areas of residential commercial and industrial areas. The open space, vegetation and marshy areas have shown significant decrease in area over the years. The study of temporal variation in land use has shown an increase of 12% built-up area from 1965 to 2010. The built-up area has increased from 36% to 48% over the period. In the period from 2005 to 2010, an increase in built-up area of 2% is noticed. The change in the land use pattern is quantified using overlay analysis by overlaying land use map of 1965 and 2010 (Figure 6)

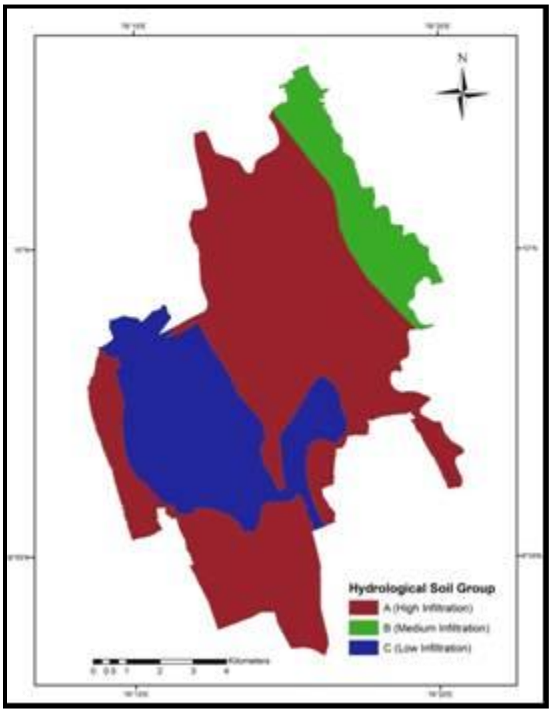

Figure 2: *Soil Map of the Study Area*

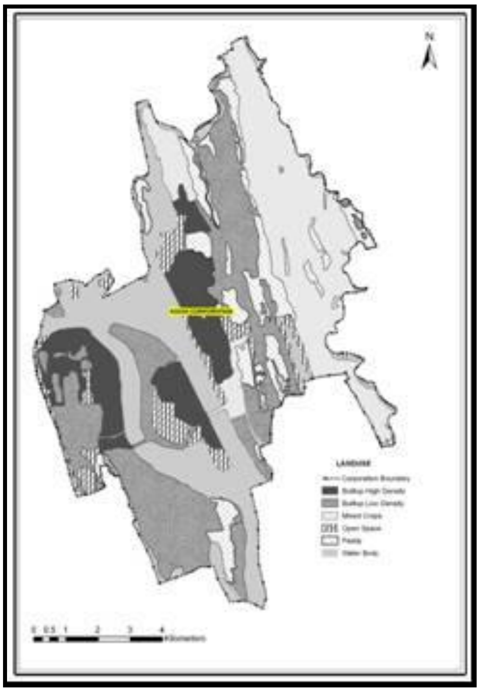

Figure 3: *Land Use Map of the Study Area from Topographic Sheet (1965)*

Figure 4: *Land use Map of the Study Area for 2005*

Figure 5: *Land use Map of the Study Area for 2010*

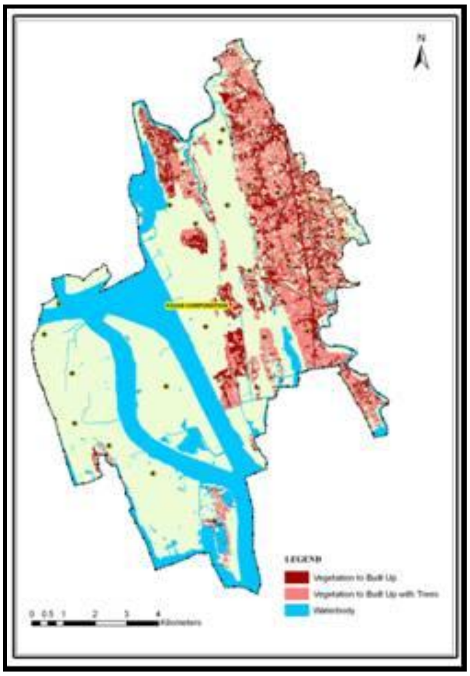

Figure 6: *Land use Changes in the Study Area for Last 45 Years*

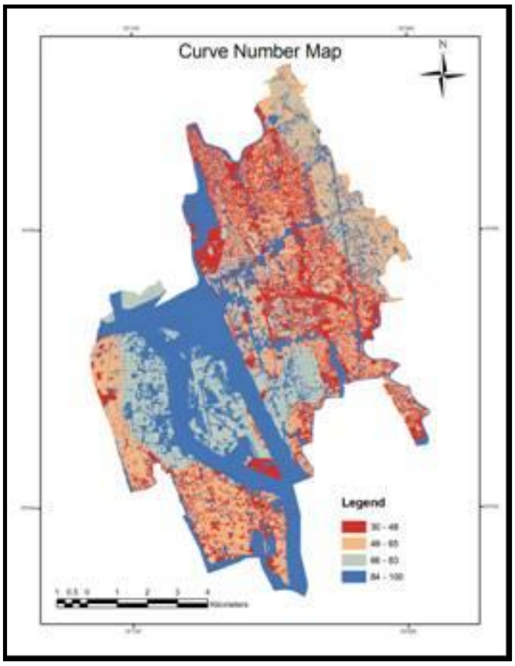

Figure 7*: Curve Number Assigned for Each Category for AMC II Condition*

3.1. Hydrologic Modeling

The runoff volume on a yearly and seasonal basis is calculated for each of the land use maps of 1965, 2005 and 2010, using daily rainfall data for a period of 30 years from 1980 to 2009. Using the daily rainfall data of a 30 year period negates the variations in rainfall over the years. The calculation is done in such a way that the daily rainfall and its corresponding antecedent moisture condition are considered. An example of Curve Numbers (CN) assigned for each category after intersecting land use (2010) and hydrological soil group is given in Figure 7. The runoff volume calculated for the corresponding land use pattern is given in Table 2. The area within Non Built up includes water body which forms almost 20% of the study area.

3.2. Sensitivity Analysis

To study the impact of higher resolution land use classification in runoff volume, a sensitivity analysis was carried out for a small area named “Thopumpady”, which showed significant increase in built-up density in recent times. The mapping was done both in high and low resolution (Figure 8). The polygons of the low resolution map were subdivided for improved accuracy. The runoff volume calculated from the higher resolution map was found to be 39.38% higher than that calculated from low resolution data.

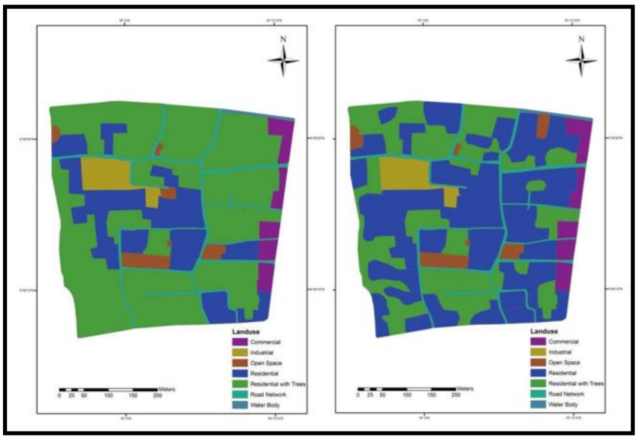

Figure 8: *Sensitivity Analysis Carried Out for Thopumpady Area. Left Side Image is the Result of Low Resolution Land Use Classification and Right Side Image is High Resolution Land Use Classification*

Table 2: *Runoff Volume for Changing Land Use Pattern*

Year	Non-Built Up (km^2)	Built up (km^2)	Non-Built Up (%)	Built Up (%)	Average runoff Volume (Mm^3)
1965	59.93	36.51	62.14	37.87	94.32
2005	50.35	46.09	52.20	47.81	116.05
2010	48.37	48.07	50.15	49.87	117.83

4. Conclusions

The land use pattern in the area has changed considerably since 1965. The built-up area has increased from 36.51 km^2 in 1965 to 46.09 km^2 in 2005 and 48.07 km^2. The most significant changes were observed in residential, commercial and industrial areas causing significant increase in impervious surfaces in the study area. The vegetated regions such as mixed crop class and paddy class as well as open spaces were converted into built-up areas, particularly into residential apartments. This increase in built-up area has resulted in an increase in runoff volume of 23.5Mm^3 in the last 45 years. The built-up area has increased by 2% in the last 5 years resulting in an increased runoff volume of 1.8 Mm^3.

The runoff volume is found to be highest in the months of June to September and it coincides with the south west monsoon season which causes the highest rainfall in the region. The seasons “February to May” and “October to January” showed considerably lower runoff volumes.

The study also conducted a sensitivity analysis to study the impact of high resolution mapping on runoff volumes. The study concluded that using high resolution land use maps significantly improves the accuracy of runoff calculations. The runoff values calculated using low resolution maps and high resolution maps showed a difference of 39.38% in runoff volume.

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References

Berthier, E., Dupont, S., Mestayer, P.G., and Andrieu, H. *Comparison of Two Evapotranspiration Schemes on a Sub-Urban Site.* Journal of Hydrology. 2006. 328; 635-646.

Geetha, K., Mishra, S.K., Eldho, T.I., Rastogi, A.K., and Pande, R.P. *SCS-CN-Based Continuous Simulation Model for Hydrologic Forecasting.* Water Resource Management. 2008. 22; 165-190.

Patil, J.P., Sarangi, A., Singh, O.P., Singh, A.K., and Ahmad, T. *Development of a GIS Interface for Estimation of Runoff from Watersheds.* Water Resource Management. 2008. 22; 1221-1239.

Ragab, R., Rosier, P., Dixon, A., Bromley, J., and Cooper, J.D. *Experimental Study of Water Fluxes in a Residential Area: 2. Road Infiltration, Runoff and Evaporation.* Hydrological Processes. 2003. 17; 2423-2437.

Soil Conservation Service: 1985, *Hydrology, National Engineering Handbook*, Supplement A, Section 4, Chapter 10, Soil Conservation Service, USDA, Washington, D.C.

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Research Article **Open Access**

On-Farm Verification of the Effects of Selected Soil Moisture Conservation Techniques on Yield and Yield Components of Early Maturing Maize Varieties at Bako, Western Ethiopia

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Abstract An on-farm verification experiment was conducted during the 2006 and 2007 growing seasons to verify the effects of different moisture conservation techniques on the yields and yield components of early maturing maize varieties on farmers' fields at Bako. The experiment on all the three locations involved two promising tied ridges and planting methods or soil and water conservation techniques and a control and three early maturing maize varieties recommended by the national maize improvement program for semi-arid areas with a local cultivar used as a control. Throughout the study period, the experiment was laid down in a randomized complete block design in a 3 by 4 factorial arrangement with three replications (locations). For the 2006 season, grain yield of maize was highly significantly ($P \leq 0.01$) affected by the main effect of both varieties and water conservation techniques. An interaction was also observed between varieties of maize and techniques of water conservation. In all the varieties, adoption of closed end tied ridge planting in furrows have resulted more grain yield production of maize in comparison to the other types of water conservation approaches indicating that it assures better conservation of available water for plant use. Above ground biomass yield excluding grain yield (AGB/GY), average ear length at harvest (AEL), average ear width at harvest (AEW), number of maize leaves per plant at 50% tasseling (ANL/pt) and maize plant height at 50% tasseling (MPH@50%ts) were significantly ($P \leq 0.01$) affected by the main effects of variety and water conservation technique. All moisture contents of soil were significantly influenced by the varietal effect (except day 2 moisture content). The table of results for 2007 season (Table 3) indicates that grain yield was not significantly affected due to the main effect of variety. However, it was highly significantly ($P \leq 0.01$) affected by the main effect of water conservation technique. Above ground biomass ($P \leq 0.01$), average ear width ($P \leq 0.05$), day 1 % moisture content ($P \leq 0.01$), day 2 % moisture content ($P \leq 0.05$), day 4 and day 5 moisture contents ($P \leq 0.01$) were also affected significantly by the main effect of water conservation approaches.
Keywords *Tied Ridges; Moisture Conservation Techniques; Closed End Tied Ridge Planting in Furrows; Main Effect of Variety*

1. Introduction

Natural resources are being used more and more intensively as people attempt to fulfil the increasing demands of a growing population. This is leading to degradation of soil and water resources that farmers need. There is a strong demand to ensure that resources are used sustainably, but to be useful in poorer countries, technologies underpinning sustainable use must be simple to use and affordable. There is a need to promote low cost soil and water conservation techniques, especially in developing countries.

The land that is considered best is the first to be exploited for agricultural purposes. At any scale of farming, priority of use is given first for the best land. Those areas which have the best production potential are the ones to be brought in to cultivation whenever there is a demand for increased agricultural production. But with a continuing demand for more land products like food, fuel, shelter, and clothing – people will be shifted to using land which is less suitable for agriculture, or land that is located in unfavourable climates. It is essential that more attention be paid to semi-arid regions by people concerned with agricultural planning, development, or production, as they are characterized by low amounts of natural precipitation. This attention is logical because there were widespread droughts in Africa in the early nineteen-seventies, and again in the mid-eighties.

It is clear to everyone that the problems of semi-arid regions cannot be solved overnight. We cannot have easy control over the unreliability and unpredictability of the rainfall as well as the occurrence of recurrent or non-recurrent drought. The abuse and mismanagement of the land in these areas is a long time process and cannot be corrected in a fortnight. Reverting only to improved yield production in the short run is neither a full story nor a solution; a program to win the confidence of subsistence farmers should be planned.

Intensive rain with a high erosivity usually characterizes most semi-arid regions. The reduced vegetative cover aggravates the exposure of these regions for severe erosion further. The problems of semi-arid regions are so complex that there is little interest to solve them through intervention or research. This resulted in insufficient introduction of technology to apply for improving agriculture. Jones (1984) pointed out that, in Africa, studies of water management techniques such as tillage and tied-ridging have several times shown great promise, but have been too brief, or too local, or restricted to experiment stations, and as a result they generated neither the depth and breadth of understanding of the technique (and the limitations imposed on it by soil, implements, economics, etc.) nor the impetus and general interest that might sustain it through a long program of wider testing, adjustment, and retesting under practical farming conditions.

The low quantities of rainfall make cropping to be possible only with the use of special techniques of soil and water conservation and in this regard tied ridge should get sufficient attention. Tied-ridging has been effective in reducing surface runoff and increasing soil water storage in different countries as reviewed by Gebreyesus et al. (2006). Soil and water resources are usually conserved together by methods of soil and water conservation, this is true of all regions including arid and semi-arid regions. Common conservation measures direct either to soil, water or both. Use of physical structures or improved land management systems that can reduce surface run-off will also help to reduce erosion. In the same manner, reducing erosion will usually prevent splashing of soil particles by rain drop impact, surface crust formation, or breakdown of structural aggregates, which in combination improve infiltration of water and contribute to water conservation.

Field experiments conducted to determine the effects of moisture conservation techniques on yields of improved varieties of maize and sorghum crops with and without N and P fertilizer applications in the semi-arid areas of Eastern Hararghe showed an average yield increase of up to 37% due to water conservation practices under unfertilized conditions and up to 60% increase with NP fertilization (Tamirie et al., 1986; Tamirie, 1986; Heluf, 1989; Heluf, 2003). According to the same, in terms of absolute yield, the combination of moisture conservation and use of NP fertilizers gave the highest attainable yield. Unfortunately, these moisture conservation techniques have not been verified or tested on farmers' fields as to their effectiveness and adaptability in other semi-arid areas such as Bako. Therefore, this study was carried out in order to verify the effects of different moisture conservation techniques on the yields and yield components of early maturing maize varieties on farmers' fields at Bako.

2. Materials and Methods

2.1. Study Area

This verification trail was conducted during the 2006 and 2007 cropping seasons in three different locations to study the effects of different moisture conservation techniques on the yields of early maturing maize varieties on farmers' fields of the Bako area.

Bako is a small town in West Shoa zone of Oromia region which is located at 09^0 06' north latitude and 37^0 09' east longitude. Its elevation is 1650 meters above sea level (masl). According to the climate data collected from 1998-2002, the total annual rainfall of the area ranges from 1040 to 1559 mm. Mean annual maximum temperature is 31 ^{0}C and the minimum being 11.2 ^{0}C. The mean relative humidity is 64%. The mean soil temperature at the depth of 50 cm is 23.3 ^{0}C. The major soil types at Bako area are Nitisols according to the FAO/UNESCO or Alfisols according to USDA soil classification systems. These soils are well drained reddish brown in color and slightly to moderately acidic in reaction with surface soil pH (H_2O) ranging from 5.3 to 6.5 (Wakene, 2001).

Maize crop is commonly cultivated by farmers around Bako area. The presence of Bako Agricultural Research Center in the area helped the release of a number of improved maize varieties, well known throughout the country. Mixed crop-livestock farming system characterizes the area better and the area is surrounded by a river named the Gibe River and has relatively more natural vegetation and grass land cover in its vicinity (Tolera, 2003). The area is known for cultivation of a number of major annual and perennial crops including maize (*Zea mays*), hot pepper (*Capsicum frutescence*), noug (*Guizotia abyssinica*), sorghum (*Sorghum bicolour*), mango (*Mangifera indica*), sugarcane (*Saccharum officinarum*), teff (*Eragrostis tef*), haricot bean (*Phaseolus vulgaris*), sweet potato (*Ipomoea batatas*), and banana (*Mussa spp*) (Asfaw et al., 1997).

2.2. Experimental Design and Procedures

Three locations were considered for conducting a field experiment on farmers' fields at Bako in the 2006 and 2007 cropping seasons to investigate the effects of selected soil and water conservation (tied ridges and planting methods) treatments on the yields of improved maize varieties. The three locations were replications in the experiment. The experiment on all the three locations involved two promising tied ridges and planting methods or soil and water conservation techniques and a control and three early maturing maize varieties recommended by the national maize improvement program for semi-arid areas with a local cultivar used as a control.

Throughout the study period, the experiment was laid down in a randomized complete block design in a 3 by 4 factorial arrangement with three replications (locations). A plot size of 9.75x10 m (97.5 m^2) was used for each variety by moisture conservation treatment combination. The maize varieties used were ACV3, ACV4, Katumani and local cultivar (control), while the moisture conservation treatments used were closed end tied ridge planting on ridges, closed end tied ridge planting in furrows and flat seed bed planting used as a control. The terms tied ridge implies that the 10 m long furrows were tied by soil bund at the midpoint that is at 5 m distance from both ends while closed ends imply that the furrows are closed at both ends with soil bunds. The flat seed bed planting method is the farmers' practice where maize is planted broadcast. Planting was made at the onset of the main rains. On each location, the experiment was conducted for two seasons between 2006 and 2008. The plot size was 9.75 x 10 m (97.5 m^2) with 13 rows at spacing of 75 cm between rows and 25 cm between plants with in a row. No mineral fertilizer was applied for the crop. Surface soil samples to a depth of 0-30 cm were collected periodically from each treatment to determine the moisture content of the soil at different intervals during the crop growth stages.

Observations on agronomic parameters including plant height, stalk diameter, number of ears per plant were recorded before harvesting the crop. Moreover, data on ear length, ear width, 1000 seeds weight, grain yield, above ground biomass yields were collected from the 11 central rows at time of harvest. Grain yield was measured by harvesting the 11 central rows of each plot at physiological maturity and adjusting to 15% seed moisture content. The yield and important yield components' data were subjected to statistical analysis using MSTAT computer software appropriate to the design to reveal the effects of the different soil moisture conservation techniques and maize varieties. Finally, significant treatment means within a set of treatments were separated using Duncan's Multiple Range Test.

3. Results and Discussion

3.1. Season 2006

The principle of tied ridging is to increase surface water storage by first making ridges and furrows, then damming the furrows with small mounds, or ties. As it is evident from the data presented in Table 1 for the 2006 season, grain yield of maize was highly significantly ($P \leq 0.01$) affected by the main effect of both varieties and water conservation techniques. An interaction was also observed between varieties of maize and techniques of water conservation. The highest grain yield (1236.8889 kg/ha) was registered by Katumani (V4) of maize and the lowest (1020.22 kg/ha) by ACV3 (V3). Highest maize yield (1616.6667 kg/ha) was achieved with closed end tied ridge planting in furrows (CPF) type of water conservation technique (Figure 2). The best performing combination was that between V4 (Katumani) and closed end tied ridge planting in furrows (CPF). In all the varieties, adoption of closed end tied ridge planting in furrows have resulted more grain yield production of maize in comparison to the other types of water conservation approaches indicating that it assures better conservation of available water for plant use. This was reflected in the larger values of measured moisture contents associated with CPF.

There is an extensive literature reporting trials of tied ridging in many countries. Some of the reports indicate problems and failures but the great majority of them declare great success for the system that one wonders why the system has not been more widely used. It has been reported that tied ridging is beneficial for reducing run-off and soil loss, as well as for increasing crop yield (El-Swaify, 1983; Dagg and McCartney, 1968). McCarthey et al. (1971) indicated that in both high and low rainfall conditions, tied ridging resulted in higher maize yields in Tanzania. But, most common reports of success are in times when areas receive low quantity of rainfall. For example, by his research in Kenya on a maize variety called Katumani, Njihia (1979) reported that tied ridging made the production of a crop of maize possible in low rainfall years when flat-planted crops gave no crop yield.

The use of tied ridging in some areas of Botswana, however, showed negative effects on productivity due to very harsh conditions. This negative result may have brought about by the higher soil temperatures created within the ridge which can be detrimental to seed germination, and shallow penetration of moisture in to the soil compared to that on flat soil when the rainfall is light (DLFRS, 1984). However, most of the researches conducted on tied ridging showed a positive response by different crops. For example, the efficiency of a fallow before cotton has shown a great increase due to tied ridging according to a research conducted by Rawitz et al. (1983) in Israel's Negev desert. Similarly, a research report by ICRISAT (1976) from India has shown that sorghum planted on broad ridges outperform sorghum that was planted on either flat planting or narrow ridges and a similar result was reported for sorghum and castor in Gujarat by Brahmbatt and Patel (1983).

Above ground biomass yield excluding grain yield (AGB/GY), average ear length at harvest (AEL), average ear width at harvest (AEW), number of maize leaves per plant at 50% tasseling (ANL/pt) and maize plant height at 50% tasseling (MPH@50%ts) were significantly ($P \leq 0.01$) affected by the main effects of variety and water conservation technique. Maize stack diameter at 50% tasseling (MSD) was also significantly influenced by variety ($P \leq 0.05$) and water conservation technique ($P \leq 0.01$) (Table 1). Interaction effect was found significant in AGB/GY ($P \leq 0.01$), AEL ($P \leq 0.01$), ANL/pt ($P \leq 0.01$) and MSD ($P \leq 0.05$) (Table 2).

All moisture contents of soil were significantly influenced by the varietal effect (except day 2 moisture content), water conservation technique effect and interaction effect (except day one moisture content) at different levels of significance. Larger moisture content values were obtained with the first and last day of measurement (Table 1). The maximum moisture content values were consistently recorded with closed end tied ridge planting in furrows (CPF) type of water conservation technique (Figure 1). This agrees with the highest production obtained in GY, AGB and largest value of MPHT with CPF as presence of more moisture in soil render plants be more productive (Table 1).

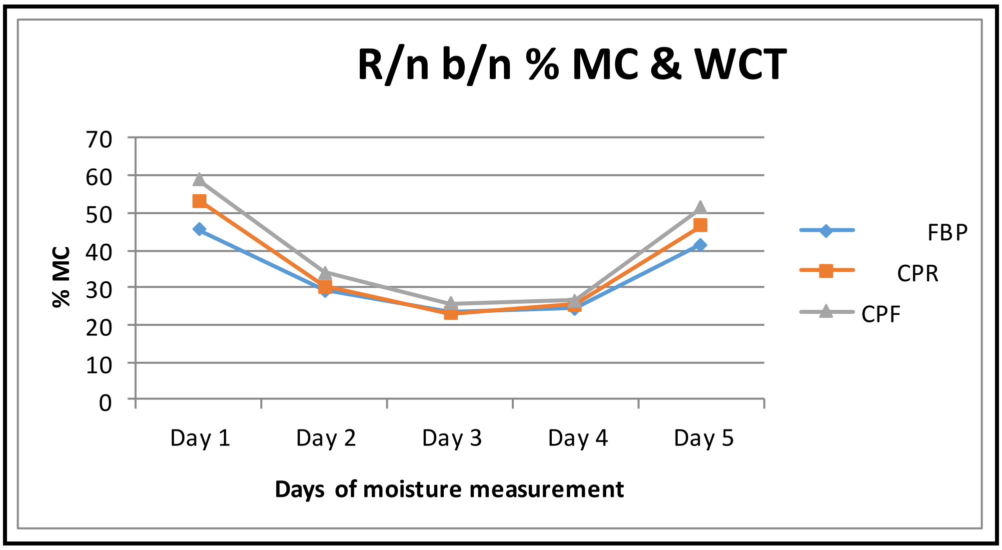

Figure 1: *Relation between Mean Soil Moisture Content and Water Conservation Techniques on Different Days of Measurement for Crop Season 2006*

% MC: Percent Moisture Content; WCT: Water Conservation Technique

Table 1: *Main Effects Due to Variety and Water Conservation Technique on Yield and Yield Parameters and Gravimetric Moisture Contents for Season 2006*

Treatment	GY (kg/ha)	AGB/GY (t/ha)	AEL (cm)	AEW (cm)	ANL/pt	MSD (cm)	MPHT @50%ts (cm)	%MC day 1 (0-20)	%MC day 2 (0-20)	%MC day 3 (0-20)	%MC day 4 (0-20)	%MC day 5 (0-20)
Variety												
Local (V1)	1097.89^{b}	1.85^{a}	11.79^{a}	11.11^{c}	11.33^{a}	1.97^{a}	91.56^{b}	54.11^{ab}	31.22^{a}	24.00^{b}	24.11^{b}	46.44^{b}
ACV3 (V2)	1102.44^{b}	1.38^{b}	10.65^{c}	12.07^{a}	10.33^{c}	1.87^{b}	95.80^{b}	48.89^{c}	31.78^{a}	24.22^{b}	24.67^{b}	44.56^{b}
ACV4 (V3)	1020.22^{c}	1.34^{b}	11.15^{b}	12.35^{a}	10.78^{b}	1.89^{b}	104.56^{a}	55.78^{a}	31.00^{a}	24.89^{a}	26.44^{a}	49.00^{a}
Katumani(V4)	1236.89^{a}	1.94^{a}	10.46^{c}	11.49^{b}	11.22^{a}	1.90^{b}	94.78^{b}	51.11^{bc}	31.00^{a}	23.22^{c}	26.56^{a}	46.00^{b}
Water Conservation Technique												
FBP	853.17^{a}	1.29^{c}	10.13^{c}	11.40^{c}	10.42^{b}	1.81^{c}	83.42^{b}	45.50^{c}	29.33^{c}	23.42^{b}	24.33^{c}	41.42^{c}
CPR	873.25^{b}	1.50^{b}	11.62^{a}	12.09^{a}	11.08^{a}	2.00^{a}	102.25^{a}	53.17^{b}	30.25^{b}	23.17^{b}	25.50^{b}	46.76^{b}
CPF	1616.67^{b}	2.09^{a}	11.28^{b}	11.77^{b}	11.25^{a}	1.91^{b}	104.33^{a}	58.75^{a}	34.17^{a}	25.67^{a}	26.50^{a}	51.42^{a}
Significance												
Variety	**	**	**	**	**	*	**	**	NS	**	**	**
Water conser.	******	**	**	**	**	**	**	**	**	**	**	**
VarietyXconservation	**	**	**	NS	**	*	NS	NS	*	**	**	*
CV (%)	8.59	14.19	4.60	4.42	4.13	4.99	7.08	8.71	3.77	2.98	6.46	6.80

%MC day 1, 2, 3, 4, 5, Indicate Gravimetric Moisture Content Values Measured at Different Dates in the Growing Season on Dry Soil Basis. GY: Grain Yield; AGBY/GY: Above Ground Biomass Yield Excluding Grain Yield; AEL: Average Maize Ear Length at Harvest; AEW: Average Maize Ear Width at Harvest; ANL/pt: Average Number of Leaves per Plant At 50% Tasseling; MSD: Maize Stalk Diameter at 50% Tasseling; MPHT@50%ts: Mean Plant Height at 50% Tasseling

Table 2: *Interaction Effect of Variety and Water Conservation Technique on Yield, Yield Parameters and Gravimetric Moisture Contents for Season 2006*

Treatment Combinations	GY (kg/ha)	AGB/GY (t/ha)	AEL (cm)	AEW (cm)	ANL/pt	MSD (cm)	MPHT (cm)	%MC day 1	%MC day 2	%MC day 3	%MC day 4	%MC day 5
FBPV1	909.7	1.60	10.88	10.93	11.33	1.80	78.0	48.7	29.7	23.0	23.0	41.7
FBPV2	858.3	1.02	9.55	11.60	9.67	1.74	80.7	43.0	29.3	23.7	24.0	36.3
FBPV3	853.0	0.82	10.77	12.05	10.33	1.86	95.3	50.3	28.7	23.3	26.3	44.7
FBPV4	791.7	1.71	9.33	11.03	10.33	1.84	79.7	40.0	29.7	23.7	24.0	43.0
CPRV1	857.3	2.00	12.75	11.49	11.67	2.06	99.0	54.3	30.7	23.3	24.3	45.7
CPRV2	876.7	1.07	10.98	12.44	10.33	1.98	100.0	47.0	30.7	23.0	24.7	46.0
CPRV3	762.3	1.51	11.59	12.69	11.00	1.98	108.7	56.0	30.7	24.3	27.0	48.7
CPRV4	996.7	1.44	11.17	11.73	11.33	1.96	101.3	55.3	29.0	22.0	26.0	46.3
CPFV1	1526.7	1.94	11.74	10.91	11.00	2.04	97.7	59.3	33.3	25.7	25.0	52.0
CPFV2	1572.3	2.05	11.41	12.17	11.00	1.87	106.7	56.7	35.3	26.0	25.3	51.3
CPFV3	1445.3	1.68	11.07	12.32	11.00	1.83	109.7	61.0	33.7	27.0	26.0	53.7
CPFV4	1922.3	2.68	10.88	11.70	12.00	1.90	103.3	58.0	34.3	24.0	29.7	48.7

%MC day 1, 2, 3, 4, 5, Indicate Gravimetric Moisture Content Values Measured at Different Dates in the Growing Season on Dry Soil Basis. GY: Grain Yield; AGBY/GY: Above Ground Biomass Yield Excluding Grain Yield; AEL: Average Maize Ear Length at Harvest; AEW: Average Maize Ear Width at Harvest; ANL/pt: Average Number of Leaves per Plant at 50% Tasseling; MSD: Maize Stalk Diameter at 50% Tasseling; MPHT@50%ts: Mean Plant Height at 50% Tasseling

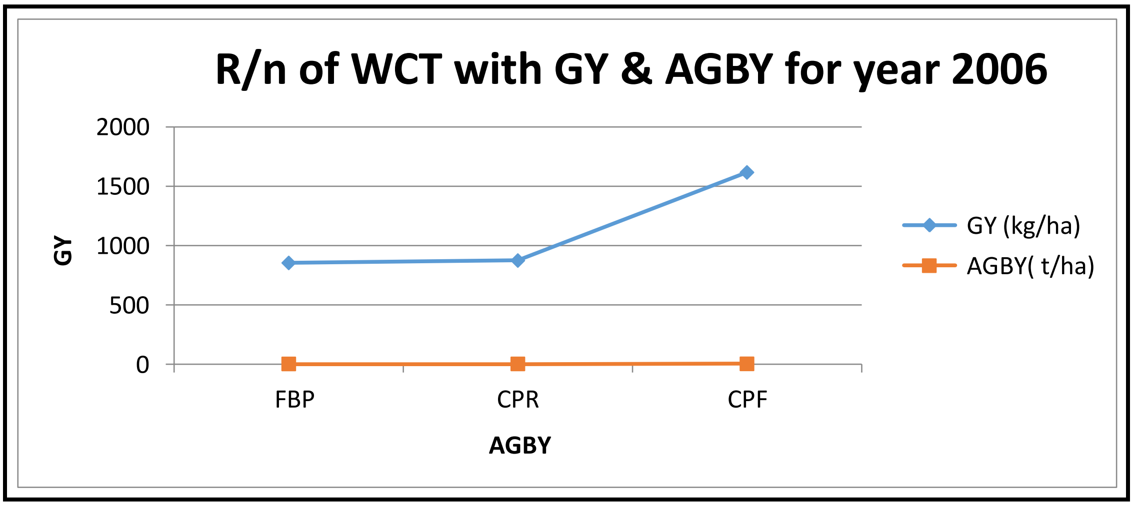

Figure 2: *The Relation of Water Conservation Technique with Grain Yield Production and Above Ground Biomass Yield in Season 2006*

GY: Grain Yield; AGBY: Aboveground Biomass Yield; WCT: Water Conservation Technique

3.2. Season 2007

The table of results for 2007 season (Table 3) indicates that grain yield was not significantly affected due to the main effect of variety. However, it was highly significantly ($P \leq 0.01$) affected by the main effect of water conservation technique. CPF is the best performing technique with regard to grain yield and above ground biomass yield (Table 3 and Figure 4). Above ground biomass ($P \leq 0.01$), average ear width ($P \leq 0.05$), day 1 % moisture content ($P \leq 0.01$), day 2 % moisture content ($P \leq 0.05$), day 4 and day 5 moisture contents ($P \leq 0.01$) were also affected significantly by the main effect of water conservation approaches (Table 4). A similar report came from Jones (1985), Honish (1973) and Warwick (1979, 1980) on their work on the effect of different tillage treatments on the yield of different crops including maize. Clark and Jones (1981) on their work in Texas, USA reported substantial increases in sorghum yield from 1420 kg/ha to 1650 kg/ha for tied ridging compared with flat planting.

Closed end tied ridge planting in furrows (CPF) was still the best water conservation approach with regard to all the parameters indicating that water is conserved well by this technique to be used for plant growth (Figure 3). This is in agreement with Gebreyesus et al. (2006) who said that tied-ridging before or at planting resulted in the best soil water status throughout the season and the best crop performance, especially when planting was in-furrow.

In moisture deficit environments like Bako, it is clear that plants would face scarcity of moisture available in the soil throughout the growing season unless they are supplied with supplemental water through irrigation or technique of conserving the natural precipitation is employed. A related report was declared by Mandiringana (2006) who found out that grain; stover and biomass yields were higher under tied-ridge treatments compared to the rip and conventional treatments indicating a possible response to better water conservation and use efficiency. No interaction effect was found significant in this season (Table 3 & 4).

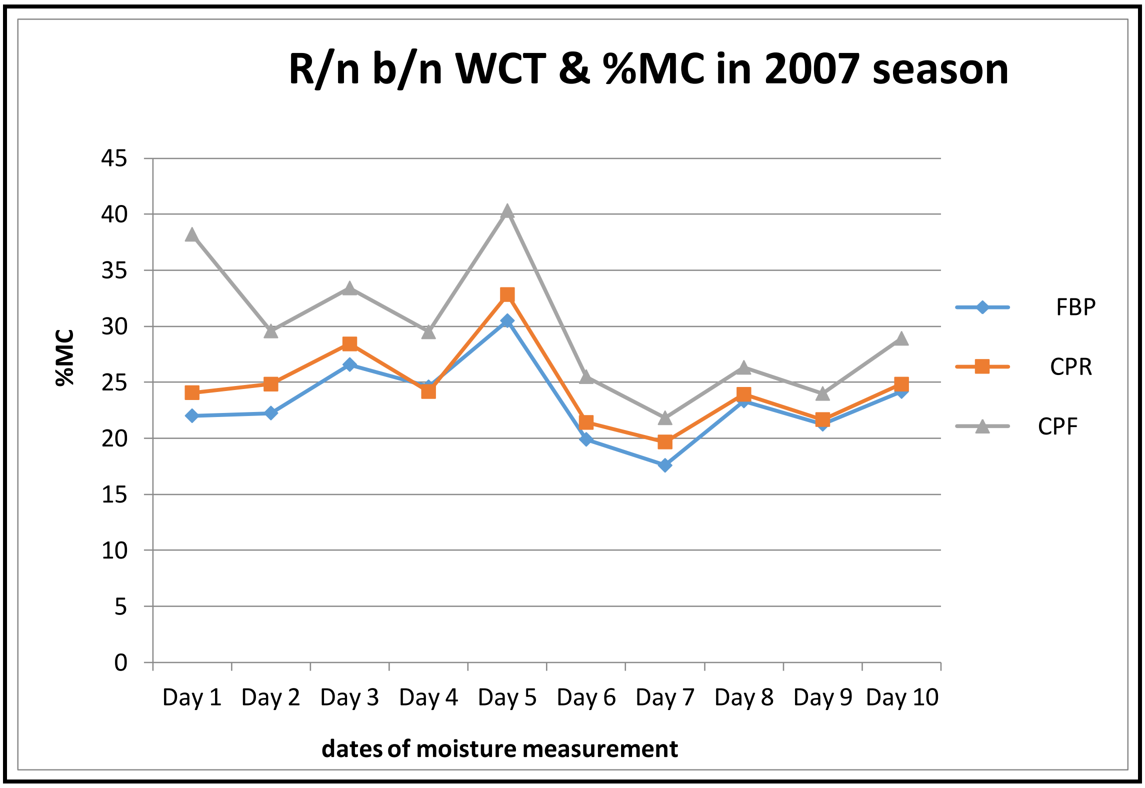

Figure 3: *Relation between Mean Soil Moisture Content and Water Conservation Techniques on Different Days of Measurement for Crop Season 2007*

% MC: Percent Moisture Content; WCT: Water Conservation Technique

Table 3: *Main Effects Due to Variety and Water Conservation Technique on Yield and Yield Parameters for Season 2007*

Treatment	GY (kg/ha)	AGB/GY (t/ha)	AEL (cm)	AEW (cm)	ANL/pt	MSD(cm)	MPHT @50%Fl (cm)
			Variety				
Local (V1)	892.8[b]	0.76[b]	13.00[a]	11.92[b]	11.22[a]	1.43[a]	97.22[a]
ACV3 (V2)	973.1[ab]	0.81[b]	13.33[a]	12.97[a]	10.44[a]	1.32[a]	98.22[a]
ACV4 (V3)	908.0[b]	0.79[b]	13.30[a]	12.71[ab]	10.67[a]	1.48[a]	104.11[a]
Katumani(V4)	1228.3[a]	1.23[a]	12.53[a]	12.46[ab]	10.89[a]	1.53[a]	99.56[a]
			Water Conservation Technique				
FBP	844.8[b]	0.72[b]	12.68[a]	12.04[b]	10.75[a]	1.38[a]	97.17[a]
CPR	675.1[b]	0.72[b]	13.18[a]	12.39[ab]	11.33[a]	1.43[a]	100.08[a]
CPF	1481.8[a]	1.26[a]	13.26[a]	13.11[a]	10.33[a]	1.51[a]	102.08[a]
			Significance				
Variety	NS	**	NS	NS	NS	NS	NS
Water conser.	**	**	NS	*	NS	NS	NS
VarietyXconservation	NS	NS	NS	NS	NS	NS	NS
CV (%)	28.35	29.66	14.66	6.96	10.82	13.76	10.38

GY: Grain Yield; AGBY/GY: Above Ground Biomass Yield Excluding Grain Yield; AEL: Average Maize Ear Length at Harvest; AEW: Average Maize Ear Width at Harvest; ANL/pt: Average Number of Leaves per Plant At 50% Tasseling; MSD: Maize Stalk Diameter at 50% Tasseling; MPHT@50%tfl: Mean Plant Height at 50% Filling

Table 4: *Main Effects Due to Variety and Water Conservation Technique on the Gravimetric Moisture Contents for Season 2007*

Treatment	%MC day 1 (0-20)	%MC day 2 (0-20)	%MC day 3 (0-20)	%MC day 4 (0-20)	%MC day 5 (0-20)	%MC day 6 (0-20)	%MC day 7 (0-20)	%MC day 8 (0-20)	%MC day 9 (0-20)	%MC day 10 (0-20)
Variety										
Local (V1)	29.75[a]	23.78[a]	28.22[a]	26.12[a]	33.67[a]	22.40[a]	19.67[a]	25.22[a]	23.11[a]	24.89[a]
ACV3 (V2)	28.36[a]	24.33[a]	30.89[a]	26.33[a]	34.00[a]	21.09[a]	19.78[a]	24.56[a]	22.11[a]	25.78[a]
ACV4 (V3)	27.03[a]	29.00[a]	31.22[a]	25.78[a]	35.33[a]	23.69[a]	20.44[a]	25.11[a]	21.67[a]	27.00[a]
Katumani(V4)	27.25[a]	25.11[a]	27.56[a]	26.11[a]	35.22[a]	21.91[a]	18.89[a]	23.22[a]	22.33[a]	26.22[a]
Water conservation technique										
FBP	22.01[b]	22.25[b]	26.58[b]	24.59[b]	30.50[c]	19.90[b]	17.58[c]	23.33[a]	21.25[b]	24.17[b]
CPR	24.07[b]	24.83[ab]	28.42[ab]	24.17[b]	32.83[b]	21.41[b]	19.67[b]	23.92[a]	21.67[b]	24.83[b]
CPF	38.21[a]	29.58[a]	33.42[a]	29.50[a]	40.33[a]	25.50[a]	21.83[a]	26.33[a]	24.00[a]	28.92[a]
Significance										
Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Water conser.	**	*	NS	**	**	**	**	NS	**	**
VarietyXconservation	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	14.38	21.34	23.89	5.54	7.36	11.19	10.28	14.85	8.56	7.64

%MC day 1, 2, 3, 4, 5, 6, 7, 8, 9, 10: Indicate Gravimetric Moisture Content Values Measured at Different Dates in the Growing Season on Dry Soil Basis

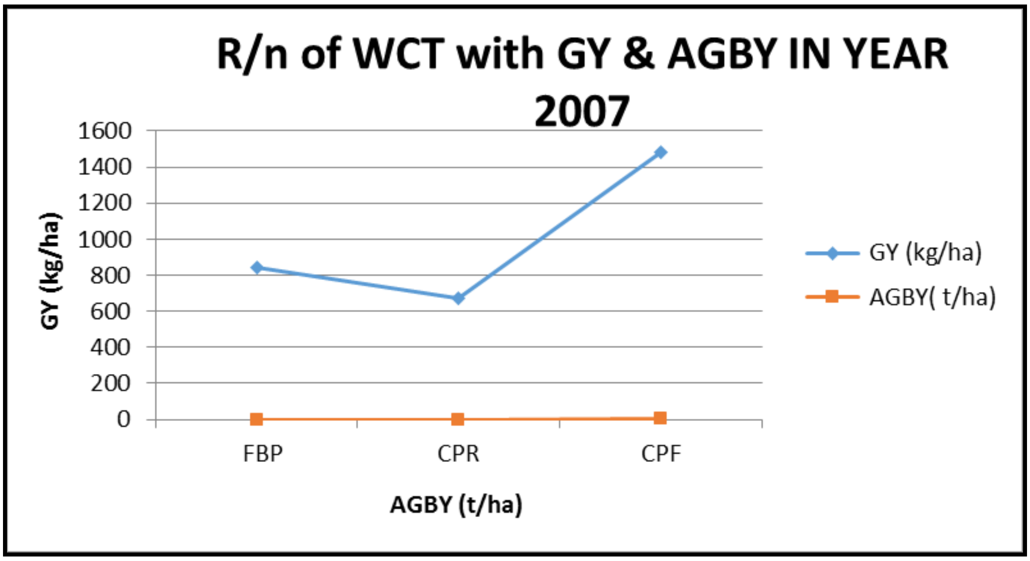

Figure 4: *The Relation of Water Conservation Technique with Grain Yield Production and Above Ground Biomass Yield in Season 2007*
WCT: Water Conservation Technique; GY: Grain Yield; AGBY: Above Ground Biomass Yield

4. Conclusion

The results of this verification trial can help us conclude the following points.

- Water conservation techniques at farm level are essential options for the semi arid Bako area for improving yield through better soil water storage.
- The CPF is the best option when measured in terms of the grain yield and related parameters of the maize varieties considered and moisture contents of soil.

- In moisture scarce environments like Bako, crop plants would face shortage of moisture available in the soil throughout the growing season unless they are supplied with supplemental water through irrigation or technique of conserving the natural precipitation is employed.
- With the current change in global climate, adaptation methods like the use of conservation approaches are to be implemented if the agriculture sector is to continue to meet the ever increasing food demand especially in developing countries like Ethiopia.

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References

Asfaw Negassa, Abdissa Gemeda, Tesfaye Kumsa and Gemechu Gedeno, 1997: *Agro- Ecological and Socioeconomical Circumstances of Farmers in East Wollega Zone of Oromiya Region.* Research Report No. 32. IAR (Institute of Agricultural Research). Addis Ababa.

Brahmbatt, B.M., and Patel, A.S., 1983: *Role of Moisture Conservation Practices for Semi-Arid Condition of Gujarat*. Gujarat Agri. Univ. Res. J.

Clark, R.N., and Jones, O.R., 1981: *Furrow Dams of Conserving Rainwater in Semi-Arid Climate.* In: Proc, Am. Soc. Eng. Conf. On Crop Production with Conservation in the 80‘s, Chicago, Illinois. 12.

Dagg, M., and Macartney, J.C. *The Agronomic Efficiency of the NIAE Mechanized Tied Ridge System of Cultivation.* Exp. Agr. 1968. 4; 279-294.

DLFRS, 1984: *Fifth Annual Report of the Dryland Farming Research Scheme (Phase III).* Agr. Res. Stn. Sebele, Botswana.

El-Swaify, S.A., 1983: *Conservation-Effective Farming Systems for the Semi-Arid Tropics.* ICRISAT, Hyderabad, India.

Gebreyesus Brhane, Charles, S.W., Martha Mamo, Heluf Gebrekidan, and Amare Belay. *Micro-Basin Tillage for Grain Sorghum Production in Semiarid Areas of Northern Ethiopia.* Agron. J. 2006. 98; 124-128.

Heluf Gebrekidan, 1989: *Summary Results of Completed Soil Science Research Projects. Hararghe Highlands, Eastern Ethiopia (1985-1988 Crop Seasons);* AUA, Alemaya. 121.

Heluf Gebrekidan. *Grain Yield Response of Sorghum (Sorghum bicolor) to Tied Ridges and Planting Methods on Entisols and Vertisols of Alemaya Area, Eastern Ethiopian Highlands.* Journal of Agriculture and Rural Development in the Tropics and Subtropics. 2003. 104 (2) 113-128.

Honisch, 1973: *Water Conservation in Three Grain Crops in the Zambesi Valley.* Dept. Agric. Lusaka, Zambia.

ICRISAT, 1975-84: *Farming Systems Annual Reports 1975-1984.* ICRISAT, Hyderabad, India.

Jones, M.J. 1985: *Conservation Systems and Crop Production. Paper Presented to Conf. on Agric.* Development in Drought-prone Africa. Royal Commonwealth Society, London, September 1985.

Macartney, J., Northwood, P., Degg, M., and Dawson, R. *The Effect of Different Cultivation Techniques on Soil Structure Conservation and Establishment and Yield of Maize at Kongwa, Central Tanzania.* Tropical Agriculture (Trinidad). 1971. 48 (1) 9-23.

Mandiringana, O.T. *Evaluation of Soil-Water Conservation Tillage Systems for Communal Farmers in the Eastern Cape, South Africa*. Agric Mech Asia Afr Lat Am. 2006. 37 (4) 27-32.

Njihia, C.M., 1979: *The Effect of Tied Ridges, Stover Mulch, and Farmyard Manure on Water Conservation in a Medium Potential Area, Katumani, Kenya.* In: Soil Tillage and Crop Production; Lal R. (Ed). IITA, Ibadan, Nigeria. 295-302.

Rawitz, E., Morin, J., Hoogmoed, W.B., Margolin, M., and Etkin, H. *Tillage Practices for Soil and Water Conservation in the Semi-Arid Zone. I. Management of Fallow during the Rainy Season Preceding Cotton.* Soi1 and Tillage Research. 1983. 3; 211-231.

Tamirie Hawando, 1986: *Increasing Agricultural Production in Ethiopia through Improved Soil-Water and Crop Management Practices.* In: Towards a Food and Nutrition Strategy for Ethiopia. Proceeding of the National Workshop on Food Strategy for Ethiopia. AUA. 243-275.

Tamirie Hawando, Heluf Gebrekidan and Yohannes Uloro, 1986: *Summary Results of Completed Soil Science Research Projects.* Hararghe Highlands, Eastern Ethiopia (1981-1985 Crop Seasons); Research Report. AUA, Alemaya. 108.

Tolera Abera, 2003: *Effects of Nitrogen, Phosphorous, Farmyard Manure and Population of Climbing Bean on the Performance of Maize (Zea Mays L.) Climbing Bean (Phaseolus Vulgaris L.) Intercropping System in Alfisols of Bako.* An MSc Thesis Presented to the School of Graduate Studies of Alemaya University.

Wakene Negassa, 2001: *Assessment of Important Physicochemical Properties of Dystric Udalf (Dystric Nitosols) Under Different Management Systems in Bako Area, Western Ethiopia.* An M.Sc. Thesis Presented to the School of Graduate Studies of Alemaya University.

Warwick, D.A. Annual Reports 1978/79 and 1979/81, Dryland Crop Agronomy Section (Big Bend). Agric. Res. Div., Min. of Ag. Swaziland. 1979/80.

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Seismic Site Classification of a Bridge Site over River Barak on Silchar Bypass Road

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Abstract Local site condition always plays a significant role in amplifying the ground motion parameters during an earthquake. To estimate site-specific earthquake hazards and to design earthquake resistant structures, it is important to characterize a site according to its class. This paper has made an effort to classify a proposed bridge site over river Barak on 'Silchar Bypass Road' which lies in a highly seismically active region (zone-V) of India. In the present study, in the absence of the shear wave velocity profile, the V_s30 for the top 30 m soil have been estimated using SPT-N value (collected from government agencies, PWD, Assam) for the 6 bore hole locations by proposing one new empirical equation correlating V_s and SPT-N for all soil type. The results have shown that all the bore hole locations are having their V_s30 and SPT-N between 180 to 360 m/s and 15N to 50N respectively, which conclude that the bridge site comes under the site class D according to the provisions of NEHRP (National Earthquake Hazard Reduction Programme).

Keywords *Site Characterization; NEHRP Site Classification; Shear Wave Velocity; Correlation; V_s30; SPT-N*

1. Introduction

For many years, the effect of local soil conditions or site effect on ground motion has been observed and demonstrated around the world. Many devastating earthquakes that have been experienced during the past decades have explained how the local geologic and soil conditions influence the level of ground shaking and the extent of damage occurred by it. Extensive studies from theoretical ground response analysis and from measured surface motions has highlighted the importance of site specific risk studies for earthquake resistant design of structures. Therefore, it is very much essential to characterize a site according to its class for the purpose of seismic microzonation and site-specific studies. Site characterization leads to the classification of a site in accordance with its average dynamic properties (mainly shear wave velocity) of the soil strata. Shear wave velocity is one of the most important parameters for dynamic site response evaluation or site characterization. The provisions of the National Earthquake Hazards Reduction Program [1] and the International Building

Code [2] have used the shear wave velocity of top 30 m (V_s30) and the average SPT-N value to classify sites into different classes. The different classes as per NEHRP provisions are site class A, B, C, D, E and F type. In the present study, an attempt has been made to characterize the study area as per the provisions of NEHRP based on V_s30. In the absence of the direct measurements of the shear wave velocity, V_s have been evaluated by proposing one new correlation between V_s and SPT-N for all type of soil.

2. Study Area

The study area is a proposed bridge site over River Barak in the Silchar Bypass Road on NH-53 which is going to be an important lifeline for the Silchar area and its adjacent states. It has a latitude and longitude of $24^0 45'$ N and $92^0 50'$ E as shown in Figure 1. Silchar is the headquarter of Cachar district of Assam in India and a major important city in the NE region. The city is situated 343 kilometers south east of Guwahati by the banks of the Barak River. It is the 2nd largest town of the state in terms of population and municipal area. As per population census report published in 2014 by Govt. of India [3], Silchar has a population of 178,865. This region has already experienced many earthquakes over the past decades including three devastating earthquakes such as the 1869 Cachar earthquake (M_w 7.8), the 1897 great Shillong earthquake (M_w 8.1) and the 1950 great Assam earthquake (M_w 8.6). A number of studies have explained that there is a huge probability of occurrence of such events in this region in the near future. So, there is a need for extensive site specific studies in terms of seismicity, microzonation to reduce the vulnerability of the structures due to future earthquakes. In the present study, an attempt has been made to classify this bridge site according to the NEHRP provision for site classification which is important for assessing the surface level hazard.

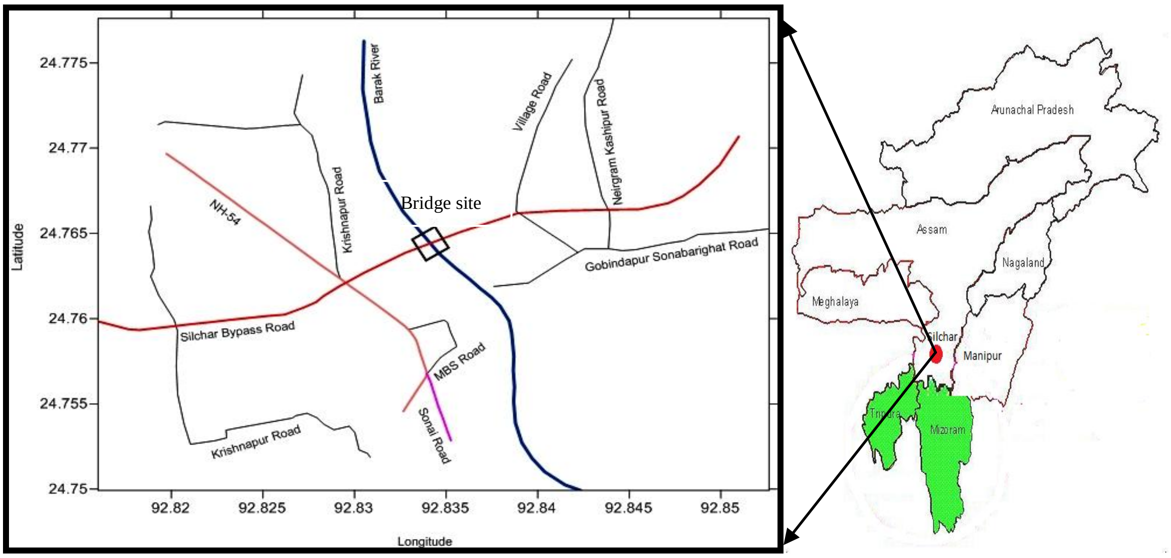

Figure 1: *Location of the Bridge Site Over River Barak on Silchar Bypass Road*

3. Geotechnical Properties

Site characterization or classification needs detailed soil investigation data regarding shear wave velocity. In the present study, due to unavailability of shear wave velocity profiles and geophysical tests data, available SPT-N values are used for investigation purpose. Detailed soil investigation report (SPT bore log) for the selected bridge site has been obtained from government agencies which are through SPT at 6 different borehole locations. Depth of each borehole is 50 m. From the SPT data it is seen that the soil deposit consists mainly silty clay and clay along with sand deposited layer wise. A typical bore log profile has been shown in Figure 2.

BH-6	Water table = 7.0 m below EGL		
Depth profile	Description of soil strata	Legend	SPT-N value
1.5	sand		11
4.0			13
7.0			16
10.0	silty-clay		31
13.0			32
16.0			34
19.0			33
22.0			46
25.0			43
28.0			52
31.0			56
34.0			58
38.5	stiff clay		72
43.0			78
47.5			65
50.0			77
	Hard rock		

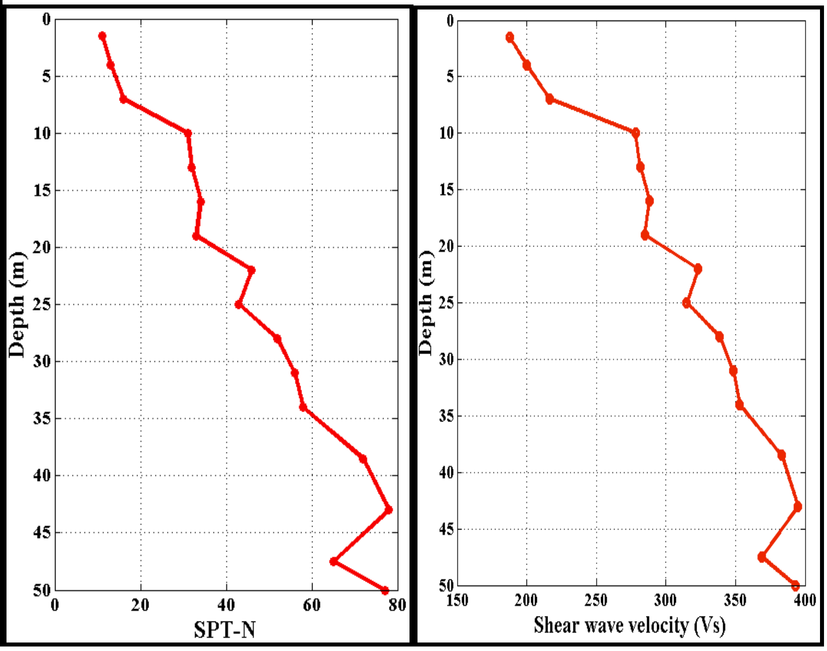

Figure 2: *Typical Bore Log Profile Showing SPT-N and V_s with Variation of Depth for the Bridge Site*

4. Developing Correlation for Estimating Shear Wave Velocity

For seismic site classification, shear wave velocity is one of the most important parameter. The NEHRP Provisions have used the V_s30 to classify sites into different categories. There are different methods to estimate the shear wave velocity including several laboratory as well as field tests such as Cone Penetration Test (CPT), Seismic Cross Hole Test, SASW and MASW etc. [4]. But these tests are not always feasible. So, in the absence of the field test data and laboratory test data, it is always preferential to measure V_s indirectly by using empirical equations correlating V_s with SPT-N value. Numbers of empirical equations have been developed correlating V_s and SPT-N value around the world. But these equations are region specific and cannot be used for all regions. In this study, the authors have made an attempt to develop a new empirical equation correlating V_s and SPT-N for all soil type based on the existing correlations. In this paper, 26 equations proposed for all soil types are selected carefully from the literatures [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29] and [30]. Further, a statistical regression analysis has been carried out using these equations.

A tabulated form of these equations is given in Table 1. An averaging technique has been adopted for developing this correlation combining all the selected equations. The developed correlation is shown below.

$$V_s = 75.478N^{0.3799} \ (R^2 = 0.9995) \text{ for all soil} \qquad (1)$$

The newly developed correlation is shown in Figure 3 by combining with other correlations for comparison purpose. It is seen that this newly developed equation has shown best fit curves with very high R^2 values, almost equal to unity when combined with the other correlations. So, it can be concluded that this newly developed correlation would be very much useful for determining shear wave velocity with good accuracy. In this study, the shear wave velocity profiles of the boreholes have been estimated for site characterization purpose using this newly developed equation.

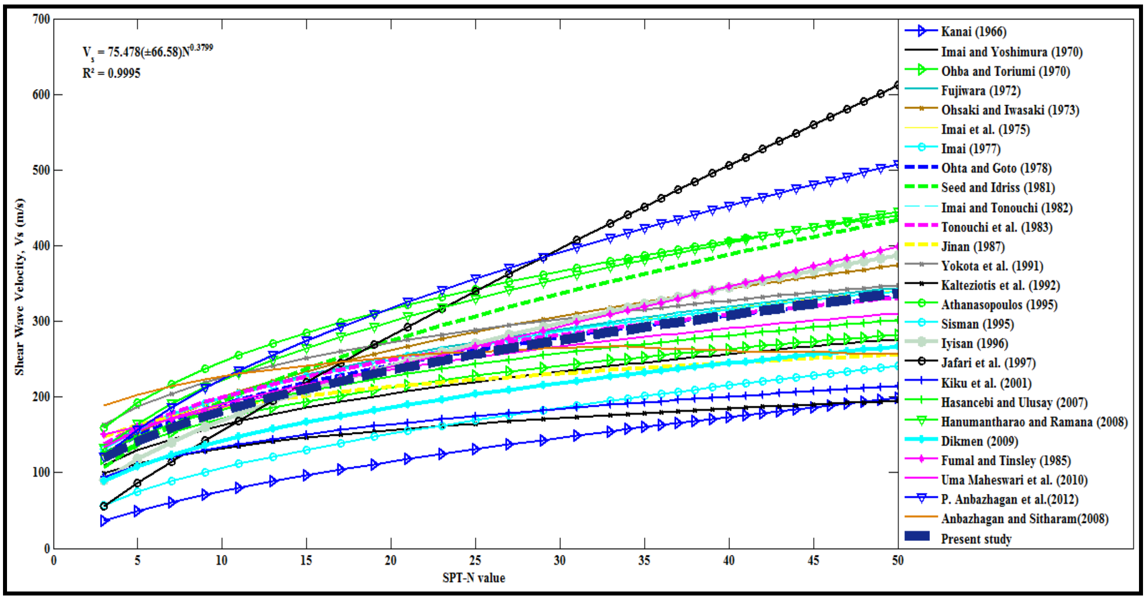

Figure 3: *Comparisons between Proposed and Existing Correlations for SPT-N and V_s for All Soils*

Table 1: *Some Existing Correlations between V_s and Uncorrected SPT-N*

Sl. No.	Author(s)	All soils
1	Kanai,1966 [5]	V_s=19N$^{0.6}$
2	Imai and Yoshimura ,1970 [6]	V_s=76N$^{0.33}$
3	Ohba and Toriumi, 1970 [7]	V_s=84N$^{0.31}$
4	Fujiwara, 1972 [8]	V_s=92.1N$^{0.337}$
5	Ohsaki and Iwasaki, 1973 [9]	V_s=81.4N$^{0.39}$
6	Imai et al., 1975 [10]	V_s=89.9N$^{0.341}$
7	Imai, 1977 [11]	V_s=91N$^{0.337}$
8	Ohta and Goto, 1978 [12]	V_s=85.35N$^{0.348}$
9	Seed and Idriss, 1981 [13]	V_s=61.4N$^{0.5}$
10	Imai and Tonouchi, 1982 [14]	V_s=97N$^{0.314}$
11	Tonouchi et al., 1983 [15]	V_s=97N$^{0.314}$
12	Jinan, 1987 [16]	V_s=116.1(N+0.3185)$^{0.202}$
13	Yokota et al., 1991 [17]	V_s=121N$^{0.27}$
14	Kalteziotis et al., 1992 [18]	V_s=76.2N$^{0.24}$
15	Athanasopoulos, 1995 [19]	V_s=107.6N$^{0.36}$
16	Sisman, 1995 [20]	V_s=32.8N$^{0.51}$
17	Iyisan, 1996 [21]	V_s=51.5N$^{0.516}$
18	Jafari et al., 1997 [22]	V_s=22N$^{0.85}$
19	Kiku et al., 2001 [23]	V_s=68.3N$^{0.292}$
20	Hasancebi and Ulusay, 2007 [24]	V_s=90N$^{0.309}$
21	Hanumantharao and Ramana, 2008 [25]	V_s=82.6N$^{0.43}$
22	Dikmen, 2009 [26]	V_s=58N$^{0.39}$
23	Fumal and Tinsley, 1985 [27]	V_s = 5.3N + 134
24	Uma Maheswari et al., 2010 [28]	V_s= 95.641N$^{0.3013}$
25	Anbazhagan et al., 2012 [29]	V_s=68.96N$^{0.51}$
26	Sitharam and Anbazhagan, 2008 [30]	V_s=78(N$_{60}$)$^{0.4}$

5. Seismic Site Classification

It has been well established that local soil condition or subsurface geology plays an important role in amplifying the ground motion parameters such as amplitude, frequency content and duration during an earthquake. So, there is a need for extensive site specific risk studies in terms of characterizing various sites into different classes. Provisions of the NEHRP have classified sites into six different categories based on the top 30 m shear wave velocity (V_s30) and SPT-N value. A tabulated form of all the site classes as per the guidelines of the NEHRP has been given in Table 2. The average top 30 m shear wave velocity, V_s30 and the average penetration resistance (N) for the top 30 m soil as defined by the NEHRP provisions is given by the following formulae:

$$V_s30 = \frac{30}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}} \quad \text{and} \quad N = \frac{30}{\sum_{i=1}^{m} \frac{d_i}{N_i}} \qquad (2)$$

Where, d_i is the thickness of soil layers, v_{si} is their respective shear wave velocity and N_i is the SPT-N value layer wise. In this study, the V_s30 and the average SPT-N for the top 30 m soil have been evaluated using the above expressions (eq-2) and the results thus obtained are shown in Table 3.

Table 2: *Site Classification System as Per the NEHRP Provisions*

NEHRP Site Class	Description	V_s30 (m/s)	SPT-N
A	Hard rock	>1,500	
B	Firm and hard rock	760–1,500	
C	Very dense soil and soft rock	360–760	N>50
D	Stiff soil	180–360	15≤N≤50
E	Soft clays	<180	N<15
F	liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils		

6. Results and Conclusion

For the purpose of assessment of site-specific earthquake hazards and for designing earthquake resistant structures, it is very much essential to characterize a site according to its class. Site classification categorizes a site in accordance with its average dynamic behavior of the soil strata. In the present study, the authors have made an attempt to characterize a proposed bridge site over river Barak on Silchar Bypass Road according to the site classification system as per the guidelines of NEHRP. Due to unavailability of shear wave velocity profile data, the V_s30 has been evaluated from known SPT-N value by proposing one new empirical equation correlating V_s and SPT-N. This newly developed empirical equation has been proposed for all type of soil. The equation when compared with other correlations for validation purpose has shown best fit curve with very high R^2 value. Based on the SPT-N values, V_s30 profile have been evaluated using the newly developed correlation for the 6 bore hole locations. The site is then classified according to the provisions of NEHRP based on the V_s30 and SPT-N value. The results as shown in Table 3 have revealed that all the 6 bore hole locations are having their V_s30 between 180 to 360 m/s and the average SPT-N value ranges between 15 to 50 that falls under site class D type.

Table 3: *Showing Estimated V_s30, Average SPT-N and Their Site Classification for the Bridge Site*

Bore Hole Location	V_s30 (m/s)	N-Average	Site Class
BH1	279.58	22.96	D
BH2	274.56	23.75	D
BH3	286.18	29.07	D
BH4	279.78	28.18	D
BH5	282.46	27.60	D
BH6	272.38	26.92	D

So, the present study will conclude that the bridge site comes under the site class D according to the provisions of NEHRP site classification system and a special design consideration should be taken which will comply with this site class.

References

[1] NEHRP, 2003: Part 1, Recommended Provisions for Seismic Regulations for New Buildings and other Structures: Provisions, Report No. FEMA450. Building Seismic Safety Council for the Federal Emergency Management Agency, Washington, D.C. USA.

[2] IBC, 2003: International Building Code 2003, ICC.

[3] Census India, 2014: Indian Cities with Population of 1 Lakh and Above. Govt. of India.

[4] Kramer, S.L., 1996: *Geotechnical Earthquake Engineering.* Pearson Education Pvt. Ltd. Reprinted 2003, Delhi, India.

[5] Kanai, K., 1966: Conf. on Cone Penetrometer. The Ministry of Public Works and Settlement, (Presented by Sakai Y., 1968) Ankara, Turkey.

[6] Imai, T. and Yoshimura, Y. *Elastic Wave Velocity and Soil Properties in Soft Soil.* Tsuchito-Kiso. 1970. 18 (1) 17–22 (in Japanese).

[7] Ohba, S. and Toriuma, I., 1970: *Dynamic Response Characteristics of Osaka Plain Proc.* Ann. Meeting AIJ (in Japanese).

[8] Fujiwara, T., 1972: *Estimation of Ground Movements in Actual Destructive Earthquakes Proc.* 4th European Symp. Earthquake Engineering (London). 125-32.

[9] Ohsaki, Y. and Iwasaki, R., 1973: On Dynamic Shear Moduli and Poisson’s Ratio of Soil Deposits Soil Found. 13; 61-73.

[10] Imai, T., Fumoto, H. and Yokota, K., 1975: *The Relation of Mechanical Properties of Soil to P- and S- Wave Velocities in Japan Proc.* 4th Japan Earthquake Engineering Symp. 89-96 (in Japanese).

[11] Imai, T. *P-and S-wave Velocities of the Ground in Japan Proc.* 9th Int. Conf. on Soil Mechanics and Foundation Engineering. 1977. 2; 127-32.

[12] Ohta, Y. and Goto, N., *Empirical Shear Wave Velocity Equations in Terms of Characteristic Soil Indexes Earthq.* Eng. Struct. Dyn. 1978. 6; 167-87.

[13] Seed, H.B. and Idriss, I.M., 1981. *Evaluation of Liquefaction Potential Sand Deposits Based on Observation of Performance in Previous Earthquakes*. ASCE National Convention (MO). 81-544.

[14] Imai, T. and Tonouchi, K., 1982: *Correlation of N-Value with S-Wave Velocity and Shear Modulus Proc.* 2nd European Symp. of Penetration Testing (Amsterdam). 57-72.

[15] Tonouchi, K., Sakayama, T. and Imai, T. *S-Wave Velocity in the Ground and the Damping Factor.* Bull. Int. Assoc. Eng. Geologists. 1983. 26-27; 327-333.

[16] Jinan, Z. *Correlation between Seismic Wave Velocity and the Number of Blow of SPT and depth* Chin. J. Geotech. Eng. (ASCE). 1987. 92-100.

[17] Yokota, K., Imai, T. and Konno, M., 1991. Dynamic Deformation Characteristics of Soils Determined by Laboratory Tests. OYO Tee. Rep. 3; 13.

[18] Kalteziotis, N., Sabatakakis, N. and Vassiliou, J. *Evaluation of Dynamic Characteristics of Greek Soil Formations.* In: Second Hellenic Conference on Geotechnical Engineering. 1992. 2; 239-246 (in Greek).

[19] Athanasopoulos, G.A., 1995: Empirical Correlations Vs-NSPT for Soils of Greece: A Comparative Study of Reliability. Proc. 7th Int. Conf. on Soil Dynamics and Earthquake Engineering (Chania, Crete). 19-36.

[20] Sisman, H., 1995: *The Relation between Seismic Wave Velocities and SPT*, *Pressuremeter Tests*. MSc Thesis. Ankara University (in Turkish).

[21] Iyisan, R. *Correlations between Shear Wave Velocity and In-Situ Penetration Test Results.* Digest. 1996. 96; 371-374.

[22] Jafari, M.K., Asghari, A. and Rahmani, I., 1997: *Empirical Correlation between Shear Wave Velocity (V_s) and SPT-N Value for South of Tehran Soils*. Proc. 4th Int. Conf. on Civil Engineering, Tehran, Iran (in Persian).

[23] Kiku, H., Yoshida, N., Yasuda, S., Irisawa, T., Nakazawa, H., Shimizu, Y., Ansal, A., Erkan, A., 2001: *In-Situ Penetration Tests and Soil Profiling in Adapazari, Turkey.* Proceedings of the ICSMGE/TC4 Satellite Conference on Lessons Learned from Recent Strong Earthquakes. 259-265.

[24] Hasancebi N. and Ulusay R. *Empirical Correlations between Shear Wave Velocity and Penetration Resistance for Ground Shaking Assessments Bull.* Eng. Geol. Environ. 2007. 66; 203-13.

[25] Hanumantharao, C. and Ramana, G.V. *Dynamic Soil Properties for Microzonation of Delhi, India.* Journal of Earth System Science. 2008. 117 (S2) 719-730.

[26] Dikmen, U. *Statistical Correlations of Shear Wave Velocity and Penetration Resistance for Soils*. Journal of Geophysics and Engineering. 2009. 6 (1) 61-72.

[27] Fumal, T.E. and Tinsley, J.C. *Predicting Areal Limits of Earthquake Induced Landsliding; In Evaluation of Earthquake Hazards in the Los Angeles Region – An Earth Science Perspective*. J.I. Ziony (ed.) US Geological Survey. 1985. 1360; 127-150.

[28] Uma Maheswari, R., Boominathan A. and Dodagoudar, G.R. *Use of Surface Waves in Statistical Correlations of Shear Wave Velocity and Penetration Resistance of Chennai soils.* Geotechnical and Geology Engineering. 2010. 28 (2) 119-137.

[29] Anbazhagan, P., Kumar, A. and Sitharam, T.G. *Seismic Site Classification and Correlation between Standard Penetration Test N Value and Shear Wave Velocity for Lucknow City in Indo-Gangetic Basin*. Pure and Applied Geophysics. 2012. 170 (3), 299-318.

[30] Sitharam, T.G. and Anbazhagan, P. *Seismic Microzonation: Principles, Practices and Experiments.* Electronic Journal of Geotechnical Engineering. 2008. Special Volume Bouquet. 8; 1-61.

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Research Article **Open Access**

Palynological Investigations of Umia Formation of Kutch Basin, Gujarat, vis-a-vis Depositional Environment and Age

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Abstract Mesozoic sedimentary sequence of the Kutch Basin is lithostratigraphically divisible into four formations namely, Patcham Formation, Chari Formation, Katrol Formation and Umia Formation in the ascending stratigraphic order. Two stratigraphic sections viz., Ghuneri Coal Mine Section and Korawadi River Section of Umia Formation were investigated in the present study. The palynological assemblage recovered from the Umia Formation of Kutch Basin comprises 88 species belonging to 48 form genera. Of these, 3 form genera and 9 species are new. These are *Venkatapollis indica* gen et sp. nov., *Aranyasporis cretacea* gen. et sp. nov., *Pyrgopites mesozoicus* gen. et sp. nov., *Echninatisporis korawadiensis* sp. nov., *Concavissimisporites trilobatus* sp. nov., *Leptolepidites psilatus* sp. nov., *Cingulatisporites intermedius* sp. nov., *Taurosporites mesozoicus* sp. nov. and *Trilobosporites indicus* sp. nov. Qualitatively the palynological assemblage of these sections of Umia Formation is dominated by Pteridophytes followed by gymnosperms, bryophytes and fungal spores indicating warm and humid climatic conditions. The age diagnostic palynotaxa such as *Crybelosporites*, *Gabonisporis*, *Rouseisporites* and *Aequitriradites* which straddle Tithonian-Neocomian time plane are well represented in Bhuj Sections of Umia Formation. The palynotaxa such as *Cyathidites, Lycopodiumsporites, Klukisporites, Concavissimisporites, Taurocusporites, Schizisporites* and *Echinatisporis* on the other hand are found to extend even up to the Aptian-Albian time. Hence investigated sediments of the Kutch Basin in all probability are of Early Cretaceous time ranging from Neocomian-Early Aptian.
Keywords *Palynology; Umia Formation; Early Cretaceous; Kutch; Gujarat; India*

1. Introduction

The present paper deals with the palynological investigations of the Umia Formation (Early Cretaceous) exposed in Ghuneri Coal Mine Section ($23^{o}\ 46^{'}\ 95^{''}$N and $68^{o}\ 50^{'}\ 43^{''}$E) and Korawadi River Section near Dharesi ($23^{o}\ 38^{'}$N and $68^{o}\ 52^{'}$E), in Kutch District of Gujrat, India (see Figure 1). The complete sequence of Mesozoic rocks ranging in age from Bathonian to Albian is well exposed in Kutch mainland, which is bounded on the west by Arabian Sea and on the south by Gulf of Kutch (sees Figure 2). The present investigations have been undertaken with the objective to explore the palynological microbiota from the Umia Formation and its implications in assigning a precise age vis-à-vis environmental constraints of palynobiota recovered there from.

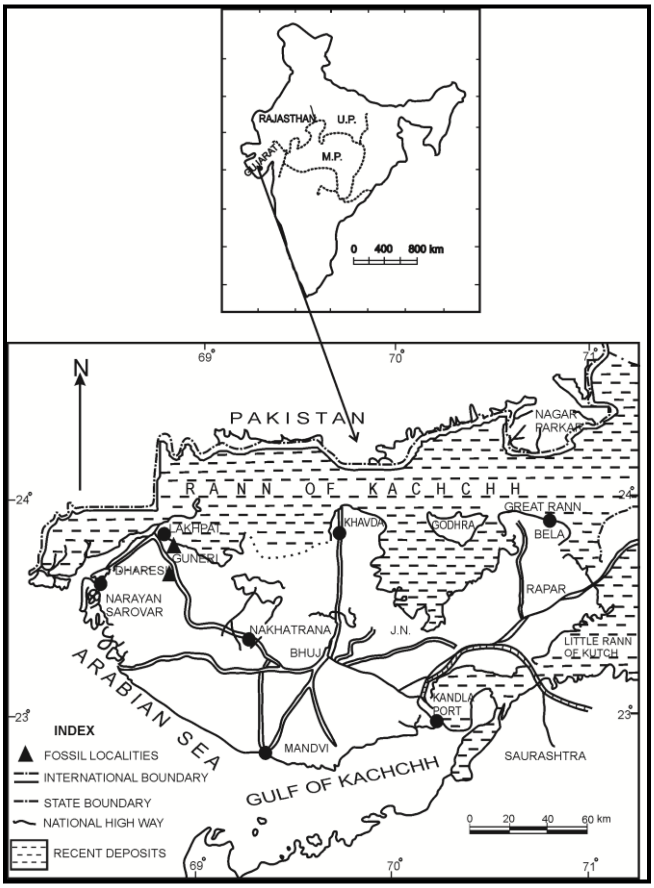

Figure 1: *Location Map of Kutch Basin*

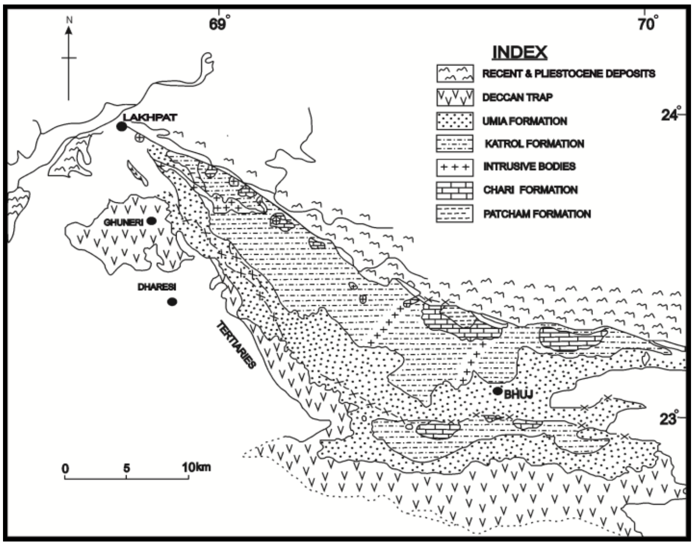

Figure 2: *Geological Map of Kutch Basin*

2. Geological Setting

Mesozoic stratigraphic succession in the Kutch Basin rests unconformably over the Precambrian basement and range in age from Middle Jurassic to Early Cretaceous. Lithostratigraphically, these rocks have been divided into Patcham, Chari, Katrol and Umia formations in the ascending order of stratigraphy (Waagen, 1875). The Patcham Formation is mainly deposited in Kaurbet and in the Islands of Patcham, Khadir and Bela. This Formation is made up of a thick succession of dark pisolitic limestones, olive green shales, cherty limestones, marls and is unconformably overlain by the Chari Formation which is composed of sandy marls, marine limestones and shales. The Chari Formation has further been subdivided into five zones namely, *Macrocephalus* beds, *Rehmani* beds, *Anceps* beds, *Athleta* beds and *Dhosa* oolite beds on the basis of ammonite assemblage in the ascending order (Spath, 1924). The overlying Katrol Formation consists of a thick sequence of shales, limestones, sandstones and grits with lenticular beds of gypseous shales. The Katrol Formation in turn is overlain by the Umia Formation, and is dominantly made up of sandstones, conglomerates and shales. The Umia Formation referred to as Umia Stage (Upper Tithonian-Neocomian) by Krishnan (1968) was divided into Barren Sandstone, Umia Ammonite beds, Barren Sandstone, Trigonia beds and Barren Sandstones. Jai Krishna (1987) formally divided the Umia Formation into four members namely, Umia, Ghuneri, Ukra and Bhuj members in the stratigraphic order. The Umia Formation is succeeded by the Deccan traps in the area.

3. Stratigraphic Succession

The stratigraphic classification proposed by Jai Krishna (1987) has been found most suitable for the purpose of the present study because the names like Patcham, Chari, Katrol and Umia are very popular and have been deeply engraved in Indian Geology.

3.1. Patcham Formation

This Formation is exposed mainly in Kaurbet and in the Islands of Patcham, Khadir and Bela. It consists of 520m thick succession of golden oolite, marl, sandstone, limestone and shale. The Formation is only 90m thick in the western Kutch (Jhumara Dome Area) and is made up of greenish shales and numerous bands of thinly bedded hard greenish coralline limestone.

3.2. Chari Formation

The Formation takes its name from the village Chari 50 Km NW of Bhuj and conformably overlies the Patcham Formation. It is exposed in the Habo dome area. This Formation is partially exposed in the Island belt but widely developed in the Kutch Mainland where it attains a thickness of 454m and comprises sandy marls, marine limestone and shales.

3.3. Katrol Formation

The Katrol Formation is named after the east-west trending Katrol-Charwar range in south of Bhuj. It comprises 757m thick marine succession of shales, limestones, sandstones and grits with lenticular beds of gypseous sandy shales. This formation is well exposed in the Kutch-Mainland.

3.4. Umia Formation

The Katrol Formation is overlain by a thick succession of Umia Formation, consisting of sandstones, conglomerates and shales. Earlier this Formation was named as Umia Group by Waagen (1875) and Umia Series by Rajnath (1932) and Krishnan (1968) and as Umia Formation by Jai Krishna (1987). The Deccan Lava flows capping this Formation protect its further erosion.

4. Stratigraphy of Investigated Sections

Two stratigraphic sections viz., Ghuneri Coal Mine Section and Korawadi River Section of Umia Formation were selected and rock samples were collected from these sections for Palynological investigations.

4.1. Ghuneri Coal Mine Section

This section is exposed along a cross-country traverse from east of Ghuneri. Here the total thickness of the succession is 3-3.5m. Lithologically, it comprises fine alternating bands of ferruginous sandstone and carbonaceous shales. The base of the section is characterized by about one meter thick coal seam presently being exploited by mine owners. All the litho units of the section exhibit a peculiar inter-fingering, a characteristic feature of the high-energy marginal deposits. This is also evident from the abundance of current bedding structures in the succession. The section is capped by the trap flows (see Figure 3). Altogether ten palynological rock samples were collected from this section, of which only four samples proved productive for palynobiota.

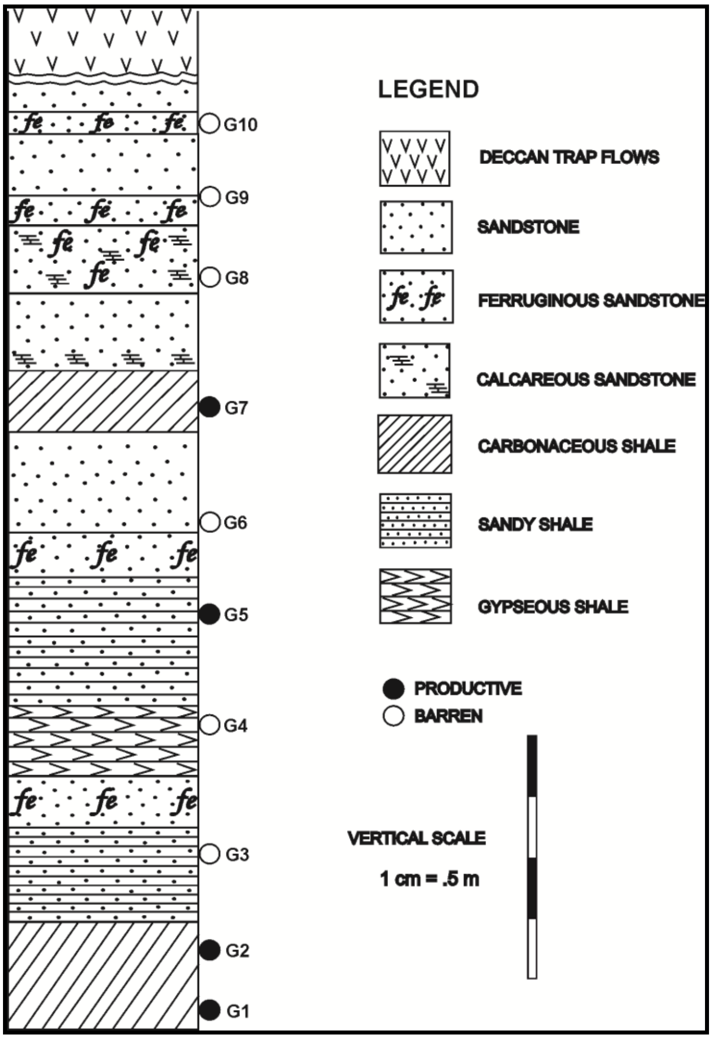

Figure 3: *Stratigraphic Section of Ghuneri Coal Mine, Bhuj*

4.2. Korawadi River Section

Korawadi River Section is located near village Dharesi, northwest of Bhuj on the Bhuj-Narayan Sarovar High way. Lithologically, the section is mainly made up of black carbonaceous shales and sandstones (see Figure 4). Out of the eight collected samples only five rock samples were found to enclose a rich palynological assemblage both in diversity and number.

Besides this, 50 palynological rock samples were also collected randomly from different localities to substantiate the temporal and spatial distribution of the palynotaxa.

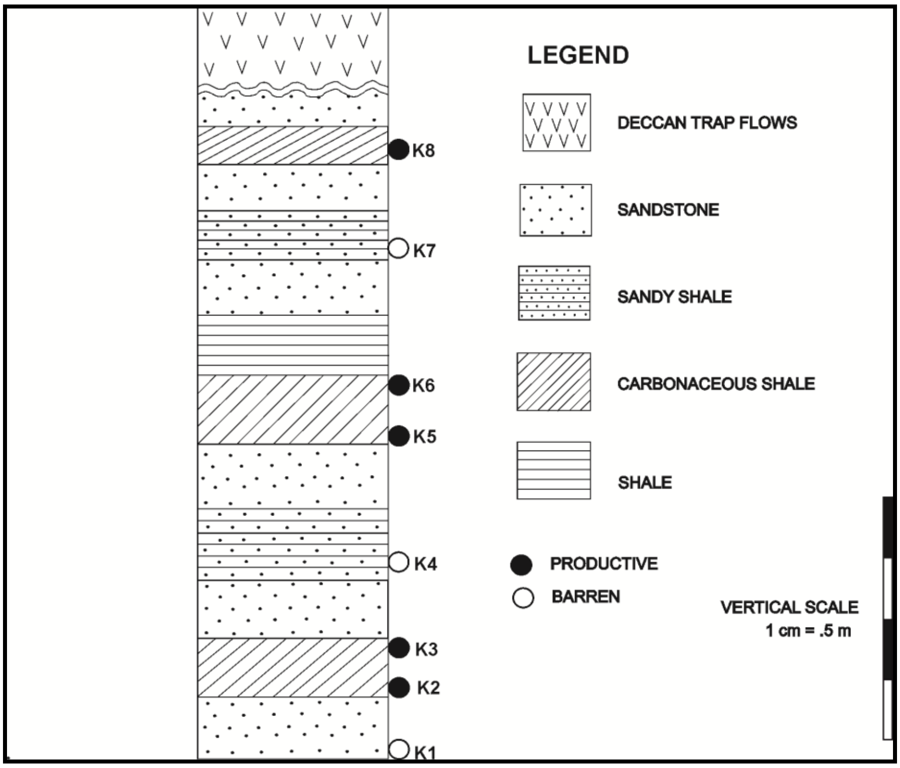

Figure 4: *Stratigraphic Section at Korawadi River, Near Dharesi*

5. Previous Palynological Studies in Kutch Basin

Several workers have palynologically investigated the Mesozoic sediments of Kutch Basin. The work was initiated by Singh et al. (1964), who for the first time reported a rich assemblage of spores and pollen grains from the coal and carbonaceous shale horizons of Ghuneri and Trambau River Sections. The mioflora from the Trambau Carbonaceous shales mainly consists of Pteridophytic miospores, megaspores and coniferous pollen grains while the assemblage obtained from the Ghuneri Coals is diversified in composition and form. The assemblage from both these localities consists of *Cyathidites, Contignisporites, Osmundacidites, Lycopodiumsporites, Gleicheniidites*, (pteridophytes), *Calliallasporites, Araucariacites, Schizosporis, Classopollis* (gymnosperms) etc. They assigned a Lower Cretaceous age to these sediments. The palynological assemblage recovered from the Mesozoic sediments of Kutch exposed on the banks of Pur and Pat rivers near Bhuj by Venkatachala (1967 & 69) closely resembles to that of Trambau and Ghuneri plant microbiota described by Singh et al. (1964). The genera common to both are *Cyathidites, Contignosporites, Schizosporis, Classopollis* and *Araucariacites.*

Venkatachala et al. (1969a, 69b and 69c) under their systematic study of spores and pollen grains reported a new trilete spore genus *Bhujiasporites* from the Mesozoic sediments of Kutch and revised the morphological description of the spore genus *Trilobosporites* found abundantly in the rock sequence**.** Jana (1984) recorded a Jurassic miospore assemblage from borehole in Sundernagar District, Gujarat. Palynological studies of Maheshwari & Jana (1986) indicated that the Jurassic-Cretaceous boundary lies somewhere in the Upper Member of Jhuran Formation. Rana et al. (2000) have also made a detailed palynological study on the Mesozoic rocks of Kutch basin.

6. Materials and Methods

Rock samples for the present investigation were collected systematically from two measured sections viz. Ghuneri Coal Mine Section and Korawadi River Section of Umia Formation. During the sampling care was taken to avoid surface contamination or mixing. Special attention was paid to the depth of weathering. Care was also taken to collect samples from fresh surfaces.

All the samples were processed by conventional technique of maceration with HCl, HF, HNO_3 and KOH. In some cases the organic matter of the recovered palynofossils was not clear enough for microscopic study. They were subjected to Acetolysis. All the slides were mounted in polyvinyl Alcohol and DPX. 15-20 slides were prepared for each sample. To facilitate the location of the spores and pollen grains, each grain was scanned with black ink. The slides in which the number of palynomorphs was high, the stage readings of the Vicke's microscope are noted. Generally 5-15 slides per sample were examined at a magnification of x100. Identifiable and well-preserved specimens of various species were counted and recorded. Thus an estimate of relative frequency of each species in each sample was made. Well-preserved specimens were microphotographed by using a Vicker's microscope.

7. Palynomorph Assemblage of the Umia Formation of Kutch Basin

The palynological assemblages of the Umia Formation of Kutch basin are made up of the 88 species referable to 48 form genera. Out of these, 3 genera and 9 species are new. For sake of brevity only the checklist of palynological assemblages recovered during the present study from the Umia Formation are given below. The new species will be described in some journal of systematics.

7.1. Fossil Spores and Pollen Grains (88 Species in 48 Genera)

Check list of Pteridophytes

Pteridophytes (65 species referable to 34 form genera)

Cyathidites: *Cyathidites minor*, *Cyathidites australis*, *Cyathidites ghuneriensis,*
Cyathidites sp. I, *Cyathidites* sp. II
Dictyophyllidites: *Dictyophyllidites harrisii*
Appendicisporites: *Appendicisporites potomacensis, Appendicisporites problematicus*
Concavisporites: *Concavisporites cutchensis, Concavisporites subverrucosus,*
Concavisporites cf. *C. punctatus*
Concavissimisporites: *Concavissimisporites trilobatus* sp. nov. *Concavissimisporites* sp.
Ceratosporites: *Ceratosporites cutchensis*
Baculatisporites: *Baculatisporite camauensis, Baculatisporites* sp.
Lycopodiumsporites: *Lycopodiumsporites ranikorensis, Lycopodiumsporites speciosus,*
Lycopodiumsporites sp.
Leptolepidites: *Leptolepidites verrucatus, Leptolepidites psilatus* sp. nov.
Leptolepidites sp.

Echinatisporis: *Echinatisporis korawadiensis* sp. nov.
Corrugatisporites: *Corrugatisporites formosus, Corrugatisporites turpitus, Corrugatisporites* sp.
Contignisporites: *Contignisporites fornicatus, Contignisporites glebulentus, Contignisporites cooksonii*
Klukisporites: *Klukisporites apunctus, Klukisporites foveolatus, Klukisporites kallameduensis*
Cicatricossisporites: *Cicatricossisporites augustus, Cicatricossisporites dorogensis*
Bullasporis: *Bullasporis minutus, Bullasporites triangularis*
Bhujiasporites: *Bhujiasporites hirustus*
Gleicheniidites: *Gleicheniidites mundus, Gleicheniidites senonicus, Gleicheniidites* sp.
Foveosporites: *Foveosporites* sp.
Sestrosporites: *Sestrosporites dettmanii, Sestrosporites pseudoalveolatus, Sestrosporites* sp.
Dictyotriletes: *Dictyotriletes* sp.
Cingulatisporites: *Cingulatisporites intermedius* sp. nov.
Boseisporites: *Boseisporites punctatus*
Plicifera: *Plicifera* sp.
Densoisporites: *Densoisporites mesozoicus, Densoisporites* sp.
Gabonisporis: *Gabonisporis bacricumulus, Gabonisporis labyrinthus*
Taurocusporites: *Taurocusporites mesozoicus* sp. nov.
Hymenozonotriletes: *Hymenozonotriletes mesozoicus*
Trilobosporites: *Trilobosporites triangularis, Trilobosporites indicus* sp. nov.
Aequitriradites: *Aequitriradites ornatus, Aequitriradites triangulatus*
Rouseisporites: *Rouseisporites reticulatus*
Crybelosporites: *Crybelosporites* sp.
Cooksonites: *Cooksonites reticulatus, Cooksonites variabilis*
Monoletes: *Monoletes intragranulosus*
Polypodiisporites: *Polypodiisporites* sp. I, *Polypodiisporites* sp. II

Check List of Gymnosperms

Gymnosperms (22 species belonging to 13 genera):

Podosporites: *Podosporites tripakshi, Podosporites microsaccatus*
Microcachrydites: *Microcachrydites antarcticus*
Alisporites: *Alisporites thomasii, Alisporites rotundus*
Podocarpidites: *Podocarpidites ornatus, Podocarpidites rarus, Podocarpidites ellipticus*
Callialasporites: *Callialasporites segmentatus, Callialasporites triletes*
Venkatapollis: *Venkatapollis indica* gen. et sp. nov., *Venkatapollis* sp. I, *Venkatapollis* sp. II
Araucariacites: *Araucariacites australis, Araucariacites cooksonii*
Schizosporis: *Schizosporis rugulatus*
Pyrgopites: *Pyrgopites mesozoicus* gen. et sp. nov.
Aranyasporis: *Aranyasporis cretacea* gen. et sp. nov.
Cycadopites: *Cycadopites sakrigalensis*
Ginkgocycadophytus: *Ginkgocycadophytus detritus, Ginkgocycadophytus* sp.
Monoulcites: *Monoulcites ellipticus*

Checklist of Bryophytes
Bryophytes (Single Taxon)
Coptospora: *Coptospora mesozoica*

8. Age and Depositional Environment

The analysis of palynological microbiota recovered from the Umia Formation of Kutch basin reveals the occurrence of Tithonian-Neocomian index taxa namely, *Crybelosporites*, *Gabonisporis*, *Rouseisporites* and *Aequitriradites.*

The palynotaxa such as *Cyathidites, Lycopodiumsporites, Klukisporites, Concavissimisporites, Taurocusporites, Schizisporites* and *Echinatisporis* on the other hand are found to extend even upto the Aptian-Albian time. Hence, based on age diagnostic palynological assemblage from the Umia Formation of the Kutch Basin, we infer an Early Cretaceous age for the formation ranging from Neocomian-Early Aptian. Qualitative spectrum of the palynological assemblage of Umia Formation counted in the present investigations is found to be dominated by Pteridophytes followed by gymnosperms, bryophytes and fungal spores, thereby indicating warm and humid climatic conditions.

9. Discussion and Conclusions

As a part of the field investigations an area about 50 sq. Km. between latitude 23^{o} 24′ 42″ N and longitude 69^{o} 50′ 43″ E was geologically mapped and formational boundaries of Patcham, Chari, Katrol and Umia formations were delineated. Two stratigraphic sections at Ghuneri Coal Mine and Korawadi River near Dharesi were measured and studied for palynobiota. The palynological assemblage recovered from Kutch basin in present study is represented by 88 species belonging to 48 form genera. Out of these 3 genera and 9 species are new. These are *Venkatapollis indica* gen. et sp. nov., *Aranyasporis cretaca* gen. et sp. nov., *Pyrgopites mesozoicus* gen. et sp. nov., *Echninatisporis korawadiensis* sp. nov., *Concavissimisporites trilobatus* sp. nov., *Leptolepidites psilatus* sp. nov., *Cingulatisporites intermedius sp. nov., Taurosporites mesozoicus* sp. nov. and *Trilobosporites indicus* sp. nov. The pteridophytes in the present assemblage are represented by 65 species referable to 34 form genera; the gymnosperms are documented by 22 species belonging to 13 genera. Besides, a single genus of bryophyta and a few fungal hyphae were also recovered. Thus qualitatively the palynological assemblage of Kutch basin is dominated by pteridophytes followed by gymnosperms, bryophytes and fungi indicating a warm and humid climate. The Umia formation along with its vast terrestrial fauna contains a variety of pteridophytes, bryophytes and a number of fungal remains. Since these are moist loving elements, their presence in the Kutch Cretaceous mioflora is a definite indicator of the existence of a considerable humidity in the atmosphere. That the climate remained more or less fairly warm is evident by the enrichment of gymnospermous elements during present investigation in the Kutch Basin.

The miofloral assemblage recovered from the Kutch basin during the present study comprises plant genera like *Cyathidites, Dictyophyllidites, Appendicisporites, Concavisporites, Ceratosporites, Baculatisporites, Lycopodiumsporites, Leptolepidites, Echinatisporis, Klukisporites, Bullasporis, Cicatricosisporites, Bhujiasporites, Glecheniidites, Sestrosporites, Boseisporites, Densoisporites, gabonisporis, Trilobosporites, Rouseisporites, Crybelosporites, Cooksonites, Podosporites, Microcachryidites, Callialasporites, Araucariacites,* and *Gingkocycadophytus* etc. Of these, formgenera like *Crybelosporites, Gabonisporis, Rouseisporites* and *Aequitriradites* are considered to be the markers of Neocomian age. The palynotaxa such as *Cyathidites, Lycopodiumsporites, Klukisporites, Concavissimisporites, Taurocusporites, Schizosporites* and *Echinatisporis,* on the other hand, are found to extend even up to the Aptian-Albian time. The above mentioned assemblage share many common elements of the palynological assemblages described from Aptian-Albian sediments of Australia (Dettmann, 1963; Dettmann and Playford, 1968), Canada (Singh, 1964;

Srivastava, 1972) and U.S.A. (Srivastava, 1975). Hence in all probability the Studied Kutch sediments enclose Early Cretaceous palynobiota ranging from Neocomian to Early Aptian. The close similarity of the palynological assemblage of Kutch basin with the Early Cretaceous sediments of Australia, United States of America and Canada also points out to the fact that the various land masses possess a uniform climate during Early Cretaceous time. This was perhaps due to their location in an isoclimatic belt or general warming of the earth during that time as postulated by Batten (1984).

References

Batten, D.J. *Palynology, Climate and the Development of Late Cretaceous Flora Provinces in the Northern Hemisphere: A Review Fossil and Climate*. Geological Journal. 1984. Special Issue 11; 127-164.

Dettmann, M.E. *Upper Mesozoic Microfloras from Southeastern Australia.* Proc. Roy. Soc. Vict. 1963. 77; 1-148.

Dettmann, M.E. and Playfold, G. *Taxonomy of Some Cretaceous Spores and Pollen Grains from Eastern Australia.* Proc. R. Soc. Vict. 1968. 81; 69-94.

Jai Krishna. *An Overview of the Mesozoic Stratigraphy of Kachchh and Jaisalmer Basins.* Palaeontological Society of India. 1987. 32; 136-149.

Jana, B.N. *A Jurassic Miospore Assemblage from a Bore Hole in Sundernagar District, Gujarat.* Geophytology. 1984. 14 (2) 208-221.

Krishnan, M.S. *Geology of India and Burma.* (Higginbotham) Madras. 1968. 1-535.

Maheshwari, H.K. and Jana, B.N. *Palynozonation of Jhuran and Bhuj Formation in Kutch basin.* Palaeobotanist. 1986. 36; 177-182.

Rajnath. *A Contribution to the Stratigraphy of Cutch*. Q. Jl. Geol. Min. Met. Soc. India. 1932. 4 (4) 161-174.

Rana, S., Singh, R.Y. and Dogra, N.N. *Geological History of the Early Cretaceous Sediments in Kutch and Jabalpur Basins- A Palynological Approach*. Bull. Ind. Geol. Assoc. 2000. 33 (1) 47-58.

Singh, C. *Microflora of the Lower Cretaceous Mannville Group, East-Central Alberta*. Res. Council Alberta Bull. 1964. 15; 1-238.

Singh, H.P., Srivastava, S.K. and Roy, S.L. *Studies on the Upper Gondwana of Kutch-1 Mio and Macrospores.* Palaeobotanist. 1964. 12 (3) 282-306.

Spath, L.F. *On the Blake Collection of Ammonites from Kutch, India.* Pal. Indica. (G.S.I.) N. Ser. 1924. 9; Mem 2.

Srivastava, S.K. *Systematic Description of Some Spores from the Edmonton formation (Maestrichtian) Alberta, Canada.* Palaeontographica. 1972. 139; 1-46.

Srivastava, S.K. *Microspores from the Fredericksburg Group (Albian) of the Southern United States.* Palaeobiologie Continentale. 1975. 1-107.

Venkatachala, B.S. *Palynology of the Umia Plant Beds of Kutch, Western India-1 Stratigraphic Palynology of the Bhuj Exposures near Walkmata (Kutch District, Gujarat State).* Rev. Palaeobot. Palynol. 1967. 5; 163-177.

Venkatachala, B.S. *Palynology of the Umia Plant Beds of Kutch, Western India-2 Bhuj Exposures near Walkmata Kutch District, Gujarat state- Systematic Palynology.* Palaeobotanist. 1969a. 17 (1) 1-8.

Venkatachala, B.S. *Palynology of the Mesozoic Sediments of Kutch, 4 Spores and Pollen from the Bhuj Exposures near Bhuj, Gujarat District.* Palaeobotanist. 1969b. 17 (2) 208-219.

Venkatachala, B.S. and Kar, R.K. *Katrolites Gen. Nov., a New Fossil from the Jurassic Rocks of Kutch, India.* Curr. Sci. 1967. 36 (22) 613-614.

Venkatachala, B.S. and Kar, R.K. *Palynology of the Mesozoic Sediments of Kutch, W. India 6. Three New Species of Applanopsis with Remarks on the Morphology of the Genus.* H. Santapau et al. (eds), J. Sen. Mem. 1969. 33-41.

Venkatachala, B.S. and Sharma, K.D. *Palynology of the Cretaceous Sediments from the Subsurface of Pondicherry Area, Cauvery Basin.* New Botanist. 1974. 1 (3 & 4) 170-200.

Venkatachala, B.S., Kar, R.K. and Raza, S. *Palynology of Bhujiasporites Gen. Nov. A New Trilete Spore Genus.* Palaeobotanist. 1969a. 17 (2) 121-122.

Venkatachala, B.S., Kar, R.K. and Raza, S. *Palynology of the Mesozoic Sediments of Kutch, Western India-3. Morphological Study and Revision of the Spore Genus Trilobosporites plant Ex.* Potonie 1956. Palaeobotanist. 1969b. 17 (2) 123-126.

Venkatachala, B.S., Kar, R.K. and Raza, S. *Palynology of the Mesozoic Sediments of Kutch, Western India-5. Bhuj Kutch District, Gujarat State*. Palaeobotanist. 1969c. 17 (2) 184-207.

Waagen, W. *Jurassic Fauna of Cutch.* Pal. Ind. (G.S.I.). Ser. 1875. 9 (1) 1-247.

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Morphometric Analysis using GIS in Pambar Sub Basin, Krishnagiri and Vellore District, Tamilnadu, India

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Abstract The study area taken is Pambar Sub-basin, covered in two districts such as Krishnagiri district and Vellore district of Tamil Nadu. It lies between the latitudes 12°10' - 12°45' and longitudes 78°15' - 78°50' of Toposheets No. 57 L/6, 57 L/7, 57 L/10, 57 L/11, 57 L/12, 57 L/14 and 57 L/15 of scale 1:50,000 published by Survey of India in 1973. Pambar basin covers total area of about 1735 SqKm. A detailed hydrogeological investigation of river basin needs a thorough understanding of the drainage basin morphology which enlight on Lithology, Structural controls, Relative runoff, Recharge, Erosional aspects and stage of development of a basin. Ever since 1895 morphometric analysis of a drainage basin has attracted more attention and it is still being apply for drawing subtle conclusions regarding nature, behaviour of geomorphology and water resources evaluation and managements. In this study an attempt has been made to understanding the various morphometric parameters in the Pambar watershed. The simpler unambiguous system of stream ordering proposed by Strahelr's has been followed which provide the mean of measuring size and form properties of watershed. In the present study, morphometric analysis of the Manas drainage basin has been carried using earth observation data and geographical information system (GIS) techniques. The morphometric parameters considered for analysis includes the linear, areal and relief aspects of the basin. frequency, Form factor, Elevation difference, Basin perimeter, Basin circularity, Drainage density and Ruggedness number were calculated and discussed salient features. Altogether sixteen parameters were computed for all the sub basins in ArcGIS environment. Drainage lines were classified under Strahler's scheme ordering system. Surface water resources could be enhanced in the region by constructing check dams and creating artificial recharge through effective planning and management.
Keywords *Morphometric Analysis; Pambar Sub Basin*

1. Introduction

The growth of population, in countries like India, and the consequent development, leads to increasing stress on water use, such as for drinking, irrigation and industrial needs. The increase in the usage of water has affected both surface and groundwater supplies, resulting in an acute water crisis. The Remote Sensing and GIS techniques are the proven efficient tools in the delineation, updating and morphometric analysis of drainage basin. The drainage basin analysis is important in any hydrological investigation like assessment of groundwater potential and groundwater management. The siting of facilities to enhance the recharge is also of great importance in planning the development of watershed programs. Infiltrating recharge water, to reach the groundwater body, depends on the surface rock-permeability, which is; generally, low, especially in the hard rock terrain (Precambrian basement) of Central and Southern India.

The Various important hydrologic phenomena can be correlated with the physiographies characteristics of drainage basins such as size, shape, slope of drainage area, drainage density, size and length of the tributaries etc. (Rastogi et al., 1976). Remote sensing data can be used in conjunction with conventional data for delineation of ridgelines, characterization, priority evaluation, problem identification, assessment of potentials and management. The hydrogeological conditions of the host rocks, which depend on the degree of weathered and fractured zones, give an indication of occurrence, movement and storage of groundwater as well as the sources of recharge of the groundwater (Fetter, 1990). The combination of these factors can give useful clues about the nature of the geological framework of a watershed, surface water flow and the recharge potential.

Morphometry concentrates on watershed features measurements. Morphometric analysis extracts meaningful information from topographic maps, digital elevation models (DEM), aerial photographs, satellite imageries and field data. Many such studies concerning these points have been done (Jenson and Domingue, 1988; Helsel and Hirsch, 1992; Beven and Moore, 1993; Gurnell and Montgomery, 2001; Davis, 2002; Lyon, 2002; Evans et al., 2003; Lin and Oguchi, 2006; Dinesh, 2008), but specific investigation on geomorphologic variables of watersheds in arid region is comparatively scarce compared to those of humid region. Once the drainage network of a watershed is defined, a variety of topological and geometric attributes can be determined (such as area, length, perimeter, slope, circularity, elongation, drainage density and the total stream lengths) and subsequently their empirical interrelationships can be determined through classic statistical regression methods.

The present paper describes the drainage characteristics of Pambar Sub-basin, obtained through RS GIS based morphometric analysis. It is felt that the study will be useful to understand hydrological behavior of basin. The quantitative analysis of drainage system is an important aspect of characterization of watershed (Strahler, 1964). Effect of different topo elements such as area, Morisawa (1958) analysed effect of different shape parameters on run-off rainfall ratios. It has been observed that the shape parameters showed a negative correlation with runoff-rainfall ratio. The morphometric study of the drainage basin is aimed to acquire accurate data of measurable features of stream network of the drainage basin. Remote Sensing (RS) and Geographical Information System (GIS) techniques were used to update drainage and surface water bodies and to evaluate linear, relief.

2. Study Area

The study area taken is Pambar Sub-basin, covered in two districts such as Krishnagiri district and Vellore district of Tamil Nadu, It lies between the latitudes 12°10’ - 12°45’ and longitudes 78°15’ - 78°50’ of Toposheets No. 57 L/6, 57 L/7, 57 L/10, 57 L/11, 57 L/12, 57 L/14 and 57 L/15 of scale 1:50,000 published by survey of India in 1973. Pambar basin covers total area of about 1735 Sqkm (Figure 1). Physiographically the area is flat with gentle slope. The study area is underlain by the Archaean crystalline rocks and the eastern side is covered by a chain of hills named Javadi and Mambakkam Reserved forest. The contribution of southwest monsoon ranges from 45 to 52 percent, whereas it ranges from 30 to 43 percent due to northeast monsoon. The basin experiences a moderately Tropical climate. Geological formations ranging in age from Archaean to Recent.

The area in and around of basin forms a part of the Archaean Peninsular complex having intensive high grade regional metamorphism with folding, faulting and shearing structures. The major rock types of the area are hornblende biotite gneiss, charnockite and epidote hornblende gneiss, granitic gneiss, calc granulites, syenites and ultra-basics (Figure 2).

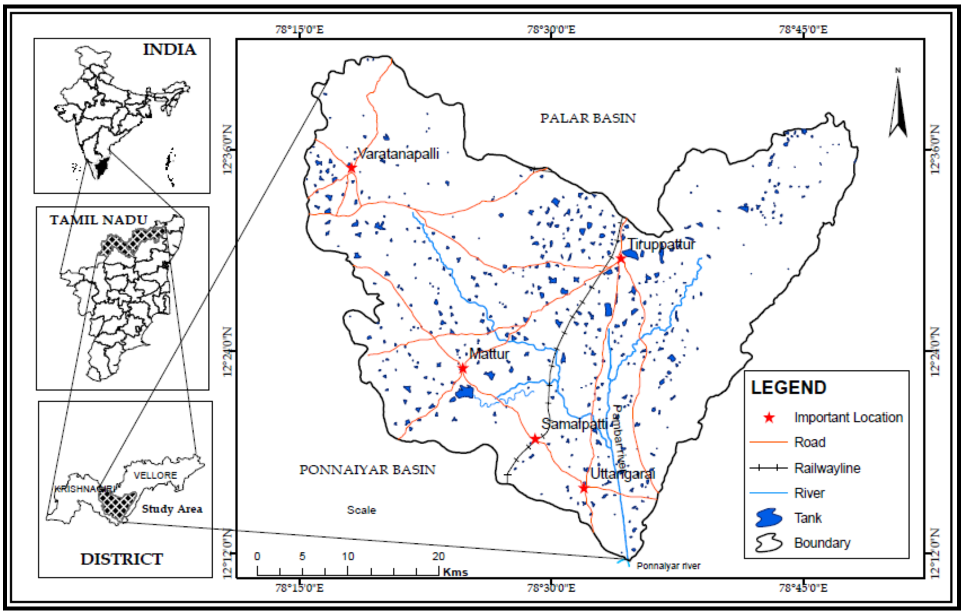

Figure 1: *Study Area Location*

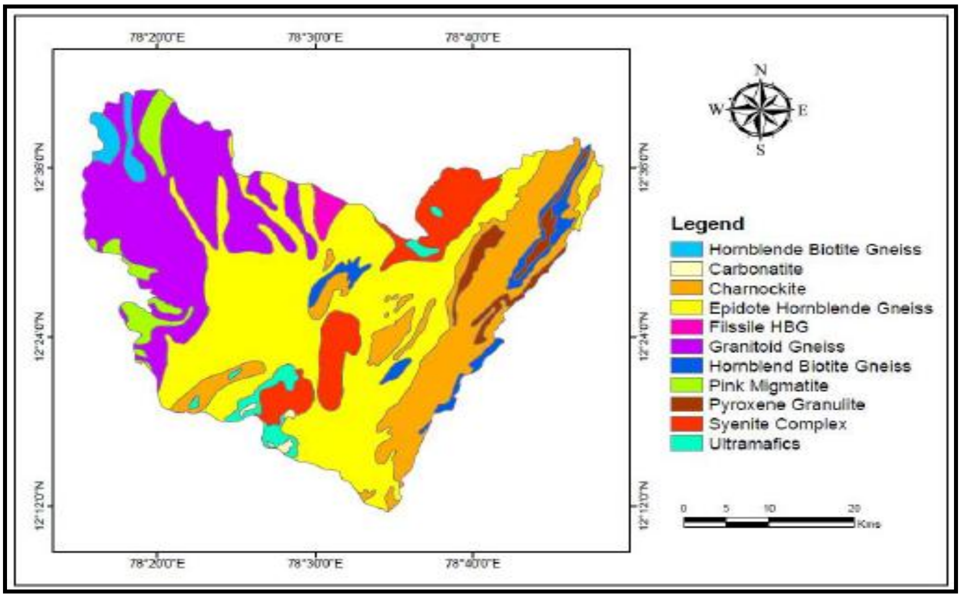

Figure 2: *Geology Map of Study Area*

3. Methodology

The Survey of India topographic maps (1:50,000) and digital elevation data (Shuttle Radar Topography Mission) were used for the delineation of Pambar basin (Fast Watershed Delineation method; ESRI, 1997) and drainage analysis was based on Horton (1945) and Strahler (1964). The morphometric variables were categorized into basic, derived and shape aspects.

3.1. Digital Elevation Models

The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe. The SRTM data are available as 3 arc sec (approximately 90-m resolution) DEMs. The generation of DEM is based on radar interferometry (INSAR). The data of tile N30E80 having projection geographic and datum WGS84 were re-projected into UTM system for further use.

3.2. Digitization of Stream Network

The detailed drainage network was digitized from Survey of India Toposheet and updated with Landsat ETM+ (2005) data as arc layer. After digitization, the layers were edited for dangle, overshoot, undershoot, etc. Arc topology was built and ordering of the drains was done following Strahler's (1957) method of stream ordering. The length and frequency of the drains were recorded for morphometric analysis.

4. Morphometric Analysis

Basin wise morphometric analysis has alternated the attention and is still being used for deriving sensible conclusions regarding a particular behavior of any hydro geological study and evaluation of water resources. Morph metric analysis is best achieved through measurement and mathematical calculation at configuration of the earth surface. The remotely sensed data was geometrically rectified with respect survey of India (SOI) topographical map at 1:50000. Image enhancement techniques were applied for better interpretation of drainage from images. The digitization of dendrite drainage pattern was carried out GIS environment.

Based on geomorphology and surface water divided marks the highest evaluation on the area. The number of streams and have a number of tributaries such as Pambar River Sub basin. The river basin area is classified into 22 sub basins of sixth streams (Figure 3 & Figure 4). The inter basin region spread over 1735 square kilometers including lower order streams that directly joins the main river course. In this river patterns are moderate and owing to medium rain fall, they river systems are lateral erosion is greater than the vertical erosion capability, which causes river takes meandering path. For detailed qualitative analysis have been done and the study area is divided into 22 sub-watersheds (Figure 4) and it is a natural hydrological entity from which surface runoff flows to a defined drains, channel, stream or river of a particular point. The sub-watersheds have been named based on the tank and villages at the outlet this analysis can be achieved through measurement of linear, aerial and relief aspects of the basin and slope contributions. In the present study, the morphometric analysis for the parameters namely stream order, stream length, bifurcation ratios, stream frequency, elongation ratio, circularity ratio, form factor, relief ratio etc., have been carried out using the mathematical formulae (Table 1). These are the important drainage characteristics required for an assessment of a watershed development plan, in association with hydrogeological information. The morphometric parameters have been considered for analysis is summarized in detail in Table 2, 3 & 4).

Table 1: *Morphology Adopted for Drainage Morphometric Parameters Analysis*

No.	Parameter	Formula	Previous Work
		Basic Parameter	
1	Area (A)	Area of the watershed	-
2	Perimeter (P)	The perimeter is the total length of the watershed Boundary.	-
3	Length (Lb)	Maximum length of the basin	-
4	Stream Order (Nu)	Hierarchical rank	Strahler, 1957
5	Stream Length(Lu)	Length of the stream	Horton, 1945
6	Maximum and Minimum Heights (H, h)	Maximum and Minimum elevation	-
7	Slope (Sb)	Sb = H-h / L	Verstappen, 1983
		Derived Parameter	
8	Bifurcation ratio (Rb)	Rb = Nu / N (u + 1)	Schumm, 1956
9	Stream length ratio (Rl)	Rl = Lu / Lu-1	Sreedevi et al., 2004
10	RHO coefficient (RHO)	RHO = RI / RB	Horton, 1945
11	Stream frequency (Fs)	Fs = $\sum Nu/A$	Horton, 1945
12	Drainage density (Dd)	Dd = $\sum Lu/A$	Horton, 1945
13	Drainage texture (T)	T = Dd × Fs	Smith, 1950
14	Constant of Channel maintenance (C)	C = 1/ Dd	Schumm, 1956
15	Basin relief (R)	R = H – h	Hadley and Schumm, 1961
16	Relief ratio (Rr)	Rr = R / L	Schumm (1963)
		Shape Parameter	
17	Elongation ratio (Re)	Re = 1.128 √A / L	Schumm (1956)
18	Circularity index (Rc)	Rc = 4π A / P^2	Miller (1953), Strahler (1964)
19	Form factor (Ff)	Ff = A / Lb2	Horton (1932, 1945)
20	Compactness coefficient (m)	0.282 P / $\sqrt{A}^{0.5}$	Gravelius (1914)

A = Area ; P = Perimeter; Lb = Length; Nu = Stream order; Lu = Stream length; H = Maximum height; h = Minimum Height; RI = Stream length ratio; Rb = Bifurcation ratio ;

Table 2: *Basic Parameters of River Basin*

					Stream Order							Stream Length			
WS	**Area**	**Perimeter**	**Length**	**Width**	1st	2nd	3rd	4th	5th	6th	Total	1st	2st	3st	4st
1	13.14	18.82	6.60	4.34	978	251	54	10	1		1295	590.79	292.60	107.69	94.09
2	16.79	19.47	6.65	4.71	382	94	22	5	1		504	234.96	117.17	41.66	55.29
3	33.96	38.10	13.13	4.91	98	22	9	4	2	1	136	94.59	34.62	3.19	1.70
4	5.14	9.10	3.37	2.52	133	36	9	3	1		182	69.88	37.19	19.07	15.90
5	19.64	22.79	7.42	4.97	210	51	11	3	1		276	108.91	33.70	15.31	13.82
6	15.34	18.31	6.98	3.65	25	7	2				34	27.16	17.12	8.77	
7	61.00	34.78	11.70	9.16	84	21	6	1			112	54.60	21.92	6.08	2.97
8	3.08	7.37	3.05	1.44	75	14	4	1			94	39.74	14.61	9.30	10.33
9	2.97	8.07	3.39	1.30	85	20	5	2	1		113	39.85	11.81	4.22	12.80
10	5.64	10.65	3.89	2.32	44	11	3	1	1		60	20.17	9.51	12.81	0.98
11	5.97	11.09	4.55	2.14	11	4	2	1			18	8.37	7.67	3.85	0.69
12	16.35	19.87	8.06	4.51	66	17	5	1			89	31.31	11.02	5.42	5.89
13	26.49	23.51	8.70	5.44	49	15	4	1			69	25.06	7.68	4.10	7.27
14	6.25	13.97	6.13	1.63	36	9	4	1	1		51	20.31	7.24	5.67	4.57
15	70.48	42.34	17.77	7.51	42	14	3	1			60	20.86	9.78	5.69	0.29
16	27.48	31.78	13.21	4.56	5	2	1				8	3.52	5.55	1.13	
17	43.81	30.79	12.56	5.87	9	3	1				13	4.71	2.92	4.44	
18	761.11	149.22	50.79	23.58	22	7	3	1			33	11.53	5.11	1.45	1.05
19	9.87	12.20	4.52	3.42	15	5	1				21	10.42	4.69	3.41	
20	19.15	17.42	6.70	5.25	14	4	1	1			20	6.36	3.20	2.29	0.61
21	350.52	130.55	39.10	26.58	9	3	1	1			14	5.21	4.69	0.20	0.02
22	190.23	169.79	47.77	15.56	7	2	1				10	4.65	2.69	0.07	

Table 3: *Derived Parameters of River Basin*

WS	Rb1	Rb2	Rb3	Rb4	Rb5	Rb	Rl1	Rl2	Rl3	Rl4	Rl5	Rl	Fs	Dd	Rt
1	3.90	4.65	5.40	5.00		4.74	2.02	2.72	1.14	5.18		2.76	3.56	2.79	3.19
2	4.06	4.27	4.40	5.00		4.43	2.01	2.81	0.75	3.48		2.26	4.09	3.19	4.57
3	4.45	2.44	2.25	2.00	2.00	2.63	2.73	10.87	1.87	0.12	2.58	3.63	4.50	2.52	2.94
4	3.69	4.00	3.00	3.00		3.42	1.88	1.95	1.20	2.15		1.79	2.83	2.42	2.20
5	4.12	4.64	3.67	3.00		3.86	3.23	2.20	1.11	1.55		2.02	2.92	2.22	2.63
6	3.57	3.50				3.54	1.59	1.95				1.77	2.81	2.48	2.78
7	4.00	3.50	6.00			4.50	2.49	3.61	2.04			2.71	3.86	2.96	7.94
8	5.36	3.50	4.00			4.29	2.72	1.57	0.90			1.73	2.33	3.29	1.90
9	4.25	4.00	2.50	2.00		3.19	3.38	2.80	0.33	143.09		37.40	2.75	2.49	1.24
10	4.00	3.67	3.00	1.00		2.92	2.12	0.74	13.02	7.64		5.88	4.00	3.28	1.97
11	2.75	2.00	2.00			2.25	1.09	1.99	5.58			2.89	2.83	3.21	2.97
12	3.88	3.40	5.00			4.09	2.84	2.03	0.92			1.93	3.67	2.70	3.47
13	3.27	3.75	4.00			3.67	3.26	1.87	0.56			1.90	3.19	2.60	4.81
14	4.00	2.25	4.00	1.00		2.81	2.81	1.28	1.24	17.68		5.75	3.00	1.93	0.93
15	3.00	4.67	3.00			3.56	2.13	1.72	19.47			7.78	3.42	2.12	4.30
16	2.50	2.00				2.25	0.63	4.90				2.77	4.29	2.69	2.96
17	3.00	3.00				3.00	1.61	0.66				1.14	3.54	1.21	1.10
18	3.14	2.33	3.00			2.83	2.26	3.52	1.38			2.39	4.74	1.45	8.68
19	3.00	5.00				4.00	2.22	1.38				1.80	2.25	1.03	0.66
20	3.50	4.00	1.00			2.83	1.99	1.39	3.78			2.39	2.25	1.07	1.03
21	3.00	3.00	1.00			2.33	1.11	22.94	9.62			11.23	4.43	1.33	3.86
22	3.50	2.00				2.75	1.73	38.50				20.11	2.63	0.78	0.80

Table 4: *Shape Parameters of River Basin*

WS	Re	Rc	Ff	Lg
1	0.30	0.47	0.30	0.72
2	0.30	0.56	0.38	0.63
3	0.15	0.29	0.20	0.79
4	0.59	0.78	0.45	0.83
5	0.27	0.48	0.36	0.90
6	0.29	0.57	0.32	0.81
7	0.17	0.63	0.45	0.68
8	0.66	0.71	0.33	0.61
9	0.59	0.57	0.26	0.80
10	0.51	0.62	0.37	0.61
11	0.44	0.61	0.29	0.62
12	0.25	0.52	0.25	0.74
13	0.23	0.60	0.35	0.77
14	0.33	0.40	0.17	1.04
15	0.11	0.49	0.22	0.94
16	0.15	0.34	0.16	0.74
17	0.16	0.58	0.28	1.65
18	0.04	0.43	0.30	1.38
19	0.44	0.83	0.48	1.93
20	0.30	0.79	0.43	1.86
21	0.05	0.26	0.23	1.51
22	0.04	0.08	0.08	2.56

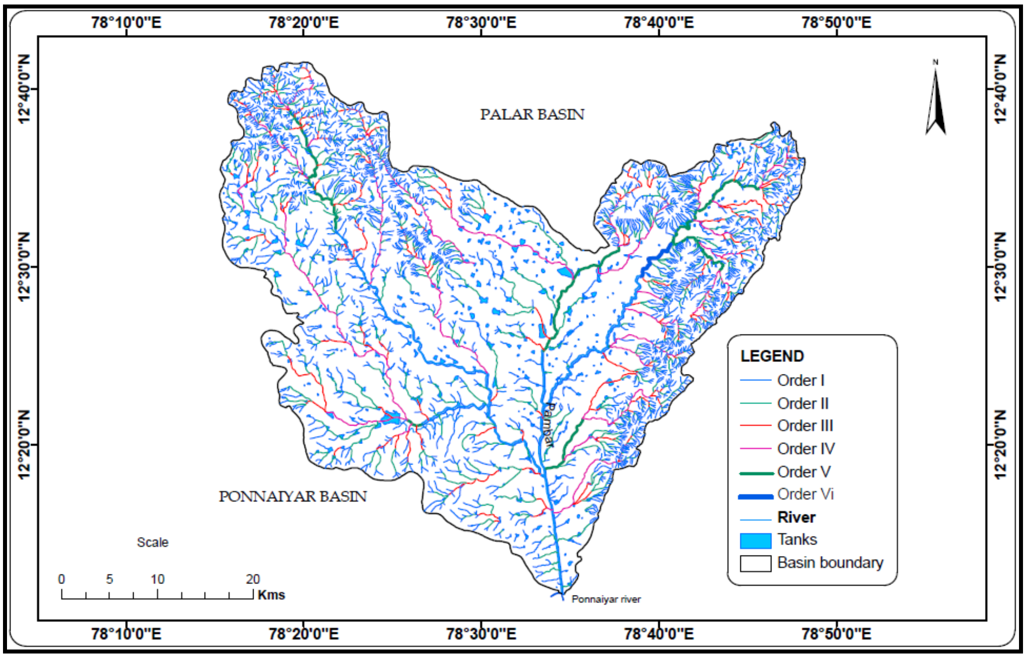

Figure 3: *Stream Ordering (By Strahler Method) of Study Area*

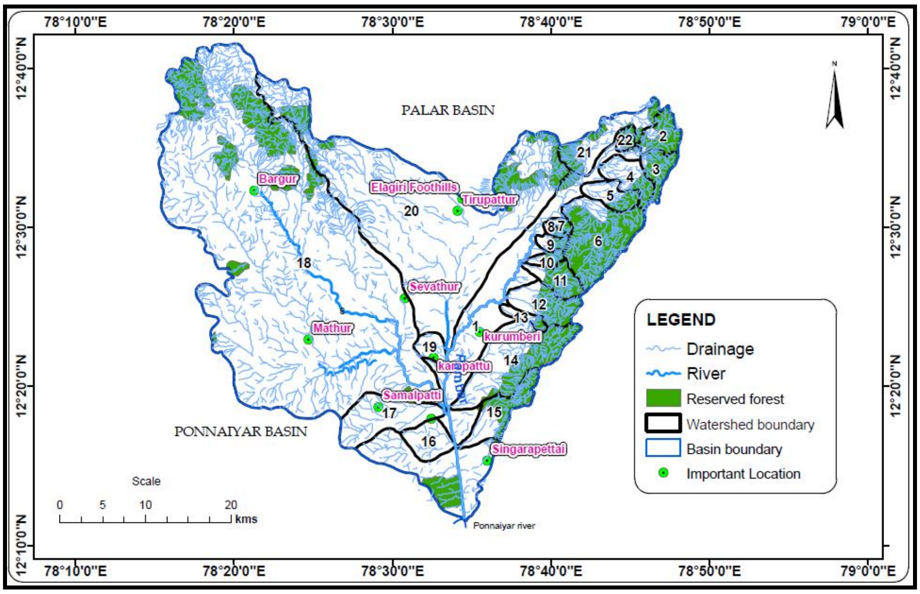

Figure 4: *Watershed Map of Study Area*

4.1. Basic Parameters

Area (A)

The entire area was considered between the divide line and the outfall with all sub and inter-basin areas. The total drainage area of Pambar basin is 1735 km^2, and the areas of each watershed are shown in Table 2. WS-9 is the smaller than twenty two watershed (A<2.97 km^2) and WS-18 is bigger than the others (A>700 km^2).

Perimeter (P)

The perimeter is the total length of the drainage basin boundary. The P of the twenty two watersheds is shown in Table 2. WS-18 has the higher value (P>169 km), while the perimeter of WS-8 is less (P<7 km) than the other watershed.

Basin Length (L)

The basin length corresponds to the maximum length of the basin and watershed measured parallel to the main drainage line. The values of L for the twenty two watersheds are shown in Table 2. WS-18 is the longer sub-basins (L>50 km) while WS-8 has the minimum value of L (L<3 km).

Basin Width (W)

The basin width corresponds to the maximum width of the basin and watershed. The maximum width observed in WS-21 (26.58 km), while smallest width observed in WS-9 (1.3 km).

Stream Order (Nu)

The primary step in any drainage basin analysis is order designation, stream orders and is based on a hierarchic ranking of streams. Ranking of streams has been carried out based on the method proposed by Strahler (1964) (Table 1). It is observed that the maximum frequency is in the case of first order streams. It is also noticed that there is a decrease in stream frequency as the stream order increases. Stream order, or classification of streams based on the number and type of tributary junctions, has proven to be a useful indicator of stream size, discharge and drainage area (Strahler, 1957). The number of streams (N) of each order (u) is presented in Table 2. The details of stream characteristics confirm Horton's first law (1945) ''law of stream numbers'' which state that the number of streams of different orders in a given drainage basin tends closely to approximate an inverse geometric ratio.

Stream Length (Lu)

Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics streams of relatively smaller lengths are characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradients. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases. The number of streams of various orders in the basin is counted and their lengths from mouth to drainage divide are measured with the help of GIS software. The stream length (Lu) has been computed based on the low proposed by Horton (1945) for all the 22 sub-watersheds. Generally the total length of stream segments in maximum is first order streams and decreases as the stream order increases. The values of length (Lu) and total stream length (Lt) are shown in Table 2. The stream length characteristics of the sub-basins confirm Horton's second law (1945) ''laws 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. Most drainage networks show a linear relationship with a small deviation from a straight line (Chow, 1964).

4.2. Derived Parameters

Bifurcation Ratio (Rb)

The term bifurcation ratio (Rb) is used to express the ratio of the number of streams of any given order to the number of streams in next higher order (Schumn, 1956). Bifurcation ratios characteristically range between 2.25 and 4.7 for basins in which the geologic structures do not distort the drainage pattern (Strahler, 1964). Strahler (1957) demonstrated that bifurcation ratio shows a small range of variation for different regions or for different environment dominates. The mean bifurcation ratio value is 2.75 for the study area (Table 3) which indicates that the geological structures are less disturbing the drainage pattern.

Stream Length Ratio (Rl)

The basin and sub-basins stream length ratios have been calculated by applying the following formula: Rl between successive streams orders varies due to differences in slope and topographic conditions, and has an important relationship with the surface flow discharge and erosional stage of the basin (Sreedevi et al., 2004). The values of Rl for the twenty two watersheds vary from 1.14 to 37.40 (Table 3).

Stream Frequency (Fs)

The stream frequency (Fs) was defined by Horton (1945) as the ratio between the total number of stream segments of all orders in a basin and the basin area: The Fs of the twenty two watersheds are shown in Table 3. It ranges from 2.25 (WS-19) to 4.74 (WS-18).

Drainage Density (Dd)

It is a measure of the length of stream per unit (Hortton, 1932) in the watershed. It is significant point in the linear scale of landform elements in stream-eroded topography and does not change regularly with orders within the basin. According to Horton (1945), the drainage density (Dd) is defined as the total length of streams per unit area divided by the area of drainage basin. It is expressed as: The drainage density (Dd) is an important indicator of the linear scale of landform elements in a stream-eroded topography (Horton, 1945). It directly expresses the closeness of spacing of the streams and indirectly reflects the structural framework of the underlying rocks of the watershed basin. The Dd values for the twenty two watersheds vary from 0.78 (WS-22) to 3.29 (WS-8) (Table 3).

Drainage Texture (Rt)

Texture ratio (T) is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain. In the present study the texture ratio of the basin is 0.66 and 8.68 categorized as moderate in nature. Table 3.

Stream Direction

The stream direction has been computed to understand the surface flowing pattern for the surface water development. The length and its direction of each drainage line have been calculated in GIS environment and the values are plotted in a polar graph sheet for each basin, presented in Figure 5. The drainage flow direction shows that the most of the sub basin fall under NW.

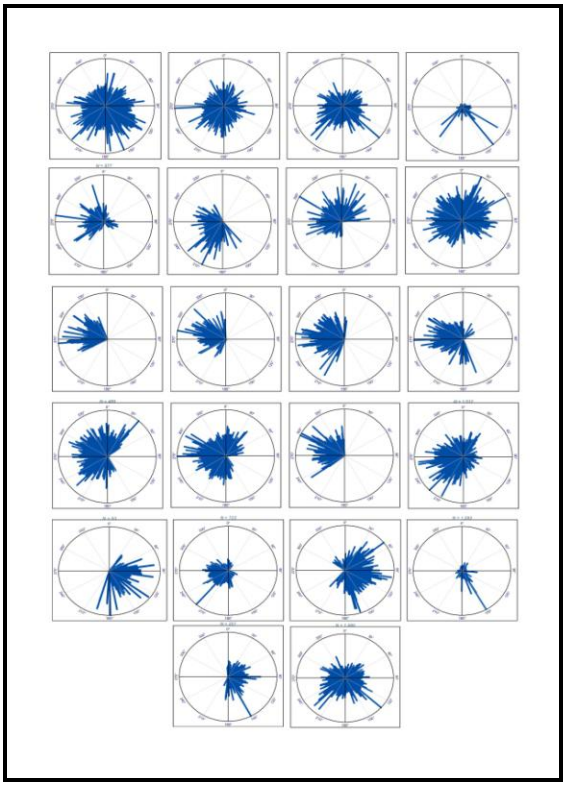

Figure 5: *Stream Direction of Sub Basin*

4.3. Shape Parameters

Elongation Ratio (Re)

The shape of the basin has a profound influence on the runoff and sediment transport process and it governs the rate at which water enter the stream, being dependent on circulatory and elongation ratio Elongation ratio (Re) was defined for Schumm (1956) as the ratio between the diameter of a circle of the same area as the basin (D) and basin length (L). The Re value for the watersheds are shown in Table 4. The Re is calculated by using the following formula: The computed Re value for the study area ranges from 0.04 (WS-8) to 0.66 (WS-18).

Circularity Index (Rc)

Basin of the circularity ratio 'Rc' is a shape measured depending on stream flow in the sub basin. The circularity ratio (Miller, 1953; Strahler, 1964) is expressed as the ratio of the basin area (A) and the area of a circle with the same perimeter as that of the basin (P):

Form Factor (Ff)

Horton (1945) proposed this parameter to predict the flow intensity of a basin of a defined area. The Ff of a drainage basin is expressed as the ratio between the area of the basin (A) and the squared of the basin length (L2). The Ff value for the watersheds are shown in Table 4.The lowest value of Ff recorded in WS-22 (0.08) and highest value found at WS-19 (0.48) (Figure 6).

Length of Overland Flow (Lg)

Horton (1945) used this term to refer to the length of the run of the rainwater on the ground surface before it is localized into definite channels. Since this length of overland flow, at an average, is about half the distance between the stream channels, Horton, for the sake of convenience, had taken it to be roughly equal to half the reciprocal of the drainage density. In this study, the length of overland flow of the Pambar Sub-basin is 2.56 and 0.61, (Table 4), which shows low surface runoff of the study area.

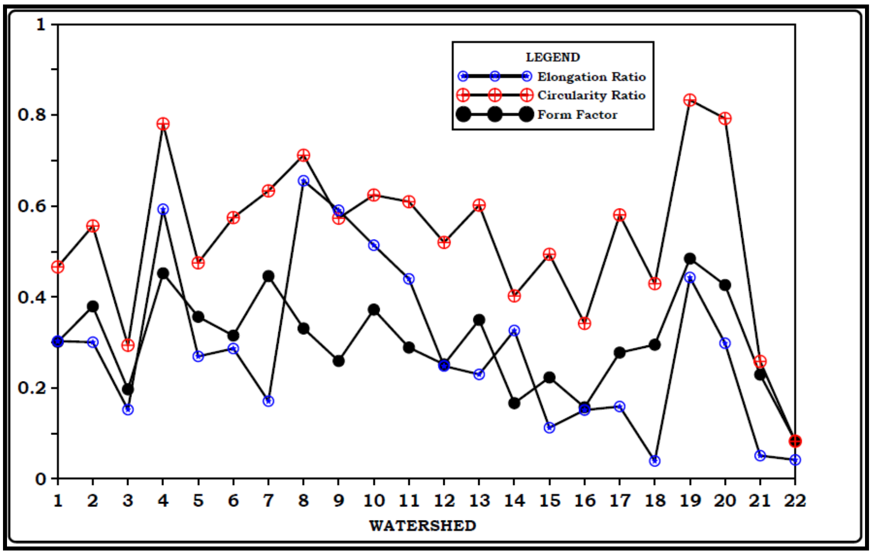

Figure 6: *Shape Parameter of Watersheds in Pambar Sub Basin*

4.4. Interrelationships of Different Morphometric Parameters

Table 5 shows the symmetrical correlation matrix of different morphometric variables. A preliminary quantitative assessment of the variables has been done using this matrix. A pictogram has been prepared (Figure 7) by rearranging the variables of highest correlation and density shading has been done to facilitate a visual examination of the data:

4.4.1. A Perusal of this Pictogram Reveals that Highest Correlation Exists Between

i. Basin length Vs Basin perimeter
ii. Stream length Vs Basin area
iii. Basin area Vs Basin perimeter
iv. Basin perimeter Vs Basin length
v. Basin elongation ratio Vs Relative density
vi. Stream frequency Vs Infiltration number
vii. Drainage density Vs Infiltration number
viii. Relief ratio Vs Stream slope

4.4.2. Principal Components

Principal Component Analysis (PCA) is a simple mathematical reduction of the data without any elaborate assumptions (Anderson, 1958; Wilks, 1964; Morrison, 1964; Rao, 1964). Loadings of first three components of different parameters along with their contribution as percentages are listed in Table 6. All the three components account for a cumulative variation of 58.15 percent in this Pambar sub basin. It could be seen in Table 6 that each component is associated with a few variables as shown below:

i. Length of over land flow, Elongation ratio and Relative density
ii. Basin perimeter, Basin area, Stream length and Basin length
iii. Drainage intensity, Elongation ratio, Relative density and Form factor

The first two components is mainly loaded on variables of length of over land flow, elongation ratio, relative density, basin perimeter, basin area, stream length and basin length. This component is a function of basin size. The third component has high positive loadings on drainage intensity, elongation ratio, relative density and form factor. This shows that the drainage texture is more in the Pambar sub basin (Figure 8).

Table 5: *Symmetrical Correlation Matrix of Important Morphometric Parameters*

Parameters	Principal Component		
	1	**2**	**3**
Total Stream Length - $\sum l_u$	-0.06	0.31	-0.13
Basin Length - L_b	**0.69**	-0.55	0.42
Basin Perimeter - P	**0.63**	-0.58	0.42
Bifurcation Ratio - R_b	-0.13	**0.92**	0.03
Length Ratio - R_l	-0.21	-0.36	0.30
Length of overland flow - L_g	0.11	-0.95	-0.06
Basin Area - A_u	**0.91**	-0.32	0.12
Basin Elongation Ratio - R_e	-0.51	0.30	-0.59
Circularity Ratio - R_c	-0.17	0.31	-0.85
Form Factor - F_f	0.08	0.32	-0.83
Drainage Density - D_d	-0.19	**0.92**	0.05
Drainage Texture - D_t	**0.83**	0.46	0.15
Stream Frequency - F_s	**0.97**	-0.13	0.10
Stream Length - L_u	**0.95**	-0.20	0.10
Relief Ratio - R_b	0.32	0.30	**0.86**
Relative Relief - R_h	0.30	0.21	**0.88**
Infiltration No - IM	**0.98**	0.05	0.12
Ruggedness No - R_n	0.10	**0.64**	**0.69**
Eigen Values	5.8	4.65	23.86
% of Total Variance	32.264	25.884	23.861
Cumulative % of Total Variance	32.264	58.148	82.009

Table 6: *The First Three Principal Components with their Loadings on Different Parameters*

	$\sum l_u$	Lb	P	R_b	R_l	L_g	A_u	R_e	R_c	F_f	D_d	D_t	F_s	L_u	R_b	R_h	I_n	R_n
$\sum l_u$	1.00																	
L_b	-0.20	1.00																
P	-0.19	0.99	1.00															
R_b	0.40	-0.51	-0.51	1.00														
R_l	-0.12	0.21	0.25	-0.18	1.00													
L_g	-0.28	0.58	0.61	-0.89	0.20	1.00												
A_u	-0.16	0.86	0.82	-0.38	0.05	0.34	1.00											
R_e	0.08	-0.72	-0.69	0.41	0.11	-0.39	-0.53	1.00										
R_c	-0.04	-0.68	-0.69	0.22	-0.31	-0.23	-0.38	0.68	1.00									
F_f	0.11	-0.47	-0.47	0.20	-0.39	-0.17	-0.19	0.47	0.87	1.00								
D_d	0.31	-0.57	-0.57	0.95	-0.16	-0.94	-0.42	0.46	0.22	0.17	1.00							
D_t	0.08	0.38	0.32	0.32	-0.26	-0.32	0.58	-0.44	-0.10	0.15	0.24	1.00						
F_s	-0.12	0.77	0.71	-0.24	-0.04	0.18	0.97	-0.52	-0.30	-0.09	-0.28	0.73	1.00					
L_u	-0.14	0.80	0.74	-0.29	-0.02	0.23	0.99	-0.53	-0.33	-0.13	-0.33	0.68	1.00	1.00				
R_b	-0.05	0.39	0.37	0.21	0.04	-0.27	0.26	-0.62	-0.66	-0.50	0.20	0.54	0.33	0.31	1.00			
R_h	-0.22	0.43	0.41	0.11	0.09	-0.19	0.29	-0.61	-0.65	-0.55	0.12	0.48	0.34	0.32	0.98	1.00		
I_n	-0.08	0.68	0.61	-0.09	-0.11	0.03	0.90	-0.54	-0.25	-0.02	-0.13	0.87	0.97	0.95	0.41	0.40	1.00	
R_n	-0.11	-0.03	-0.06	0.51	-0.10	-0.59	-0.06	-0.29	-0.31	-0.28	0.55	0.49	0.07	0.02	0.85	0.84	0.22	1.00

Name of the Parameter's

- $\sum l_u$ – Total Stream Length
- L_b – Basin Length
- P - Basin Perimeter
- R_b - Bifurcation Ratio
- R_l - Length Ratio
- L_g - Length of over land flow
- A_u - Basin Area
- R_e - Basin Elongation Ratio
- R_c - Circularity Ratio
- F_f - Form factor
- D_d - Drainage density
- D_t - Drainage texture
- F_s - Stream frequency
- L_u - Stream length
- R_b - Relief ratio
- R_h - Relative Relief
- I_n - Infiltration Number
- R_n - Ruggedness Number

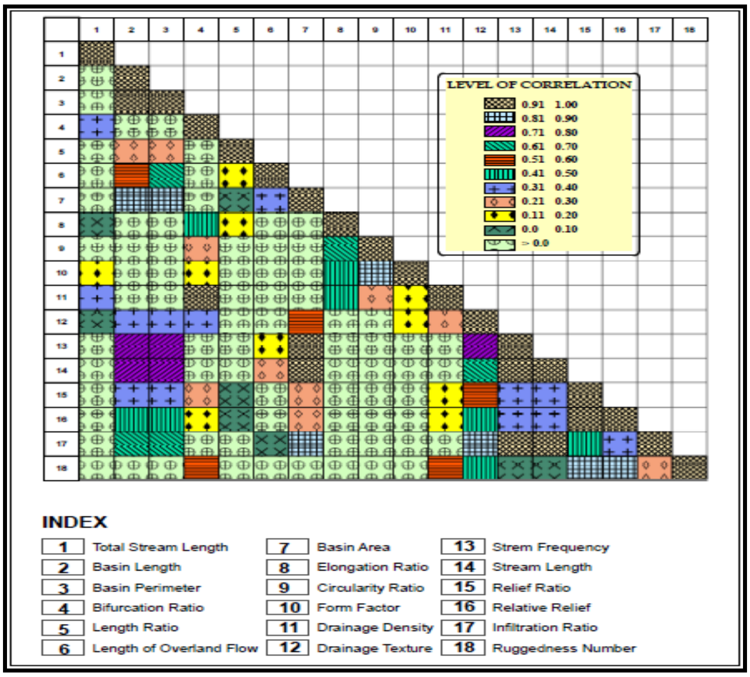

Figure 7: *Pictogram of Correlation of Morphometrical Variable in the Study Area*

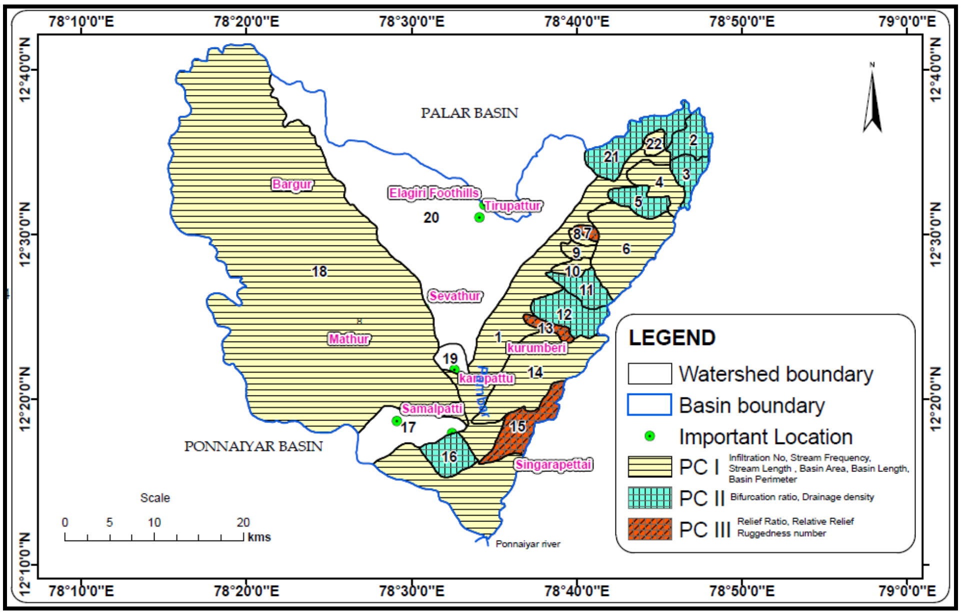

Figure 8: *Morphometrical Model Map of Study Area*

5. Conclusion

The characteristic drainage patterns are Dendritic, Sub-dendritic and Sub-parallel this implies that the rocks are homogeneous having uniform resistance in the horizontal direction. Six minor sub basins major (sub-basin 17, 18, 19, 20, 21 and 22) show low values of drainage density (less than 2) and Three (sub – basins No. 8, 19 and 20) showing less stream frequency that is less than 2.5. The above said sub-basins indicating more relative recharge of groundwater and high transmissivity of aquifer. The remaining sub- basins are moderate to well-drained indicating greater run off and lesser infiltration. Higher Bifurcation ratio has been noted in the sub-basin of hilly and forested portions in the study watersheds. Low stream frequency and low channel slopes indicate greater recharge rates. This is characteristic of sub-basins No. 8, 19 and 20. Triangular area lying between sub- basins surrounding the main stream are to be paid more attention for ground water developmental activities and also suitable site for implementing artificial groundwater recharge projects.

References

Anderson, T.W., 1958: *An Introduction to Multivariate Statistical Analysis.* John Wiley & Sons, New York.

Beven, K.J. and Moore, I.D., 1993: *Terrain Analysis and Distributed Modelling in Hydrology. Advances in Hydrological Processes.* Chichester: John Wiley & Sons. 336.

Chow, V.T., 1964: *Handbook of Applied Hydrology*. New York: McGraw Hill. 1453.

Davis, J.C., 2002: *Statistics and Data Analysis in Geology.* Chichester: John Wiley & Sons Inc. 638.

Dinesh, S. *Computation and Characterization of Basic Morphometric Measures of Catchments Extracted from Digital Elevation Models.* J Appl Sci Res. 2008. 4 (11) 1488-1495.

Evans, I.S., Dikau, R., Tokunaga, E., Ohmori, H., Hirano, M., 2003. *Concepts and Modelling in Geomorphology.* International Perspectives, Terrapub, Tokyo.

Fetter, C.W., 1990: *Applied Hydrogeology.* CBS, East Delhi, India. 592.

Gurnell, A.M. and Montgomery, D.R., 2001: *Hydrological Applications of GIS.* Chichester: John Wiley & Sons. 176.

Helsel, D. and Hirsch, R., 1992: *Statistical Methods in Water Resources.* Amsterdam: Elsevier. 625.

Horton, R.E. *Erosional Development of Streams and Their Drainage Density: Hydrophysical Approach to Quantitative Geomorphology.* Geol. Soc. Amer. Bull. 1945. 56; 275-370.

Jenson, S.K. and Domingue, J.O. *Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis.* Photogramm Eng Remote Sensing. 1988. 54; 1593-1600.

Lyon, J.G., 2002: *GIS for Water Resources and Watershed Management.* London: Taylor & Francis. 288.

Lin, Z. and Oguchi, T. *DEM Analysis on Longitudinal and Transverse Profiles of Steep Mountainous Watersheds.* Geomorphology. 2006. 78; 77-89.

Morisawa, M.E., 1959: *Relation of Quantitative Geomorphology to Stream Flow in Representative Watersheds of the Appalachian Plateau Province.* Project NR 389-042, Tech. Rep. 20, Columbia University, Department of Geology, ONR, Geography Branch, New York.

Strahler, A.N. *Quantitative Analysis of Watershed Geomorphology.* Transactions of the American Geophysical Union. 1957. 38; 913-920.

Strahler, A.N., 1964: *Quantitative Geomorphology of Drainage Basins and Channel Networks.* In: V.T. Chow (Ed.) Handbook of Applied Hydrology. New York: McGraw-Hill. 439-476.

Smith, K.G. *Standards for Grading Texture of Erosional Topography.* American Journal of Science. 1950. 248; 655-668.

Schumm, S.A. *Evolution of Drainage System and Slope in Badlands at Perth Amboy, New Jersey.* Geological Society of American Bulletin. 1956. 67; 597-646.

Miller, J.R., Ritter, D.F. and Kochel, R.C. *Morphometric Assessment of Lithologic Controls on Drainage Basin Evolution in the Craweord Upland, South-Central Indiana*. Am J Sci. 1990. 290; 69-599.

Wisler, C.O. and Brater, B.F., 1959: Hydrology. New York: Wiley. 408.

Wilks, S.S., 1963: Mathematical Statistics. New York: John Wiley and Sons.