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WATERSHED MANAGEMENT OF THE WESTERN REGION OF AKKALKOT TALUKA: DHUBDHUBI BASIN, SOLAPUR DISTRICT, MAHARASHTRA

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Abstract— **Morphometric analysis includes various parameters in preparation of drainage networks maps ordering the various streams, measurements of catchment area, perimeter, relative relief, and relief ratio, channels, drainage density, drainage frequency, bifurcation ratio, texture ratio, circulatory ratio of the western region watershed of Akkalkot Taluka i.e. Dhubdhubi basin. The Morphometric studies helps to understand the nature of the drainage properties of watershed, which in turn gives a valid reasoning for the soil transportation and its conservation. Geographic Information System (GIS) and Remote Sensing is the most efficient tools in delineation of drainage patterns and water resources planning worldwide.**

The hydrological investigations provides the information for planning, delineating, evaluation, exploitation and management of groundwater resources. The main sources is the rainfall that plays a vital role in fluctuation of water table. Depending upon the hydrogeological characters of the subsurface, the rate of recharge after the rainfall event decides the groundwater levels and there is always a time gap, which is defined as lap time to attain the maximum water level and subsequently there is a time gap for attaining lowest water level which is also a function of Geology and differences in the heads provide the flow of water from higher potential to lower potential. This flow of water brings down the water levels increasing the gap between the surface and the water table which is designated as the vadose zone. This also delineates the area feasible and non-feasible for artificial recharge.

Present study is an attempt to evaluate the nature of the drainage basins and its relationship with characters of the terrains and for deriving means to conserve and manage the resources and overcoming the water management system.

Keywords— **Dhubdhubi basin, watershed Morphometric analysis, GIS.**

1. INTRODUCTION

Morphometric analysis using remote sensing technique is powerfully emerging tool in recent years. Morphometry of stream channels is measurement and mathematical analysis of the configuration of the earth surface, slope, dimension of landform (Clarke, 1966). The analysis helps in deciding the basin geometry or variations in the rock hardness, structure controls, geological history of drainage basin (Strahler, 1964). Horton's law of stream length advice a geometric relationship between the number of stream segment in sequential stream orders and landforms (Horton, 1945). River basin comprise a distinct morphologic region and have special relevance to drainage pattern and geomorphology (Doornkamp and Cuchlaine, 1971; Strahler, 1957). The study is used for aerial and relief aspects of the catchment area using geographic information system tools.

The high resolution of remote sensing data couples with topographical data analysis procedure have made satellite data based morphometric analysis highly effective tool to understand and manage natural resources. Geographic information systems (GIS) is presently widely used in several geomorphologic, morphometric, flood management, and environmental application (eg. Dawod and Mohamed, 2009, EI Bastawesy et al, 2010, Rao et al, 2010, Dawod and Mahamed, 2008 and Dongquan et al, 2009).

Evaluation of the morphometric parameters involves preparation of drainage networks maps ordering of the various streams, measurements of catchment area, perimeter, relative relief, and relief ratio, length of drainage channels, drainage density, drainage frequency, bifurcation ratio, texture ratio, circulatory ratio and constant channel maintainers which helps to understand the natures of the drainage properties of basin.

Hydrological investigations provides the valid information for planning, delineation, evaluation, exploitation and management of groundwater resources. The main input source is rainfall that plays an important role in fluctuation of water table. Depending upon the hydrogeological characters of the subsurface the rate of recharge after the rainfall event decides the groundwater levels and there is always a time gap, which is defined as laps time to attain the maximum water level and subsequently there is a time gap for attaining lowest water level which is also a function of Geology and differences in the heads provide the flow of water from higher potential to lower potential.

2. OBJECTIVE

The survey in the study area and the field investigations leaded to set the following objectives:

- Geomorphological study to find out the use of modern tool i.e. remote sensing and geographic information system in Geo-morphometric analysis and slope analysis.
- To study drainage morphometry and its influence on hydrology.
- Groundwater fluctuations, aquifer performance, vadose zone studies for geo-hydrological analysis.

2.1. STUDY AREA

The present study area occurs in the Survey of India OSM toposheet no. E43P14, E43P15, E43Q1, E43Q2, E43Q3, E43Q6 and E43Q7 of scale 1:50000 in the Maharashtra state. These maps have been adopted in the present investigations in the Dhubdhubi basin, the area falls in South Solapur City region and Akkalkot Taluka of Solapur District, Maharashtra. It lies between latitude $17^0 21'$ to 17^0 41" N and longitude 76^0 00' to 76^0 11" E. (Fig. 1).

3. GEOLOGY OF THE STUDY AREA

From the accompanying map showing the regional geological setting, it will be seen that the area includes Deccan trap lava flows and they have assumed a great importance in Indian stratigraphy because of the great variety of rock types, complex structural features.

The study area shows the basaltic lava flows which represent the peripheral portions of the Deccan traps. They occupy the western, central and southern India. The Deccan traps are the most extensive geological formations of the Indian peninsula, ranging in age from upper cretaceous to Oligocene (Krishnan, 1968). The traps are divided into three main divisions, viz the upper, the middle and the lower with the inter –trapping beds at the base. They are generally composed of fine grained compact basalts which at places are vesicular and amygdaloidal, amygdales containing secondary minerals like zeolites and different from the silica. However, few places the basaltic flows are intercalated with ash beds, volcanic breccia's and acid and these deccan traps are considered to be the olelitics plateau basalts.

The Dhubdhubi basin consists of basaltic lava flows representing the Indrayani stratigraphic unit of Sahyadri group of Deccan trap formation from Upper Cretaceous to lower Eocene age (GSI 2001). Sabale, 2008 discussed the litho-units of the basin, according to him, Weathered zeolitic/ fragmentary litho-unit is exposed in the southern portion of the basin, at Kudal and Devkavate villages and is overlained by red boles of 1m thickness, around Andhewadi and near Kalhippargi, representing oldest flow (1st flow) in the basin. The thickness of this flow is 21m. Flow 2nd, also of 21m thickness, consisting of lower 8m thick weathered basal clinker, starts at an altitude of 431m between Shaval and Kalhippargi. This is further overlained by fractured/massive basalt of 12m thickness, around Kalhippargi, Handral, Karajgi, Shirval and Kadabgaon villages. One meter thick red bole graded into zeolitic/vesicular basalt is exposed towards the NE of Handral, Jeur, Ingalgi, Achegaon, Tillyal, Hipale, extending beyond Ratnapur (Borul). It is the bed marker between 2nd and 3rd flow. This is overlained by 4m thick unit of Basal Clinker around Hanjagi, South of Karjal and north of Hipale. Above these rocks, massive basalts of 19m thickness are resting and are outcropped around Akkalkot station, Dodyal, Konhalli, Karjal, Shingadgaon, Hanamgaon and Rampur. Vesicular zeolitic basalt unit of 22m thickness is overlaying around Bagehalli, NE Konhali, North of Dahitanewadi, Walsang, Gurdehalli and Kardehalli. This vesicular zeolitic litho-unit is graded into 1m

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thick red bole and basal clinker of the younger flow, exposed near Wadgaon. The total thickness of the 3rd flow is 46m. This is overlained by fractured / massive basalts of the younger flow (4th flow) in the basin around the villages Halhalli, Dindur, West of Thirth, North of Wadgaon, Dhotri and North of Shirpanhalli. The basin boundary in the North and NE shows exposures of zeolitic basalt. The massive portion of 1st, the oldest flow in Dhubdhubi basin is not represented. The general gradient of lava flows in the basin is around 1:550 to 1:800 towards SE. However, the exposures of alluvium with thickness range of 4-6 m are the quaternary formations exposed in the basin around Andhewadi (K) and near Handral along the stream.

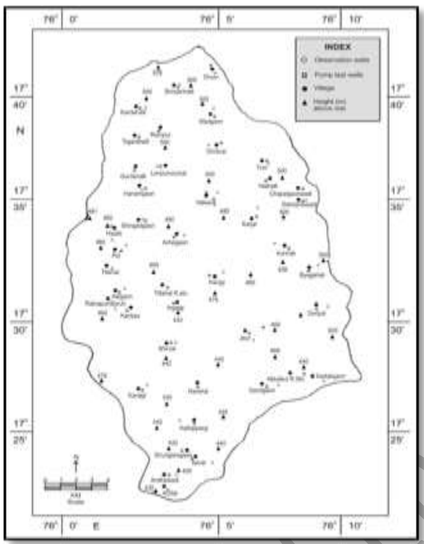

Fig. 1: Present Study Area.

4. METHODOLOGY AND DATA USED

4.1 Application of Geographical Information System (GIS) in Geo-morphometry:

The morphometric analysis is quantitatively done is the (ARC GIS 10.0) and ERDAS which is a powerful tool and it is advanced very easily measuring basin length, basin, area, automatic creating of drainage network, stream order, stream length, circular area of basin etc. Shows how to use in the creation of basin, delineation of drainage network, stream length, flow direction and stream orders Geena & Ballukraya (2011). Using Arc GIS technique the work of mapping, statistics, analysis, displaying the data and output is done. In the process of morphometric analysis Arc GIS tools like analysis tools (AT), conversion tools (CT) data management tools (DMT), Geostatistical tools (GT) and spatial analysis tools(SAT) etc. are used. Using all the tools, morphometric analysis of Dhubdhubi Odha basin is carried out quantitatively using Arc GIS 10.0 software.

Geographic information system (GIS) is a special type of information system in which the database consists of observation on spatially distributed features and procedure to collect, stores, retrieve, analyse and display such geographic data. Geographic information system (GIS) links map features with database attributes. The integration of digital mapping and data base capabilities is what sets geographic information system (GIS) apart from other information system

4.2 Methodology:

4.2.1 Data preparation:

The major goal of the study is to develop a viable methodology for producing geographic information system (GIS) data model for drainage morphometric analysis to discover holistic stream properties from the measurement of various stream attributes using Arc GIS software. The required necessary data sources for morphometric analysis were carried out through the use of survey of India (SOI) Toposheets of the area. The Toposheets were geometrically rectified and georeferenced by taking ground control points (GCPs) by using UTM projection and WGS 84 datum further, all the geocoded images were mosaic using Eardas imagine 2011 image processing software. After that digitization work has been carried out for entire analysis of the basin for morphometric analysis using Arc GIS 10.0 software.

4.2.2 Data analysis in geographical information system (GIS)

The order was given to each stream by following Horton (1969) stream ordering technique. The parameters like the number and length of stream of each different orders, drainage area, basin perimeter and basin length were calculated using Arc GIS software (10.0). From the above parameters drainage density drainage frequency, shape, form factor, circulatory ratio, elongation ratio etc. we calculated. The methodology adopted for the compotation of morphometric parameters is given below. With the help of covers ion tools in the Arc tool box; the data is converted into raster to vector form. Coverage tools and personal geodatabase tools were used in the area to estimate stream length. Topology tool was used to edit the line errors like polygon, point and node of overlapping and gap for accuracy. With the help of data management tools

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projection and transformation was made by registering of raster image with satellite image and topographical map. After this process bifurcation ratio, form factor, elongation ratio, drainage density, drainage frequency, steam frequency and drainage texture were analysed. The drainage basin analysis was carried out quantitatively aspects wise such as linear aspects, aerial aspect and relief aspect. The linear aspects, stream order stream length, bifurcation ratio, mean stream length, stream length ratio and mean stream length ratio were analysed. In aerial aspect, the basin area, drainage density, drainage frequency, infiltration number, drainage texture, form factor ratio, elongation ratio, circulatory ratio was calculated. In relief aspects, basin relief, relief ratio, dissection Index, channel gradient and basin slope were analysed. The method of calculation and the procedure involved in estimating each parameter is briefly descried.

4.3 Data Used

4.3.1 Morphometric analysis

The morphometric analysis is carried out through measurement of linear, aerial and relief aspects of the basin and slope contribution.

5. AERIAL ASPECT

Arial aspects (Au) of a water shed of given order u is defined as the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and includes all tributaries of lower order. Area of basin (A) and perimeter (p) are the most important parameters in quantitative morphology. The area of basin is defined as the total area projected upon a horizontal plane contributing to cumulate of all order of basins. Perimeter is the length of the boundary of the basin which can be drawn from topographical maps. The aerial aspects of the drainage basin such as drainage density (D), stream frequency (Fs), Drainage texture (Te) elongation ratio (Re), circulatory ratio (Rc), form factor ratio (Rf). Infiltration number were calculated and results have been given in table 2.

Table 1: Illustrates the formula for areal aspects.

Formulas for the parameters of Areal Aspects		
1	Basin Area (A)	Area from which water drains to a common stream and boundary determined by opposite ridges.
2	Drainage Density (Dd)	$Dd = L\mu / A$ Where, $L\mu$ = Total stream length of all orders. A = Area of the basin.
3	Drainage Frequency (Fs)	$Fs = N\mu / A$ Where, $N\mu$ = Total no of streams of all orders. A = Area of basin.
4	Infiltration Number (If)	$If = Dd * Fs$ Where, Dd = Drainage Density. Fs = Drainage Frequency.
5	Drainage Texture (Dt)	$Dt = N\mu / P$ Where, $N\mu$ = No. of streams in a given order. P = Perimeter.
6	Form Factor Ratio (Rf)	$Rf = A / Lb$ Where, A = Area of basin. Lb = Length of basin.
7	Elongation Ratio (Re)	$Re = \sqrt{A} / \pi / Lb$ Where, A = Area of Basin. Lb = Basin Length.
8	Circulatory Ratio (Rc)	$Rc = 4\pi A / P^2$ Where, A = Area of Basin. P = Perimeter.

Drainage Density

With the help of Horton (1932), the quantitative measures of the average length of stream channel for the whole basin is carriedout. The drainage density measurement made over a wide range of geologic and climatic types that a low drainage density is more likely to occur in region of highly resistant of highly permeable subsoil material under dense vegetative cover and where relief is low. The high drainage density is the resultant of weak or impermeable sub-surface material, vegetation and mountain relief. Low drainage density indicates to coarse drainage texture while high drainage density demarks to fine drainage

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texture (Strahler, 1964). Drainage density is controlled by the type of formation in the basin areas with impervious formation will have higher drainage density than those with pervious formations (Gokhale, 2005). In the study area Drainage density is 1.97.

Drainage Frequency

The basins of some drainage density differing the stream frequency and basin of the same stream frequency differing in drainage density. The stream frequency of the present study area is 2.19.

Drainage Pattern

The drainage pattern of the study area shows dendritic to sub parallel in nature (Fig. 2).

Drainage Texture

The value of drainage texture of the study area is 11.04 and it shows the very worse grain drainage texture. The high value of drainage texture and lower value of Drainage density (1.97) indicating the presence of highly resistant permeable material with moderate to high relief.

Form Factor Ratio

The value of form factor would always be greater than 0.78 for perfectly circular basin. Smaller the value of form factor, more elongated will be the basin. The form factor of the study area is 0.25.

Elongation Ratio

The elongation ratio of the study area is 0.07 and it generally shows the highly elongated shape. A circular basin is more efficient in the discharge of the run-off than an elongated basin (Singh and Singh, 1997).

Circulatory Ratio

It is the significant ratio which indicate the stage of dissection in the present study region. Its low, medium and high values have correlation with youth, mature and old stage of the cycle of the tributary watershed of the region and the value obtained. The circulatory ratio of the study area is 0.66.

Table No. 2: Illustrates Calculation of Areal Aspects of Drainage Basin

S. No	Morphometric Parameters	Symbols and Formulas	Results of the Study Area
1	Basin Area (sq.km)	A	478.67
2	Basin Perimeter (km)	P	95.34
3	Drainage Density	Dd = Lu / A	1.97
4	Stream Frequency	Fs = N / A	2.19
5	Infiltration Number	Dd x Fs	4.33
6	Drainage Texture	Σ Nu / P	11.04
7	Form Factor Ratio	Rf = A / (Lb)2	0.25
8	Elongation Ratio	Re = 2√ (A/π) / Lb	0.071
9	Circulatory Ratio	Rc = 4πA/P2	0.66

6. RELIEF ASPECT

Relief Ratio (Rf)

Difference in the elevation between the highest point of a watershed and the lowest point on the valley floor is known as the total relief of the river basin. Schumm (1956) found that sediments loose per unit area is closely correlated with relief ratios. In present study area, the value of relief ratio is 100. It is observed that areas with low to moderate relief and slope are characterized by moderate value of relief ratios. (Table 3) & (Fig. 3)

Fig. 2: Drainage Map of Dhubdhabi Watershed Area.

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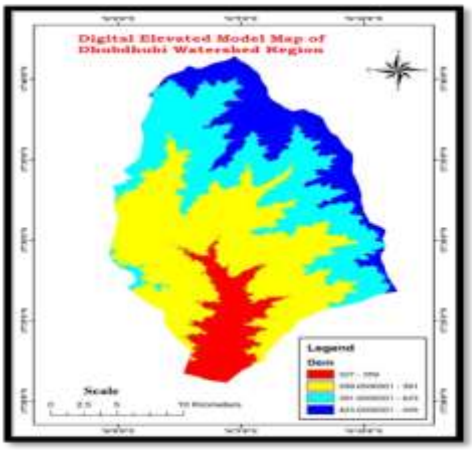

Fig. 3: DEM Map of Dhubdhubi Watershed Area.

Channel Gradient (Cg)

The total drops in elevation from the source to mouth were found for the Dhubdhubi basin and horizontal distances are measured along the channels. Author has drawn the longitudinal profile which are 4.15 m/Kms. It is seen from that the mean channel slope decreases with increasing order number. These tests valid the Horton's Law of stream slopes.

Ruggedness Number (Rn)

Ruggedness number is the product of the basin relief and the drainage density and combines slope steepness with its length. The Dhubdhubi basin has a ruggedness number of 19.7, the low ruggedness value of watershed suggest that area is less prone to soil erosion and have intrinsic structural complexity in relationship with relief and drainage density.

Gradient Ratio (Rg)

Gradient ratio is display of channel slope, which enables assessment of the runoff volume (Sreedevi et al, 2005). Basin has an Rg of 2.28, which reflects the mountainous nature of the terrain.

Comparison of Drainage Basin Characteristics

The details of the morphometric investigation and comparison of drainage basin characteristics of Dhubdhubi watershed are present in Table No 3.

Table No. 3: Illustrates Calculations of Relief Aspects of Drainage Basin.

Sr. No.	**Morphometric Parameters**	**Symbols and Formulas**	**Results of the Study Area**
1	Basin Relief	H = Z – z	100
2	Relief Ratio	Rf = H / Lb	2.28
3	Basin Slope	Bs= H / Lb	2.28
4	Channel Gradient	Cg = H / (π / 2) * Lb	4.15
5	Ruggedness number (Rn)	Rn = Dd * (H /1000)	19.7

7. GROUNDWATER FLUCTUATION STUDIES

The unconfined aquifers are developed due to weathering of upper vesicular/zeolitic flow unit of basalts and jointed/fractured basalts (CGWB 2005). The unconfined aquifers to understand the behavior of groundwater levels in the Dhubdhubi basin, 38 observation wells (Fig. 1) are monitored and water levels were recorded on monthly basis for 5 years starting from July 2012 to May 2017. The wells were selected such that they represent weathered formation, jointed/fractured basalts and vesicular/zeolitic basalts. The rainfall and groundwater level fluctuations are shown in Fig. 4.1 to 4.6, from which the following observations are made:

The pre-monsoon water levels in weathered formations (Fig. No. 4.1 and 4.2) range between 7.60 m below ground level (mbgl) at Kardehalli and 14.50 m at Limbichincholi. This indicates that pre- monsoon water levels of the basin are always below 7.6m in the weathered formations.

The post-monsoon water levels in the weathered formation (Fig. No. 4.1 and 4.2) range between 2.25 m bgl at Kardehalli and 8 m bgl at Limbichincholi.

Water levels in wells from jointed /fractured basalts (Fig. No. 4.3 and 4.4) range between 5 m bgl at Dahitanewadi and 14 m bgl at Karajgi during pre-monsoon season and between 2 m bgl at Dhotri to 8 m bgl at Dodyal, during post-monsoon season.

The vesicular / zeolitic formations (Fig. No. 4.5 and 4.6) have water levels between 7.20 m bgl at Hipale and 13.80 m bgl at Gaudgaon (B) during pre- monsoon and that for the post-monsoon are 2 m bgl at Hiple and 7 m bgl at Auj.

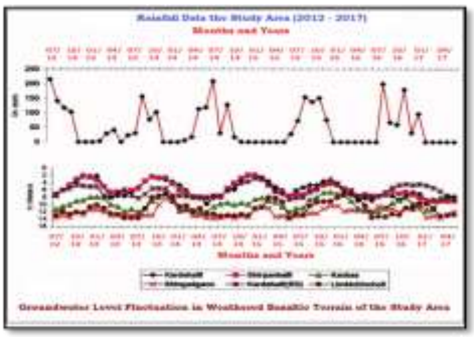

Fig. 4.1: Rainfall Data of the Dhubdhubi area [2012-2017]. (Kardehalli-Shirpanhalli-Kanbas-Shingadgaon-Kardehalli RD-Limbichincholi)

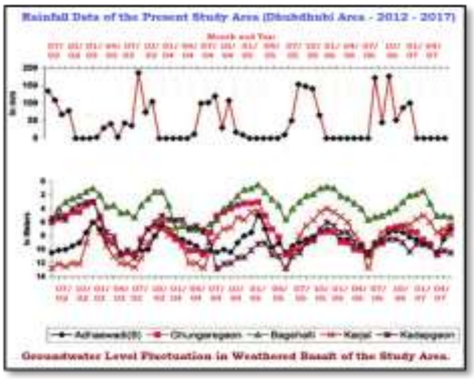

Fig. 4.2: Rainfall Data of the Dhubdhubi area [2012-2017]. (Adhaewadi B-Ghungaregaon-Bagehalli-Karjal-Kadapgaon)

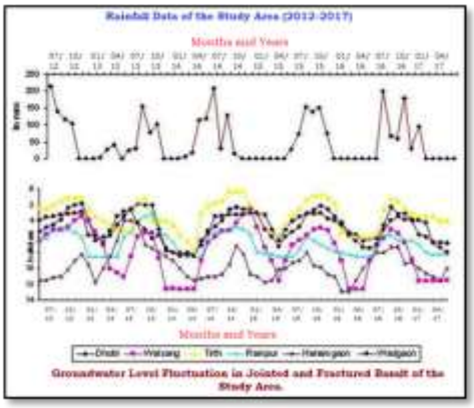

Fig. 4.3: Rainfall Data of the Dhubdhubi area [2012-2017]. (Dhotri-Walsang-Tirth-Rampur-Hanemgaon-Wadgaon)

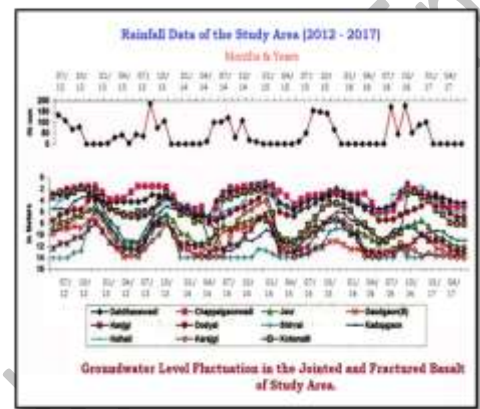

Fig. 4.4: Rainfall Data of the Dhubdhubi area [2012-2017]. (Dahlthanewadi-Japalgaonwadi-Jeur-GaudgaonB-Hanjgi-Dodyal-Shirwal-Kapadgaon-Halhalli-Karajgi-Kohanhalli)

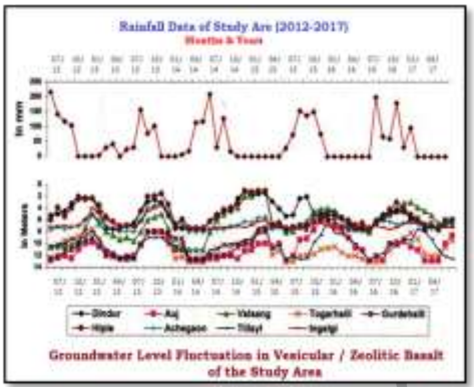

Fig. 4.5: Rainfall Data of the Dhubdhubi area [2012-2017]. (Dindur-Auj-Walsang-Togarhalli-Gurdehalli-Hiple-Achegaon-Tillayl-Ingalgi)

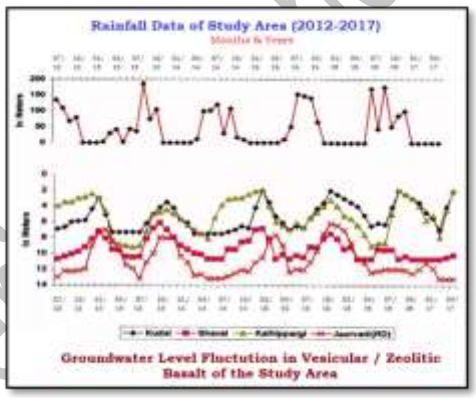

Fig. 4.6: Rainfall Data of the Dhubdhubi area [2012-2017]. (Kudal-Shaval-Kalhippargi-Jeurwadi RD)

8. LAPS TIME STUDIES FOR MAXIMUM RAINFALL AND RISE IN GROUNDWATER LEVEL:

The groundwater recharge system, rainfall becomes the feeding source, water precipitated on the surface of the earth, percolates in groundwater system through infiltration from the rock strata. There is a lag between the peaks of rainfall and water level rise in the wells, this lag authors assume as *'laps time for rise'*. Similarly, this rise in water level in absence of rainfall begin to fall, the maximum fall of water level also has a lag, this authors state as *'laps time for fall'*, these laps times for rise and fall are shown in Fig. 5, the time required for water level to get maximum and minimum saturated thicknesses helps in understanding the rate of rise and fall in water levels.

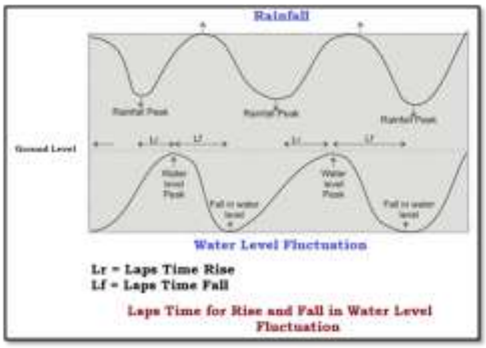

Fig. 5: Laps Time for Rise and fall in Water Level Fluctuation.

The lap's time for rise and fall as recorded for two rain fall zones in the basin are described in the following:

a) Akkalkot Rainfall Zone:

1) Lapse time for maximum water level rise after rainfall peak for all the three geological formations are between three and four months.
2) Average Lapse time for maximum water level fall is six months.

The fluctuations in water levels for different formations are as follows.

Jointed/fractured basalts 3.6m
Vesicular/zeolitic basalts 2.8m
Weathered formations 3.4m

b) South Solapur Rainfall zone:

1) Lapse time for maximum water level rise after rainfall peak is between two and four months for jointed/ fractured basalts whereas for vesicular/ zeolitic formations and for weathered rock, it is between three and four months.
2) Lapse time for maximum water level fall is six to seven months for fractured basalt and for Vesicular/ Zeolitic basalt and weathered formations it is between five and six months.

The average fluctuation in the water level for different formation is as follows:

Jointed/fractured basalts 4.2m
Vesicular/zeolitic basalts 3.4m
Weathered formations 4m

9. AQUIFER PERFORMANCE TEST:

Aquifer Performance Test:

The pump test on 32 observation wells having weathered, jointed, fractured, and vesicular/zeolitic rock types are carried out initially by using the modified Cooper Jacob method (1948). The values of transmissivity and storativity acquired are used as initial values to archive the refinement by the computer aided method (Gupta and Singh, 1988). The results of the aquifer tests are given in Table 5. It can been illustrated from the results that transmissivity (T) varies between 9 m^2/day and 368 m^2/day and storativity from 3.33×10^{-5} to 7.70×10^{-2}, the values are higher where the rocks are weathered, highly jointed, fractured and occurrence of zeolitic basalts within the streams.

10. VADOSE ZONE STUDIES:

Vadose zone is that part of the aquifer which is unsaturated and lies between ground surface and water table. This zone is potential for recharge. More the Vadose zone more is the scope for recharge. The volume of saturation involved in the process of change in saturation in Vadose zone (Zone of weathering) is far larger than the changes in volume of water involved in the elastic storage of water below the water table. Therefore the dynamic resource in groundwater reservoir is governed by the "Vadose Zone" through which water level fluctuates. Therefore information regarding water saturation, thickness and permeability of vadose zone / weathering zone are to be known before going for recharging schemes (CGWB 1994 and 2002, Kolhe and Sathe, 2019 a&b). For Dhubdhubi basin, the thickness of the Vadose zone for pre and post-monsoon period are observed and presented in figure 6 and 7, respectively.

Figure 6, represents the pre – monsoon vadose zone in which the following features are observed:

1) There are four zones (H1, H2, H3, and H4) with high vadose thickness, one on the north, one at the center and two are on the south. These are potential regions for artificial recharge.
2) There are two regions with low Vadose zone thickness, one on the north and the other in the south. These are less suitable for artificial recharge.

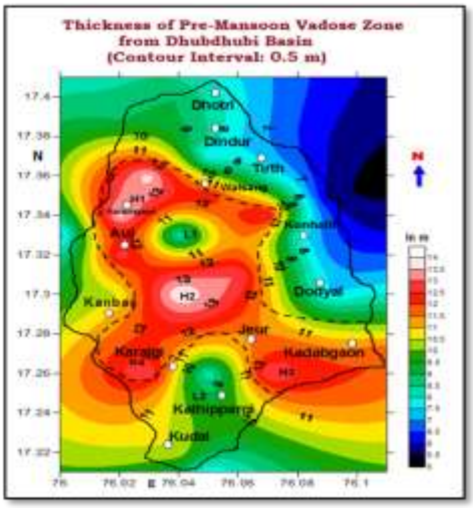

Fig 6: Thickness of Pre-Monsoon Vadose zone for the study area.

Figure 7, represents the post – monsoon vadose zone in which the following features are observed:

1) There are three regions with Vadose zone thickness (>5 m) shown as H1, H2 and H3 with a NW-SE trend. The central region (H2) is thicker.
2) The southern part (L) has vadose zone thickness less than 1m.

11. CONCLUSION

The study reveals that GIS based approach helps the analysis of different morphometric parameters and to enhance the affiliation between the drainage morphometry and properties of landforms. The morphometric analysis of drainage network of the watershed showed dendritic with moderate drainage texture. The bifurcation ratio in the watershed indicates the normal watershed category and the presence of moderate drainage density suggesting that it has moderate permeable sub-soil and coarse drainage texture. The value of form factor and circulator ration suggests that Dhudhubi watershed is less elongated. Hence, from the present analysis it can be concluded that Cartosat (DEM) data, coupled with GIS techniques can help in morphometric analysis (More et al, 2013 and Patki et al, 2013).

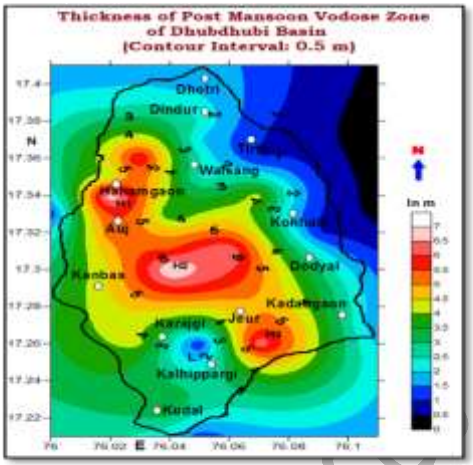

Fig 7: Thickness of Pre-Monsoon Vadose zone for the study area.

Following are the conclusions derived from above all studies:

- ✓ The drainage densities calculated for whole basin is 1.97 indicating the probability of branching of streams. The bifurcation ratio varies between 2.33 to 5.57. Generally high bifurcation ratios indicates the geological and structural control. The variation of bifurcation ratio within the successive phase of drainage order could be due to change in irregularly and variation in a change of stream network and structural control of the Dhubdhubi basin.
- ✓ In the present study GIS software is used to preparation of Base map, elevation map and base map of Dhubdhubi basin. The elevation map basically used for the calculation of slope.
- ✓ The Dhubdhubi basin represents three sets of confined aquifers, formed by basal clinker, vesicular/zeolitic and jointed/fractured basalts which are sandwiched between the compact basaltic flows. The aquifers formed by vesicular/zeolitic unit and weathered basalt, shows less seasonal variations in water levels and the water table rise after the rainfall peak, which takes two to three weeks. This shows relatively high permeability for these formations. Aquifers formed by jointed and fractured basalts shows water level fluctuations of several meters. The deepest water level 14m, below surface, is observed during pre-monsoon and the minimum depth of water table is 1m, below ground level for post-monsoon periods.
- ✓ It has been observed from the results of the aquifer test that the transmissivity (T) varies

between 9 m^2/day and 368 m^2/day. Storativity (S) ranges between 3.33×10^{-5} to 7.70×10^{-2}. The values are higher where the weathered highly jointed, fractured and vesicular / zeolitic basalts, forms the litho sections along the streams, which shows preferred flow paths. This confirms that hard rock formations normally show heterogeneous character.

- ✓ Pre- monsoon water levels in the basin are always 7.6 m, below ground level and that for post–monsoon the range is between 1 and 8 m, below ground level. There are four zones with high vadose zone thickness in the north, central and southern zones of Dhubdhubi basin.
- ✓ It is observed that if the depth to water table is more than 4 m, below ground level during post- monsoon and the areas having more than 4 m, difference between pre and post – monsoon are suitable for artificial recharge, on this basis 61% of the total area is favorable for artificial recharge/groundwater harvesting in Dhubdhubi basin. It is also observed that there are three regions during post – monsoon having more than 5m; thickness of Vadose zones which are favorable for artificial recharge, on this basis 60 to 62% area in the basin is favorable for artificial recharge.

Table 5: Transmissivity and Storativity from Aquifer test analysis for the different locations in the Dhubdhubi Basin.

Sr. No.	Q. No.	Well No.	Lat	Long	Village	T	S	Lithology
1	2	1	17.40	76.04	Shripanhalli	224.64	0.003358	Weathered Basalt J/F
2	3	2	17.41	76.05	Dhotri	60.72	0.0340	F/J Basalt
3	5	3	17.39	76.04	Kardehalli	82.17	0.00442	Weathered Basalt J/F
4	6	4	17.39	76.05	Wadgaon	76.58	0.04533	F/J
5	9	5	17.35	76.02	Hanamgaon	335.00	0.7700	Zeolitic Basalt
6	10	5	17.37	76.05	Dindur	368.018	0.03617	Zeolitic Basalt
7	11	7	17.36	76.07	Tirth	56.56	0.02198	F/J Basalt
8	13	8	17.33	76.02	Hiple	64.38	0.00046	Zeolitic
9	14	9	17.34	76.02	Shigadgaon	136.00	0.059	Weathered Basalt
10		10	17.33	74.04	Achegaon	28.83	0.00030	Zeolitic Basalt
11	15	11	17.39	76.05	Walsang	12.00	0.008	Massive Basalt
12	16	12	17.34	76.07	Karjal	53.31	0.000333	Massive Basalt & weathered Basalt
13	17	13	17.35	76.09	Dahitanewadi	210.00	0.056	Massive Basalt & J/F
14	19	14	17.32	76.02	Auj	79.51	0.00047076	Zeolitic Basalt
15	20	15	17.32	76.01	Tillehal	26.81	0.0024949	Zeolitic Basalt
16	21	16	17.31	76.06	Hanjgi	42.60	0.020063	Zeolitic Basalt
17	22	17	17.33	76.08	Konhalli	124.34	0.0342	Weathered Basalt
18	23	18	17.32	76.09	Bagehalli	283.00	0.0652	Massive Basalt
19	25	19	17.30	76.01	Alegaon	9.00	0.033	Weathered Basalt
20	26	20	17.30	76.02	Kanbas	84.65	0.001032	Weathered Basalt
21	28	21	17.29	76.06	Jeur	21.00	0.085	Zeolitic & Massive Basalt
22	29	22	17.30	76.11	Dodyal	15.00	0.018	Massive Basalt
23	31	23	17.28	76.04	Shirval	163.00	0.048	J/F Basalt
24	32	24	17.26	76.05	Handral	108.00	0.020	Zeolitic Basalt
25	33	25	17.26	76.07	Gaudgaon	115.00	0.039	Zeolitic & Massive Basalt
26	34	26	17.27	76.09	Kadabgaon	119.38	0.04276	Weathered Basalt
27	36	27	17.26	76.03	Karajgi	63.74	0.075048	Massive Basalt
28	37	28	17.25	76.05	Kalhippargi	175.00	0.052	Zeolitic Basalt
29	40	29	17.22	76.04	Andhewadi	98.00	0.034	Weathered Basalt
30	41	30	17.23	76.05	Shaval	51.68	0.027	Massive Basalt & Zeolitic
31	42		17.22	76.04	Kudal	275.040	0.075	Zeolitic Basalt
32	43	9	17.35	76.02	Limbi – Chincholi	51.75	0.03055	Weathered Basalt J&F

*** J & F – Indicates –** Jointed or Fractured Basalt

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