CHAPTER-7

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Sitanadi is one of the important west flowing rivers in Udupi district. It covers an area of approximately 643.65 sq km. It takes its origin in the Western Ghats and flows along the steep slopes of high land region before joining the Arabian Sea. The data collected in the field, various literature, different organisations and analysis pertaining to hydrometeorology, hydrology, morphometric analysis, water and soil quality and spatial data generation forms a database of the study area. The data collected during the period of study are analysed and the results obtained are discussed below.

Hydro meteorological data from 1970 to 2008 reveals that in July month the average relative humidity is more and it reaches nearly 97% and minimum of 41% in the month of January. The maximum and minimum temperatures are observed in the month of April (35.5°C) and January (18.5°C) respectively. Due to higher atmospheric temperature, pan evaporation is also high (6.09mm/day) in the month of May and low (2.71mm/day) during September.

Rainfall data from 1067 -2009 from six rain gauge station which are situated in and around the basin are statistically analysed. Average depth of rainfall over Sitanadi basin computed from arithmetic mean, Thiessen polygon and isohyetal methods are 4923, 4832 and 4759mm/year respectively. The rainfall data shows Agumbe station receives maximum rainfall of 7707mm/year and minimum of 3705mm/year at Kota station located along the west coast. The rainfall increases from coast towards Western Ghats in the east. July month on an average receives highest rainfall and February month receives minimum rainfall.

Station wise annual PR indicates lower PR for Haladi station and highest for Agumbe. The PR value indicates stable rainfall over the basin.
Season wise rainfall statistics shows large variations. During monsoon season Agumbe station has minimum and in Haladi and Ardi stations it is more. Large variation indicates abnormality during PRM and POM seasons.

On an average, nearly 90% of the annual rainfall occurs during monsoon season (June to September) and monsoon rainfall is highly dependable (CV = 19.5%) and in PRM (338%) and POM (251%) it is undependable.

Decadal rainfall departure from normal is observed as excess and deficit during all the decades. In general, the rainfall decrease is observed during the period from 1970 to 2000 and slight increase from the year 2000 to 2009. During the decade there is excess and deficit rainfall in all the stations. In case of percentage of deficit rain fall years there is fluctuations between the successive decades and in the last decade (2001-2009) there is sharp increase in the percentage of deficit rainfall years. Regarding to the percentage of normal rainfall years it increased from the year 1970-71 up to 1999-2000. In the last decade, from the year 2001-2009 there is a drop in the percentage of normal rainfall years.

In the month of June an increase of about 6 to 7% is observed from 1991-2000 to 2000-2009 in all the rain gauge stations and decrease in rainfall (about 10%) in the month of July from 1991-2000 to 2000-2009 in all rain gauge stations. In September and October months, increase in rainfall is noticed from 1970-80 to 2000-09 in all the rain gauge stations. All the rain gauge stations show almost uniform trend in percentage contributions between the decades to decade.

According to Standardized precipitation index calculated for the data available period shows that in Kota and Ardi (2.38%) stations experience extreme drought. Severe drought cases are observed in all the rain gauge stations except in Haladi. Percent of severe drought varies from 7.14% (in Brahmavara and Sitanadi stations) to 2.38% in Kota and Ardi.
Groundwater level fluctuation data for 22 years for dug wells and tube wells reveals that there is annual cyclic variation in the water table. In general, the water table reaches its maximum during the month of July and minimum in the month of May. Seasonal variation in water level indicates that during wet season, the water table rises at a faster rate due to highly porous geological formations and gradually decrease in water table takes place due to groundwater discharge and withdrawal.

Regression lines drawn for the log values log stream numbers and stream length versus stream order for the whole basin as well as for the sub-watersheds shows nearly a perfect correlation and follows Horton's laws. The stream length ratio indicates that the fourth order streams in the sub-watersheds flows over more permeable ground surface than the lower order streams and are governed by both geomorphological structural factors. Lower values of bifurcation ratio suggest that the sub-watersheds are less disturbed than those with high bifurcation ratio values. Some of the sub-watersheds situated on the steep ground slopes have shorter flow paths with high surface runoff and less infiltration. Computed values of elongation ratio for the sub-watersheds shows that they vary in shape from elongated to circular. Since the drainage density of the sub-watersheds vary from 1.52 to 4.23 km/km² revels that the nature of subsurface strata is permeable which characteristic feature is of course/very course drainage. Drainage texture in the sub-watersheds follows drainage density.

Low stream frequency values indicate that the regions with low relief with permeable subsurface and high stream frequency values indicate less permeable strata, sparse vegetation and high relief.

In view of understanding the quality of groundwater, two sets of groundwater samples were collected from 56 dug wells during POM and PRM seasons and are subjected to physic-chemical analysis. Based on the standards prescribed by WHO and BIS for drinking water standards, majority of the water samples are found within the desirable limits and only few samples are within maximum allowable limits. Hence, they are suitable for drinking purpose.
Spatial variation maps prepared for the study area using geochemical data also indicate variation in quality during POM and PRM seasons. The variation during POM season is mainly because of leaching of salts, fertilizers and chemicals in the wet season. In coastal wells, salinity has increased marginally during PRM season.

Quality of water for irrigation purpose also indicates that majority of water samples are suitable for irrigation on all types of crops and soil conditions. With reference to sodium hazard and magnesium hazard some well water samples are not suitable for irrigation purpose. In such situations suitable amendments has to be proposed. USSL salinity diagram and Wilcox diagram for classification of irrigation water clearly shows the water is excellent for irrigation purpose.

Chloro-alkaline indices indicates that cation exchange takes place because of the presence of clay in the study area that are formed due to weathering of silicate minerals. Chadha diagram depict that the water samples of PRM seasons fall under the subdivision of alkaline earths exceed alkali metals and weak acidic ions exceed strong acidic anion - Ca – Mg – HCO₃ water type.

The Pearson correlation matrix generated shows that pH has negative correlation with SO₄²⁻ and Mg²⁺ during PRM season. EC shows strong correlation with TDS, TH, Cl⁻, NO₃⁻, Na⁺, and moderate correlation with HCO₃⁻, SO₄²⁻, Ca⁺, K⁺, Mg²⁺ in PRM. In POM, EC showed strong correlation with TDS, TH, Cl⁻, Na⁺ and moderate correlation with HCO₃⁻, SO₄²⁻, Ca⁺, K⁺, Mg²⁺ and NO₃⁻. Both PRM and POM results indicating that most of the ions are involved in physico-chemical reactions such as oxidation-reduction and ion exchange and also indicating their origin from the same source. The results of high correlation indicate impact of agricultural activity and sea water intrusion/ingression leading to increase in salinity in the area. Moderate correlation between various parameters in both seasons indicates a possible ion-exchange process in the aquifer system. The leaching of sodium and potassium from schist’s and granites is the main source of alkali enrichment.
The results of factor analysis for PRM data set provided three factors with Eigen value greater than one (Table 5.12b). That explains approximately 81.458% of the variability of the data. The variance explanations of the factors are 40.072% for factor 1 (with variables Na⁺, Cl⁻, NO₃⁻, K⁺, EC, TDS, have high positive loadings and SO₄ have medium positive loading), 30.414 % for factor 2 (with variables HCO₃⁻, Ca⁺, and TH have high positive loading and EC, pH and TDS have medium positive loadings) and 10.972 % for factor 3 (with variables Mg²⁺ have high positive and pH have medium negative loading).

The results of factor analysis for POM data set provided two factors with Eigen value greater than one (Table 5.13b). That explains approximately 65.085% of the variability of the data. The variance explanations of the factors are 40.121% for factor 1 (with variables EC, TDS, Na⁺, Cl⁻, Mg⁺ and TH have higher positive loading and SO₄²⁻ and NO₃⁻ have medium positive loading), 24.964 % for factor 2 (with variables higher positive loading of Ca⁺, and HCO₃⁻ with medium positive loading of K⁺).

All together in PRM and POM three different processes that are responsible for various component loadings are

1. Geological effects (due to weathering) and other processes.
2. Seasonal effects, i.e., monsoon prevailing in the study area.
3. Agricultural sources (fertilizers and micronutrient fertilizers).

Based on Hierarchical cluster analysis (HCA), groundwater samples were clustered into three groups of similar characteristics in terms of water quality. Dendrogram generated for Sitanadi basin shows 3 major groups of wells in the study area for both seasons.

Groundwater quality index of water samples in Sitanadi basin varies from 3.81 (well no-49) to 17.43 (well no-42) and 4.98 (well no-47) and 21.77 (well no-19) in PRM and POM season respectively and are found to be of excellent quality in PRM and POM seasons.
The WQI study thus gives an overview of drinking water quality of groundwater in the study area and it identify water quality indicators would help to concentrate on few attributes during regular water quality check-up process such as Sulphate, Sodium and Calcium. This saves time, energy and expenditure to a great extent without compromising on the quality of output.

The pH value of the soil samples in the study area varies from 4.5 to 5.9 and 4.8 to 5.8 in PRM and POM seasons respectively and majority of the samples are strongly acidic. Because of acidic nature of the soil, the availability of nutrients such as Nitrogen, Phosphorus, Sulphur, Calcium, Magnesium and Molybdenum are restricted to crops, even if the quantity of these nutrients are adequately present in the soil. In uptake of other plant nutrients such as Potassium, Iron, Manganese, Boron, Copper and Zinc are unaffected since these nutrients can be drawn by the plants even at low soil pH in the basin.

Nutrient index of macronutrients in Sitanadi basin indicates it is medium in respect of organic carbon and available phosphorus where as for available potash it is low. Potash can be supplemented by external application. Soil-water-crop compatibility indicates good compatibility in respect of four locations and moderate in respect of one.

The availability of high-resolution satellite data at frequent intervals for IRS satellites provides sufficient timely reliable information for the watershed development. The satellite data can be effectively utilized beginning from prioritization work to generation of natural resources data base and action plans in GIS environment.

The IRS LISS IV + PAN merged data of 2005 and 2009 data was geometrically corrected and re-sampled taking toposheets as reference. Land use/land cover classification based on image characteristics such as tone, texture, size, shape, association and field knowledge was followed to delineate various land use/land cover categories. The interpreted details were then ground checked to verify the doubtful areas and based on the ground verification, land use and land cover units were finalized.
In the study area, six classes of LULC under level I and 19 classes such as Village, Kharif crop, Kharif + Rabi (Double Crop), Fallow land, Agricultural Plantation, Evergreen / Semi-evergreen Dense Forest, Scrub Forest, Degraded Forest, Dense Grass Land/Grazing Land, Barren Rocky / Stony Waste / Sheet Rock Area, Land with scrub, Sandy area, Lake / Tanks, River / Stream, Aquaculture ponds, Habitation with Vegetation, Mixed Vegetation, Tree Groves and Marshy / Swampy Area have been identified under level III.

In the study area 81% of the basin is covered by Tree Grooves occupies approximately 205 sq km area of the basin followed by Evergreen / Semi-evergreen Dense Forest (179sq km) and Kharif crop (137sq km). Similar to whole basin, LULC for twenty sub-watersheds were also calculated. In all the sub-watersheds tree groves are present. Whereas, other classes of land use and land cover are not present in all the sub-watersheds.

From land use land cover analysis of sub-watersheds, it is found that from the coastal region towards the Ghats, the land use land cover classes goes on decreasing and in the Western Ghats region we find three classes only.

By visual interpretation, geomorphic units/landforms are mapped at basin and sub-watershed level. The basin area has been classified into fifteen major geomorphic units/landforms such as Alluvial Plain Shallow (AOS), Back Swamp (BS), Butte (B), Channel Island (CI), Coastal Plain (CP), Dissected Pediment (DPD), Dyke ridge (DR), Lateritic Plain Shallow (LPS), Mesa (M), Pediment (PD), Pediplain Shallow Weathered (PPS), Structural Hills (SH), Valley (V), and Valley Fills (VF).

Dissected Pediment (DPD) in which groundwater prospects is poor occupies nearly 228sq km of the basin which constitute about 35% of the geographical area of the basin. This is followed by Structural Hills (SH) is also Poor to Nil with respect to groundwater is concerned. This unit of landform occupies about 154 sq km (24%) of the geographical area. Valley
Fills (VF) is very good from the point of view of groundwater prospects and occupies about 72 sq km (11%) of the basin area. Other landform such as Valley (V) (67 sq km), Pediplain Shallow Weathered (PPS) (60 sq km) and Lateritic Plain Shallow (LPS) (35%) in which groundwater prospect is very good to moderate occupies majority of the basin area. Rest of the landforms will constitute less than 0.02% of the geographical area of the basin.

From this it is concluded that in nearly 50% of the basin groundwater prospect is good. In spite of it some of the regions face acute shortage of water during summer months due to discharge of groundwater in highly porous geological formations.

Geomorphological/landforms are also identified in the sub-watersheds. In sub-watershed such as SWS -12, SWS -13, SWS -14 and SWS -15 it is completely covered by structural hills in which groundwater prospects is poor.

The soils of the Sitanadi are classified in to six types of soils such as Soils of high hill range, Soils of Undulating uplands, Soils of coastal plateau summits, Soils of Bars and Ridges, Soils of marshes and Soils of Beaches. Some of the soils are well drained and others like clay are poorly drained.

Overexploitation of groundwater and inadequate aquifer recharge has depleted the groundwater potential in different parts of the world. Hence, the need for groundwater management and the conservation at watershed level has gained importance worldwide. Therefore, in the present study we have tried to prioritize the sub-watersheds in Sitanadi basin by different approaches. They are based on morphometric parameters, and geomorphology/landforms.

In, morphometry, linear/areal parameters (bifurcation ratio, drainage density, drainage texture and stream frequency) and shape parameters (form factor, elongation ratio, circularity ratio, and shape factor) are used for prioritization of sub-watersheds for development of groundwater.
Based on these morphometric compound values, the sub-watersheds are prioritized. The sub-watershed compound parameters based on morphometry varies from 5 to 13.5. Based on compound parameters, the sub-watersheds are given priority numbers. Priority 1 indicates that the sub-watershed is poor in groundwater prospect and priority 20 indicates high groundwater potential in Sitanadi basin. Hence, first priority should be given to low priority value sub-watersheds to improve the groundwater potential.

For soil conservation measures morphometric parameters such as bifurcation ratio, drainage density, stream frequency, form factor, circulatory ratio, elongation ratio and constant of channel maintenance were used in the present study.

Based on compound parameter values, the sub-watersheds are prioritized from 1 to 20 in Sitanadi basin. The compound parameter values for sub-watersheds vary from 3 to 15. In eleven sub-watersheds the values are less than ten and in others it is more than ten. Based on these values, prioritization values are assigned to sub-watersheds for conservation of soil. Priority 1 indicates that the sub-watershed has high rate of soil erosion and priority 20 indicates low rate of soil erosion in sub-watersheds of Sitanadi basin. Hence, priority should be given first to low priority value sub-watersheds to conserve soil.

In the present study, to identify locations for construction of check dams for conservation of soil and water in the basin, thematic layers such as slope, land use land cover and streams are used. The shape files were converted into grid format. Using the map query in ArcView 3.2 version GIS software, different conditions were applied to identify the check dam positions and identified 19 locations. Among these check dams two will on the first order streams and rest will be on third order streams. Before construction of check dams soil properties like porosity, permeability and thickness of soil layers are to be considered.