CHAPTER - 03
METHODOLOGY

The sub-basins in the Central part of Suvarnamukhi river basin fall in the central dry zone of Karnataka state. As per previous literature Suvarnamukhi river is a non-perennial river which flows for not more than four months during the monsoon season. Groundwater is being used in this area for all purposes irrespective of the seasons for many years. Hence it is important to suggest appropriate strategies for proper development and management of groundwater in this area.

Groundwater development and management is an area specific problem. Replication of these techniques can be done only if the local hydro-geological and hydrological environments match. In the present study, the following criteria are identified and followed.

- Determination of water source and its long-term trend.
- Assessment of the available water resources and studying the long-term trend.
- Understanding the hydro-geological conditions of the area and identification of groundwater prospect zones.
- Understanding the quality of water in the area and vulnerability mapping.
- Identification of areas suitable for artificial recharge of groundwater.
- Suggesting suitable strategies for groundwater development and management.

The methodology followed is presented in Fig. 3.1.
3.1 PREPARATION OF BASE MAP AND DRAINAGE CHARACTERISTICS

Initially, the study area was demarcated using survey of India toposheets bearing No. 57C and 57G of 1:250,000 scale and 57C/9, C/10, C/11, C/13, C/14, C/15, G/2 and G/3 on 1:50,000 scale. The drainage extracted from these toposheets were exported to GIS environment and the outer boundary delineated based on the surface drainage characteristics.

The drainage network of a basin reflects the groundwater conditions of the area. The morphometric analysis of the drainage network is related to the recharge characteristics. The drainage thus extracted is analyzed based on Strahler’s stream ordering for all the five sub-basins and also to the area draining to the main stream in the north of the study area. The drainage network thus obtained is updated from satellite imagery using ERDAS Imagine software.

The remotely sensed digital data used in the study are the IRS 1C and 1D geocoded FCC of both LISS III and PAN merged data. The resolutions of the data used are 23.5m and 5.8m for LISS and Pan respectively (Available data from KSRSAC).

Various morphometric parameters like linear, areal, shape and relief aspects are determined for all the five sub-basins. Using a statistical procedure called random sampling technique, fifty watersheds of third order are selected. The morphometric parameters for all the third order basins are calculated and further used for preparation of drainage density map. The Principal Component Analysis (PCA) of this data is also carried out.

The drainage density of the area explains the recharge characteristics of any terrain. Hence drainage density map of the area is generated determining the drainage density of fifty watersheds of third order. These values are assigned to
the centre point of the watershed and are converted to polygons in the GIS environment.

The PCA considering fifteen geomorphic parameters is carried out. PCA is performed to identify the components contributing to the data structure and to determine the interrelationships among the parameters. In the present study, PCA is attempted using the statistical software SPSSWIN. Initially, a correlation matrix is calculated using the geomorphic parameters for all the watersheds. The correlation matrix indicates that some of the information available in one variable is also contained in some of the other remaining variables. More specifically, the first principal component is that linear combination of the original variables which contributes the maximum to their total variance. The second principal component, uncorrelated with the first, contributes the maximum to the residual variance, and so on until the total variance is analyzed. This explains the limited interrelationship of geomorphic parameters. Hence, using the above correlation matrix, the principal component loading matrix is determined. From the above analysis, the parameters having Eigen value greater than one are identified. This Eigen value indicates how well each of the identified factors fit the data from all the geomorphic parameters on all the principal components.

3.2 HYDROMETEOROLOGICAL DATA

Rainfall being the primary source of water in any region is one of the important inputs for groundwater. Monthly rainfall data from 14 rain gauge stations from 1901 up to 2007 was collected from the Department of Economics and Statistics, Government of Karnataka. The existence of a trend is determined through Mann-Kendall non-parametric test. The periodicities in the rainfall data are determined using moving averages and auto correlation methods. The above two analyses are done using the statistical software SPSSWIN. Meteorological data such as temperature, wind speed, relative humidity from 1985-2007 are
collected from the Indian Meteorological Department, Bangalore. Using the
temperature data, the climate type of the area is determined (Krishnan 1991).

The meteorological drought of the area is assessed based on the Indian
Meteorological Department method. In the present study an attempt has been
made to assess drought using 3 different methods, viz., Parthasarathy method
(1987), IMD Method and Standardized Precipitation Index method modified by
Bhuiyan et.al, (2006). Meteorological drought in the area is assessed using 25
years rainfall data (1983 – 2007) of the 12 raingauging stations in and around the
study area.

3.3 HYDROGEOLOGICAL CONDITIONS

Understanding the hydrogeological conditions of the area is a prerequisite
in any study on groundwater management as it influences the amount of water
recharged to the underlying aquifer from the surface. The hydrogeological
condition of the area is determined by preparing various thematic maps like
geology, structure, landuse/land cover, slope, landforms etc.

The geological map of the study area is extracted from the district resource
maps of Tumkur and Chitradurga (GSI, 2000). This map is further upgraded by
overlaying it on the satellite imagery using image interpretation keys. The
geomorphic units have been delineated based on the technical guidelines of Rajiv
Gandhi National Drinking Water Mission (NRSA, 2000). The landuse/landcover
map is generated using supervised classification by assigning suitable training
sites. The lineament map is prepared by superposing the drainage map on the
satellite data. The lineament map is then superposed on the landforms map and the
lineaments are classified into three classes to understand their effects on
groundwater prospecting. The ground verification of the interpreted data has been
carried out in the field and necessary modifications are incorporated in the final
thematic maps. The soil map of the study area is extracted from the Soil map of Tumkur and Chitradurga districts (NBSS & LUP, 2001).

A Digital Elevation Model (DEM) is generated by extracting the contour data from SOI toposheets on 1:50,000 scale. ERDAS Imagine is used for the generation of DEM. The DEM thus prepared was used to generate the slope map based on the guidelines of Department of Space, Govt. of India (NRSA, 1995). GIS software like Map Info, Arc View, Arc GIS and image processing software ERDAS imagine have been used for digitization, computation and output generation purposes.

The groundwater potential zones are mapped by integrating the thematic maps like lithology, geomorphology, soil, lineament density, slope and landuse/landcover, isohyetal map of rainfall and drainage density after assigning suitable weightages. The delineation of groundwater potential zones in the present study is based upon multiple criteria, which give the linear combination of probable weights. Based on prior knowledge of the water potential availability and influence exerted by various terrain parameters on movement, accumulation and yield of groundwater, the ranking of various parameters and their subunits have been evolved for groundwater prospect mapping. Later, all the thematic layers have been systematically integrated one after the other using Arc-GIS software. The integrated map has been classified based on the total weightages delineating the groundwater potential zones. The flow chart is presented in Fig.3.2. The groundwater potential zones thus obtained are validated with the groundwater yield data.

3.4 GROUNDWATER RESOURCES AND ESTIMATION

The available groundwater resources are assessed based on the guidelines given by the Govt. of India, (GEC-1997). GEC-1997 is based on seasonal estimation of groundwater recharge in an assessment unit through lumped water
balance method during monsoon season and the empirical norms during non-
monsoon season. The time period for groundwater recharge estimation is one year
(12 calendar months), which commences with the onset of monsoon of one
calendar year and culminates just before the monsoon season for the next calendar
year, which is termed as a groundwater year. In areas experiencing southwest
monsoon, the groundwater year is between June/July of one calendar year and
May/June of the next calendar year. In areas with northeast monsoon, it is between
October of one calendar year and September of the next calendar year. Assessment
of replenishable groundwater resource and categorization of stage of development
is as shown in Fig. 3.3. Steps for the estimation of annual replenishable
groundwater resource and categorization of assessment units/sub-units are
presented in Fig. 3.4.

The water-level data for a period of around a decade of 12 monitoring
stations maintained by Department of Mines and Geology is used in resource
computation. The normal rainfall data are the long-term averages (107 years).
Data on cropping pattern are extracted from statistics year book (2007-08)
published by Department of Economics and Statistics. The recharge computations
are mainly based on various norms recommended by GEC-1997. These norms
have been derived from various water-balance studies carried out by Central
Ground Water Board (CGWB), State ground water departments (SGWD) and
academic/research institutions.

3.5 GEOCHEMISTRY

Water samples are collected during October 2008 and May 2009 which
corroborates to post-monsoon and pre-monsoon respectively from the 55 hand
pump fitted borewells of the Rural Water Supply Department located all around
the study area. The sample locations chosen are same for the two seasons.
The pH and Electrical Conductivity (EC) are measured at the time of sample collection in the field. However, the water samples are subsequently analyzed for the major cations, anions, silica and trace elements as per APHA (1992) procedures.

Calcium (Ca$^{2+}$), magnesium (Mg$^{2+}$), bicarbonate (HCO$_3^-$), carbonate (CO$_3^{2-}$) and chloride (Cl$^-$) are analyzed by volumetric methods. Sodium (Na$^+$) and Potassium (K$^+$) are estimated by using flame photometer.

Nitrate (NO$_3^-$), Sulphate (SO$_4^{2-}$), Silica (SiO$_2$), phosphate (PO$_4^{3-}$) and total iron (Fe) is determined using UV spectrophotometer. Phosphate (PO$_4^{3-}$) was below detectable limit in the area in both the seasons.

Fluoride (F$^-$) is determined by selective ion electrode method.

The trace elements like Copper (Cu$^{2+}$), Manganese (Mn$^{2+}$) and Zinc (Zn$^{2+}$) are determined using Atomic Adsorption Spectrophotometer (AAS).

Total hardness as CaCO$_3$ and total dissolved solids (TDS) are calculated using empirical formulae.

The rock-water interaction studies have been carried out in order to understand the quality of groundwater, so that strategies for further management can be suggested. The thermodynamic approach and inter-relationship of the chemical constituents is used to study rock-water interaction. The rock-water interaction studies include the study of the various chemical reactions involved during the transformation of water from surface to the underlying aquifer with the surrounding materials. Initially, the units of the chemical parameters are converted from milli-grams per litre to milli-moles per litre. Using the geochemical software WATEQ4F and Aquachem, the saturation indices are determined and the values are plotted on the silicate solubility diagrams for Ca, Mg, Na and K systems. The plots suggested the possible clay mineral phases of the water samples. The inter-
relationship of chemical parameters present and Index of Base Exchange values helped in concluding the possible weathering processes in the area. The accuracy of interpretation is validated by comparing the conclusions drawn through factor analysis.

Factor analysis has been done using SPSS statistical software package. In the first step correlation matrix has been computed for the given set of hydrochemical parameters. Initial factor solutions are extracted by the Principal Component Analytical method. Factor score coefficients are derived from the factor loadings. Factor scores are computed for each sample by a matrix multiplication of the factor score coefficient with the standardized data. The value of each factor score represents the importance of a given factor at the sample site.

The samples have also been checked for their suitability for domestic and irrigation purposes by various standard classifications. The suitability of samples for domestic purpose is checked through Water Quality Index (WQI) method. For computing WQI three steps are followed. In the first step, each of the twelve parameters that are important with respect to drinking purpose have been assigned a weight ($w_i$) according to its relative importance in the overall quality of water for drinking purposes. The relative weight for each parameter is determined in the second step. In the third step, a quality rating scale ($q_i$) for each parameter is assigned by dividing its concentration in each water sample by its respective standard based on the guidelines laid down in the BIS. The computed WQI values are classified into five types, “excellent water” to “water- unsuitable for drinking”. Based on the WQI value obtained for each sample, a spatial distribution map is prepared.

The suitability of water for irrigation is determined using various standard classifications like USSL classification, Wilcox classification and SAR, % Na etc.
The vulnerable zones prone for pollution in the study area are delineated by integrating various thematic maps like recharge due to rainfall, the weathered zone thickness, fractured zone thickness, soil depth, soil type, transmissivity etc. The above map is validated using the Water Quality Index values for post-monsoon season as much of the recharge in the aquifers of the study area is after monsoon rainfall. The detailed flow chart related to chemical quality is presented in Fig. 3.5.

3.6 GROUNDWATER DEVELOPMENT AND MANAGEMENT

The various parameters studied in the previous sections revealed the importance of the artificial recharge of groundwater as the aquifers are being overexploited and the water table is also declining. The artificial recharge zones are identified by integrating nine thematic layers viz., Slope, soil, weathered zone thickness, fractured zone thickness, rainfall, Landuse/landcover, geology, lineament density, landforms, drainage density, waterlevel in post-monsoon season for the groundwater assessment year (2008) and decadal mean of post-monsoon waterlevel after assigning suitable weightages. Further, the weightage limits are derived by equal interval method for delineating the poor, moderate and good zones for implementing artificial recharge zones. The steps for the identification of artificial recharge zones are given in Fig. 3.2. The validation of artificial recharge zone map is done using the yield data collected and compiled by Central Ground Water Board (CGWB).

The sites for constructing artificial recharge structures are identified by superposing the lineaments map on the good artificial recharge zone as the areas in the vicinity of the intersection of the lineaments are considered to be the best sites for groundwater recharge. The soil characteristics and the slope of the terrain are also considered while selecting the sites for artificial recharge. Farm ponds, check dams, percolation tanks and sub-surface barriers are suggested in appropriate places.
Fig. 3.1: Flowchart of Methodology for Groundwater development and Management in Central Part of Suvarnamukhi River Basin

Study area delineation → Data Collection and Compilation

Satellite Data

Generation of Thematic maps → Integration

Secondary Data

Rainfall → Estimation of Available Resources

Water level → Subsurface Geology

Stage of GW development → Vulnerable Zones

Polluted Zones using WQI → Water–Rock Interaction

Sample Collection → Analysis

Results in GIS environment

REMEDIATION

Groundwater Prospect Zones

Artificial Recharge Zones

Artificial Recharge Structures (site specific)

Strategies to overcome Nitrate and Fluoride Problem, Precautions in vulnerable zones

GROUNDWATER DEVELOPMENT AND MANAGEMENT
Fig. 3.2: Flowchart for delineating Groundwater Prospect Zones and Artificial Recharge Zones

- SOI Toposheets
  - Generation of base map
    - Drainage Map
      - Drainage Density Map
      - DEM
      - Geology
        - Soil
        - Isohyetal Map
        - Rainfall

- Remote Sensing Data
  - IRS-IClD (PAN + LISS III)
    - Landforms
    - Landuse/Landcover
    - Lineaments
    - 3D PERSPECTIVE (DEM+ IRS data)
      - Field Data (secondary data)
        - Transmissivity
        - Water table map

- GIS DATABASE
  - Analysis Criteria
    - Ranking of thematic parameters
    - Regrouping based on weightages

- GROUNDWATER POTENTIAL ZONES

- ARTIFICIAL RECHARGE ZONES
Fig. 3.3: Assessment of replenishable Groundwater Resources and Categorization (After Chatterjee and Purohit, 2009)

1. Estimation of annual replenishable groundwater resources and net groundwater availability for each sub-unit.
2. Estimation of groundwater draft for irrigation and domestic uses.
3. Determination of stage of groundwater development.
4. Working out long-term water-level trend.
5. Categorization of assessment unit (based on stage of groundwater development and water table trend).
Fig. 3.4: Estimation of annual replenishable Groundwater Resources and Categorization
(Based on Rajagopalan et al., 1997)

- Estimation of Groundwater Draft for irrigation and domestic purposes
- Recharge from other uses (return flow from irrigation and recharge from tanks)
  - Normal rainfall recharge from Rainfall Infiltration Method for monsoon and non-
    monsoon seasons separately.
  - Rainfall recharge through Waterlevel fluctuation method for monsoon season only
    Normalization of rainfall recharge (WLF method)

- Comparison of PD between WLF and RIF method within 20?
  - Yes
    - Normal rainfall recharge (WLF method)
  - No
    - Normal rainfall recharge (RIF method)

- Normal monsoon rainfall recharge
- Total rainfall recharge = Normal monsoon rainfall recharge + Non-monsoon season recharge
- Recharge from all sources = Rainfall recharge + Normal rainfall recharge (Net annual groundwater availability)
- Unaccounted annual natural discharge = 5 to 10% of net annual groundwater availability
- Stage of groundwater development = (Groundwater draft/ Net ground water available) * 100
- Long-term water-level trend (pre-monsoon and post-monsoon)
- Categorization of assessment unit (based on stage of groundwater development and long-term waterlevel trend)
Fig.3.5: Flowchart for evaluating chemical quality in Central Part of Suvanamukhi River Basin

- Sample Collection in field
- In situ measurement of EC, pH, Eh field
- Laboratory Analysis - Major and Trace elements.

- Pre-monsoon
- GIS Environment (Spatial Distribution)
- Post-monsoon

- Rock Analysis
- Water – Rock Interaction
  - Validation by Factor Analysis
  - Soil Analysis Data
  - Irrigation
  - Drinking
  - Water Quality Index
  - GIS Environment (Spatial Distribution)
  - Pre-monsoon
  - Post-monsoon

- Suitability for different purposes
  - Rainfall Recharge
  - Soil type, Soil Depth
  - Weathered and Fractured zone depth
  - Transmissivity
  - Drainage Density
  - Water level for Post-monsoon
  - Vulnerability Mapping
  - Validation