CHAPTER IX

SUMMARY AND CONCLUSIONS
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The results obtained from detailed geological, geomorphological, hydrogeological, geophysical, hydrogeochemical, artificial recharge, and groundwater modeling studies carried over the Kobi Nala and the Dhawagiri Nala watersheds, Taluka Warud, District Amravati, Maharashtra, have been summarized, discussed and therefrom conclusions have been drawn in the following paragraphs.

The drainage pattern in the study area is dendritic and the Kobi Nala has subrounded shape while Dhawagiri Nala is elongated indicating structural control. Both the streams are fifth order streams. Bifurcation ratios for both the streams indicate mature stage of development but the weighted mean bifurcation ratio of the Kobi Nala indicates the structural control of drainage. Stream length analysis indicate that mean length ratio and weight mean length are nearly same for the Kobi Nala indicating its maturity while in case of the Dhawgiri Nala the development of higher order stream is controlled by linear zone of structural weakness. Such streams are of great importance as they enhance the capability of recharging and thereby increase the potentialities of groundwater.

Shape analysis shows that the Dhawgiri Nala is compact with low circularity ratio (0.347) than the Kobi Nala (0.811) and hence in the Dhawgiri Nala watershed
surface water has to flow for a long distance thereby increasing scope for infiltration. Low drainage density, stream frequency and relative relief (0.00016 and 0.0013) indicate favorable condition for infiltration, so also the length of overland flow (0.165, 0.180) and ruggedness number (18.67 and 19.77) corroborates the inferences earlier drawn. The hypsometric integrals values of 0.273(III), 0.216(IV) and 0.204(V) for the Kobi Nala and 0.279(III), 0.233(IV) and 0.185(V) for the Dhawgiri Nala indicates that the basin has reached the monadnock stage of development and therefore middle and lower reaches of the basin are favorable for groundwater occurrences.

On the basis of spectral signature on imagery the area has been classified into five units such as highly dissected plateau, moderately dissected plateau, slightly dissected plateau, alluvium deposit and gullied land. The moderately dissected plateau forms a recharge zone whereas slightly dissected plateau alluvium and valley fill unit act as storage zone.

Statistical analysis of the lineaments indicate that the most prevalent lineament orientations are NNW-SSE and NE-SW. Further, the mean resultant length (0.9657 for NNW-SSE and 0.4450 for NE-SW) and circular variance (0.093 for NNW-SSE and 0.555 for NE-SW) indicate that each group of lineaments are tightly bunched around their statistical mean direction i.e. the lineaments within each group are genetically related.

Based on similarity of their field characters, major physiography breaks, the presence of marker horizon, phenocrystic assemblages and shift in chemical trends at or
near the top of sequence, mapable sequence of 17 lava flows have been identified. These lava flows has been divided into two subgroups Northern and Southern of the main Salbardi fault. Southern subgroup is divided into A and B formation with 7 different lava flows. The Northern subgroup is divided into 3 formations, C, D and E, which consist of 10 lava flows. Further five chemical types have been recognized based on the behavior of crucial oxides and elements such as MgO, CaO, TiO₂, P₂O₅ and ratio of TiO₂/P₂O₅.

Most of the lava flows appears horizontal in field. However based on field observations the flow on southern side of Salbardi fault shows 1:440 to 1:520 dips in southwest direction. The flows on the northern side of Salbardi fault dips northwest but flow gradients have not been calculated. Two faults have been identified in the study area. A major Salbardi fault extends up to 1.5 km NE of Dhamandas where the outcrops of Gondwana rocks are exposed along this line. Another NNE-SSE fault has been inferred in the study area on the basis of variation in the characters of flows, which does not match with either side of this fault.

The main water bearing formation in the study area is Deccan basalt lava flows and alluvium. The alluvium is confined to the southern part of the watersheds on northern bank of the Wardha River. It is a flood plain deposit with the thickness up to 30 meters. The depth of weathering is the controlling factor for the potential subsurface reservoir. Therefore, the contour map for the thickness of weathered zone has been
prepared and presented which indicated that the thickness of weathered zone is more in central eastern part and generally increases from north to south.

Water level analysis indicates that the pre monsoon depth to water levels varies from 4.56 to 24.2 mbgl. Deeper Water Levels are noted in the central part of the area. The post-monsoon depth to Water Levels varies from 0.68 to 22.4 mbgl, but in major part of the study area, it is more than 12 mbgl indicating that there is a good scope to store surplus monsoon runoff in the lower reservoir.

The analysis of the historical water level trends indicate that during pre-monsoon, period the rate of decline is to the extent of 0.32 m/year while in the post monsoon period it is 0.24 m/year. This suggests that the part of aquifer is being desaturated every year and not replenished even after the rainy season. In order to study the impact of groundwater recharge and surface water conservation structures on the groundwater regime that gained momentum since 1990, the trend analysis period was divided into three segments a) up to 1990 b) up to 2000 and c) 1990 to 2000. The results indicate that most of the wells show declining trend from 0.028 - 0.32 m/year during pre-monsoon up to 2000, indicating that groundwater development is increasing. Post-monsoon data also shows similar trend except near Manikpur where it rises, which may be due to the construction of Percolation tank. Water level trend analysis up to 1990 has also showed declining trend both for pre and post-monsoon except in the northern part where it has shown rising trend due to negligible development and presence of the irrigation tank. Pre-monsoon water level varies from 0.064 to 0.80 m/year. The central
part shows greater decline due to heavy exploitation. Post monsoon declining trend ranges from 0.09-0.62 m/year. In major part, it is more than 0.24 m/year. This also indicates that every year the part of the aquifer was not saturated with natural recharge of rainfall. Water level trend analysis for a period 1990-2000 was made to evaluate the impact of artificial recharge structures constructed during these period. The trend for pre and post monsoon shows a mixed response. During pre-monsoon, the declining trend has reduced down. These three-trend analyses also indicate that in addition to artificial recharge structures designed in the area, there is also a need to optimize and rationalize the pumping rate and cropping pattern in order to improve groundwater aquifer system.

In order to understand the movement of groundwater, water table (AMSL) contour maps had been prepared of pre and post-monsoon for a period 1994-1999 and are presented. The altitude of water levels in the watershed varies from 460 to 330 m above mean sea level. The general groundwater flow direction is from north to south with the gradient of 2.6 m/km. In general, the gradient is not uniform. In the northern and western part, the gradient varies from 4.4 to 5.8 m/km. In the central part, the gradient is gentle (1.8 to 2.0 meter/cm.) which began again steep in southern part (2.0 to 2.8 m/km). Water table fluctuations in upland exceed 10 met. whereas in plain it varies between 2-4 met. The maximum head loss for the flow system is between 100-120 met. and the head loss increases from basin boundary to the valley in the Southern part of the watersheds. Lateral flow system boundaries are formed by water table high and low
within the watersheds giving rise to different Ground Water flow systems. Based on water level gradients and the spacing of water level contours, the scope for development of groundwater in decreasing order in the study area is as below –

1) Palsona-Benoda
2) Natala- and further south
3) Karegaon-Sawanga-Karajgaon
4) Jholamba and adjoining zone

The aquifer system of the Kobi Nala and the Dhawagiri Nala watersheds consists of three aquifers separated by two aquitards. The upper unconfined aquifer consists of weathered and shallow fractured basaltic lava flows, sandy horizon and alluvium. The thickness of this aquifer generally increases from North to South and extends up to 25 mbgl. Most of the dug wells are tapping this aquifer. The second semi confined aquifers constitute the interflow zones, which is mainly vesicular, and zeolitic basalt, which were fractured at moderate depth. This aquifer at times extends up to a depth of 130-150 mbgl. The lower aquifer is mainly interflow zone of zeolitic lava flows and deeper fractured zone trapped between the two massive lava flows or between upper fractured and lower massive rocks.

The quantitative assessment of aquifer potentials, indicate that the transmissivity value and storage coefficient value for the various location in the watershed varies from 6.8 to 318m²/day and .013 to .240 respectively. These values have further calibrated during modeling and the calibrated transmissivity value was about 1.2 times the original
value in upper reaches while they were 0.8 times the original value in the lower reaches of the watershed.

The interpreted geophysical sounding data revealed 18 two layer, 39 three layer, 48 four layers and 15 five layers earth sections. The litho logs obtained from the bore wells and the interpreted sounding data showed reasonably good correlation near existing bore wells. This reflects that the resistivity measurement could be used to delineate subsurface geological formation and with the knowledge of local geology, it is possible to predict the water bearing horizons.

Resistivity contouring at different electrode spacing $a = 10.00$ meter, 25 meter, 50 meter, 75 meter and 100 meter resolved five different horizons. Four major low resistivity zones comprising of weathered / zeolitic or alluvium top layers have been identified. High resistive zone on the northern part and western part with exposure of hard basalt have been demarcated by $a = 10.00$ meter interval contour map. Three zones having contour closure elongated towards East, possibly corresponding to NNW-SSE trending lineaments and four low resistivity zones have been observed in the contour map of $a = 25.00$ meter. For electrodes spacing $a = 50$ meter, number of smaller low resistivity closures including thicker low resistivity closures indicating thicker low resistivity formations around Pimpalkhuta and near Surwari are were noted. The low resistivity zone on the east has shifted towards further east. A large portion of the basin shows high resistivity values indicating relatively hard rocks with greater thickness. Examination of contour for $a = 75$ meter, have been useful to see low resistivity
gradients indicating the response of deeper regional structure. The contours get sparser for the electrode spacing \( a = 100 \text{ met.} \) and thereby indicating lineament remained evident for all electrode spacing. Hence, it is concluded that the resistivity contours for different spacing provides synoptic view over the entire basin.

The surface contour after the first layer has been removed which shows striking resemblance to the groundwater table contours and can conveniently be used to indicate the flow direction. This also facilitates location of phreatic or water table aquifer. Subsurface structure contours after first two layers are taken off, shows a large number of closures, thereby indicating an undulating surface. The central part enclosed by 450 m contour indicates a number of depressions some of which are good aquifers. The resulting new surface when the entire top three layers have been stripped off gets flatter on SW and the central part whereas the depressions still exist on the eastern margin of the watershed. The elevated zone in the northern part of the area exhibits fresh rocks.

Based on the chemical composition of the groundwater, hydrochemical facies have been established from recharge to discharge areas which are characterized by Mg > Ca > AlK, Ca > Mg > Alk, Ca > Alk > Mg and Alk > Ca > Mg hydro chemical facies. Similarity, the trends of Ca and Mg reflect their common source of origin while the absence of any similarity between Ca and Na indicates insignificant control of plagioclase feldspar over groundwater. It has been found that groundwater is dominated by Ca, Mg > Na + K - HCO₃ + CO₃ hydro chemical type followed by Na + K - HCO₃ + CO₃ and Na + K - SO₄ + Cl + NO₃ indicating cation - anion exchange processes.
Temporal variation in chemical parameters shows that Ca and Mg cations and HCO₃ and Cl anions decrease from pre-monsoon to post-monsoon due to dilution while Na increases from pre-monsoon to post-monsoon due to cation-anion exchange caused by absorption of sodium by clays. It has also been found that the ionic content of groundwater increases during pre-monsoon period.

Impact of irrigation has been established on the observation that there is an increase in the electrical conductivity (EC) and high concentration of dissolved constituents, Cl₂, SO₄, NO₃ and TDS in irrigated areas as compared to non-irrigated areas as well as pressure of diverse hydrochemical characteristics indicated by chemical evolution of groundwater from Ca + Mg - HCO₃ type to Na + K - SO₄ + Cl + NO₃ type in the irrigated areas.

Suitability of groundwater for agricultural purpose based on EC, TDS, SAR, Kelley's ratio and soluble sodium percentage indicates that the quality of groundwater is good in basaltic aquifer with few exceptions. However, groundwater occurring in the alluvium is marginally suitable from agriculture point of view. But in contrast to this Boron toxicity studies indicate that the area is affected by high to very high boron toxicity (above 2 ppm) and was found to be 51.2% during post-monsoon and 26.6% in pre-monsoon which is a quite alarming rate. This might be one of the reasons for the decrease in orange production and its deteriorating quality in this region.

Evaluation of the efficiencies of artificial recharge structure indicates that the efficiencies of percolation tanks vary from 63 to 82%. Seepage loss range from 5.2 to
14% while evaporation losses accounts up to 10.6%. The maximum efficiencies from percolation tanks can be achieved if water remains in tank only till January. The total capacity utilization of percolation tanks during years of good rainfall can be up to 150% due to repetitive fillings. The rise in water levels is even up to 8 met. in the command area.

The efficiencies of cement plugs vary from 78 to 90.5% while evaporation losses ranges from 8.2 to 20.5%. Higher evaporation losses were observed in cement plugs that stored water for longer periods. The area benefited varies from 2-10 hectares and rise in water levels in such areas ranges from less than 0.5 meter to over 2.5 meter. The cement plug is filled 3-4 times during rainy seasons depending on rainfall incidence and at times capacity utilization is up to 300%. About 5 TCM of surface water could be consumed in each cement plug benefiting an area of 10 hectares each.

The cost benefit analyses of three-percolation tanks and four cement plugs indicates that the cost benefit ratio ranges from 1:2.00 to 1:1 in case of percolation tanks and 1:75 to 1:0.72 for the cement plugs.

The aquifer system of the Kobi Nala and the Dhawagiri Nala watershed has been modeled as a single layer system using MODFLOW. Calibration of the model was done under steady state and transient conditions. The model was further tested for January 2000 and later simulated for three prediction scenarios. Prediction scenario –I was based on the assumption that the maximum draft of 1998 would be continued up to 2008. Prediction scenario-II assumed that by changing cropping pattern 20% of the draft would be reduced. In the prediction scenario-III it was assumed to optimize the
draft by reducing it up to 40% in the upper reaches of the watershed and 25% in the lower reaches. It was found that under prediction scenario-I both the upper and lower aquifer would be depleted by 2006. Under prediction scenario-II it was found that partially lower semi-confined aquifer could be recovered. Under prediction scenario-III the semi-confined aquifer would be recovered up to an extent of 92% while the upper unconfined aquifer can be partially recovered in the lower reaches of the watershed. The present model study has brought out explicitly the dependence of lower aquifer on the upward leakages. With no river derived recharge, the situation becomes critical during 2004 by which time, the upper unconfined aquifers get depleted and the semi-confined aquifer starts affecting, even at a 20% less draft (approx-3000m$^3$/day). The simulation indicate that under present conditions, of abstraction is possible for next four years if one does not mind the higher influx from lower aquifers. A reconfiguration of pumping (Prediction Scenario III) with less production over lower reaches appears to extend the life of wells beyond 2008. Thus, aquifer modeling has been found to be a useful management tool for the present planning and future decision-making.