CHAPTER - 10

SUMMARY AND CONCLUSIONS

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10.1 Summary

The Khapri watershed of district Dangs, Gujarat, western India is characterized by uniformly spread less transmissible basaltic rocks, rugged trappean highlands and moderate to very steeply sloping surfaces. These terrain conditions give rise to higher runoff than infiltration, leading to acute shortage of groundwater as compared to other parts of the district in non-rainy period. The objectives of the present study are (i) Identification and demarcation of the groundwater potential zones in the Khapri watershed. through remote sensing and GIS, (ii) Assessment of groundwater quality and its suitability for drinking and irrigation purposes and (iii) To decipher groundwater recharge patterns through stable isotope tracer technique and suggest suitable locations for the groundwater recharge structures. To achieve these objectives the thematic maps of geo-environmental parameters (GEPs) (geology, drainage, geomorphology, slope, lineaments, soil and land-use) are prepared using techniques of remote sensing and GIS. These thematic maps were integrated based on AHP derived weightages to derive the groundwater potential zones. The groundwater samples are analysed for physicochemical parameters as well as stable isotope composition to know the status of water quality and groundwater recharge patterns respectively. The role of various GEPs, status of groundwater quality and recharge patterns are summarized in the paragraphs to follow.

Geologically, the Khapri watershed is completely underlined by nine basaltic flows of Cretaceous-Eocene age and unconformably overlain by recent alluvium and alluvio-colluvial sediments of Quaternary age. These flows are intruded by ENE-WSW, WNW-ESE, NNE-SSW, NW-SE and NE-SW trending doleritic dykes and are transacted by numerous regional joints as well as fractures. In Khapri watershed, lineaments are categorized into two viz. (i) Positive lineaments and (ii) Negative lineaments. The ridges, plateaus and dykes on the satellite data are categorized as positive lineaments while the offsets, regional and decipherable local joints, straight stream segments are categorized as negative lineaments. These negative lineaments promote the formation of zones of localized weathering and induce the secondary porosity and permeability, for infiltration as well as the storage of water in the sub-surface.

Drainage characteristics and hydrological setup of Khapri watershed is analysed through morphometric analysis. The watershed is the sixth order basin

characterized by 98.6% of lower than fourth order streams. This higher number of lower order streams can be attributed to the rugged topographic setup and occurrence of hard and low permeable basaltic rocks in the watershed. The linear plot of stream number versus stream order shows inverse relationship and follows Horton's law. The bifurcation ratio values for Khapri watershed ranges from 3.5 to 4.4 for first to fifth order streams, is the result of homogenous lithology of Deccan trap with less significant structural control. The higher bifurcation ratio value of 7 for the trunk stream indicates significant structural control (Dongare et al. 2022). The lower stream length ratios (0.26 to 0.68) obtained for first to fifth order streams suggest that they are draining over relatively less permeable rocks on steeper slopes. Compared to lower order streams, the sixth order stream having high stream length ratio (0.89) flows over relatively more permeable rocks with gentle slopes. Overall, the fine drainage texture of the Khapri watershed also suggests the low to moderately transmissible nature of underlying lithology. The value of drainage density reveals the less transmissible nature of underlying lithology. Within the watershed, areas with high drainage densities are closely associated with steeper slopes, while the low drainage density is associated with gently sloping regions. The presence of competent basaltic rocks with occurrence of secondary porosity and permeability along the divides of watershed shows very low to low drainage densities suggesting less runoff and more infiltration in this region of the watershed. Moderate to high classes of stream frequencies spreads around 85% of the watershed area. These are in association with the significant break in slopes and are characterized by numerous first order streams suggesting higher runoff and low infiltration for this region of the watershed. The analysis of shape factors indicates elongated shape of Khapri watershed. In addition to joints and fractures the elongated shape of the watershed increases the possibility of infiltration. More than 60 percent of watershed possesses appreciably steep slopes, suggesting its significant control over drainage characteristics. The higher value of dissection index and ruggedness number suggests presence of steeper and longer slopes with rugged topography. The hypsometric integral (0.5) and the hypsometric curve of Khapri watershed indicate the mature stage of geomorphic development.

Hydrogeomorphic analysis is carried out to understand the role of landforms and slope in groundwater occurrence and distribution. The nine geomorphic features are demarcated in the Khapri watershed and are analysed with respect to runoff-infiltration

capacity. The escarpments are near vertical or almost vertically sloping faces with negligible groundwater potential. Highly dissected plateau (HDP) regions characterized by high drainage density indicate high runoff-zones and poor groundwater potential. On the other hand, the low dissected plateau (LDP) with gentle slopes, low to moderate drainage densities leads to moderate groundwater potential. In between, the moderately dissected plateau (MDP) having moderate drainage density exhibit good to moderate groundwater potential. The flat top surfaces of the linear ridges and plateaus mark the planation surfaces and is characterized by moderate groundwater potential. Pediments are gently sloping surfaces with veneer of weathered and colluvial material characterized by good to moderate groundwater potential which is enhanced on account of high lineament density. Pediplains are gently sloping undulating surfaces marked by moderate to good groundwater potential. Alluvial plains are gently sloping depositional surfaces with unconsolidated sediments having very good to excellent groundwater potential. Valley fills are mainly consisting of weathered products of the surrounding basaltic rocks, gravels, pebbles, sand and silt sized particles deposited by the action of stream transport and gravity resulting in good to very good groundwater potential.

Soil texture plays a significant role in occurrence and movement of groundwater. It affects the infiltration capacity, permeability, water holding capacity, groundwater recharge and quality. As per NBSS&LUP, (2006) the Khapri watershed is composed of three soil series viz. 140-Ahwa series, 142-Bedmal series and 144-Vadhvania series. The soil of 140-Ahwa series is classified as fine, hyperthermic and lithic haplustepts, positioned on very gently to gently sloping foothill slopes. The soil of this series is excessively drained with rapid permeability. The soil of 142-Bedmal series is loamy, mixed, hyperthermic and lithic haplustepts, resting over very gently to gently sloping foothill slopes. The soil of this series is excessively drained with rapid permeability. The soil of 144-Vadhvania series is clayey, smectitic, hyperthermic and lithic haplustepts and located on gently to moderate sloping lower foothill slopes and exhibits moderate to severe erosion due to rainfall. The soil is moderately well drained with moderately rapid permeability. Overall, the three soil series are shallow to very shallow, gravelly clay in nature with low water holding capacity and are well drained.

Land-use such as natural vegetation, forest, barren lands have specific impacts on water infiltration. Khapri watershed is characterized by seven land use viz., dense

forest, scattered forest, agriculture, mixed built-up, built-up and barren land. The dense forest exhibits 60 to 100% infiltration of precipitation, while agricultural land is characterized by 45-50% infiltration. Similarly, the mixed built-up allow 50 to 60 % infiltration, while the urban areas exhibit hardly 10% infiltration. The maximum area (>50%) of Khapri watershed is covered by the dense forest followed by agriculture (35.18%), scattered forest (5.16%), water body (4.7%), mixed built-up (1.91%), barren land (0.95%) and built-up land (0.38%). The highest aerial coverage by dense forest and agriculture land use (>85%) together indicate the land use is favouring the good water infiltration in major part of the Khapri watershed.

Groundwater Potential Zones are derived through AHP-MCDA based overlay analysis in Arc-GIS 10.4 by integrating the thematic layers of various GEPs. The PCM in AHP-MCDA provided a robust statistical framework to derive weightages of the individual GEPs instead of arbitrary weightage and thereby reduce the human bias. Based on the AHP-MCDA, groundwater potential zones in the Khapri watershed are classified into five categories viz. Very good, Good, Moderate, Poor and Very poor. The maximum area (154.28 km^2) of Khapri watershed is occupied by the moderate category of groundwater potential zone, while the category of very good groundwater potential zone covers the minimum area of 38.81 km^2. The very good to moderate groundwater potential zones is the result of combinations of alluvial plain, valley fills, low dissected plateau, pediments and pediplains, very high to moderate lineament density, gentle to moderate slope and land uses such as dense forest or agriculture. These are encountered near villages Sinband, Ukhatiya, Chavadvel, Rawchond, Sunda, Chichigaontha, Dhodhalpada, Koylipada, Amania, Pimpri, Kudkas, Chikar, Gaurya, Borkhal, Moti and Lahan Dabhas, Nirgudmal etc.. The poor category of groundwater potential zones shows ubiquitous distribution, while the very poor category is restricted to the south western and central part of the watershed near villages Vanar, Wanki, Chirapada, Gaurya, Bhavandagadh and Mulchond. These categories are due to combinations of escarpments, highly dissected plateaus, very low lineament density and very steep slopes, which are unfavourable for the occurrence of groundwater. The thematic layers of GEPs and the resultant groundwater potential zones are validated by ground truth verification as well as pre-monsoon (2022, 2023) and post-monsoon (2021, 2022) groundwater fluctuation data. The total accuracy of AHP derived groundwater potential zones comes to be 75%. Moreover, the quantitative validation of AHP derived groundwater potential zone map is

carried out through ROC curve method to indicate the performance of the model. The ROC value of 0.75, indicate the good predictions and performance of the AHP model for mapping of groundwater potential zones.

Hydro-geochemistry of groundwater samples (May-2023) is carried out to determine the suitability for drinking and agriculture purposes as well as to understand the dominant mechanism controlling the water chemistry. The in-situ recording of physicochemical parameters such as pH, EC, TDS and temperature is carried out using Hanna Portable Pen type pH and TDS-EC-TEMP meters. The physicochemical parameters such as total hardness (TH), total alkalinity (TA), cations (Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Sodium (Na^{+}) and Potassium (K^{+})), anions (Nitrate (NO_3^{-}), Sulphate (SO_4^{2-}), Chloride (Cl^{-}) and Bicarbonate (HCO_3^{-})) are analysed in lab. The suitability of groundwater for drinking purpose is determined considering the BIS (2012) standards for drinking water while, suitability for irrigation purpose is determined based on indices such as Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Kelly's ratio. To understand the dominant mechanism that govern the groundwater chemistry, Gibbs, 1970 diagram is used. The analytical results of pH indicate neutral to weakly alkaline, Ec indicate low conductive and TDS indicate fresh nature of groundwater in Khapri watershed. The chemical analysis of groundwater suggests, the calcium and magnesium are the dominant cations followed by sodium and potassium. Among anions, the bicarbonate is dominant followed by chloride > sulphate > nitrate. The comparison of the cations and anions in the groundwater with BIS (2012) standards indicate that the water is suitable for drinking. The higher values of bicarbonate may attribute to silicate weathering of the basalt. The Piper trilinear diagram indicates the Ca-HCO_3^{-} type chemical character of groundwater. The Gibbs diagram reflects rock weathering is the dominant mechanism governing the groundwater chemistry. The values of indices such as SAR (0.02-0.4), RSC (-1.21 to 2.12) and Kelly's ratio (0.11 to 0.19) indicate the groundwater is suitable for irrigation purposes.

Stable isotope (Oxygen and Hydrogen) study highlights four groundwater recharge patterns through different sources viz. (i) Meteoric water which directly infiltrates through negative lineaments that act as a conduit for recharging the shallow groundwater aquifers (ii) Rivers and reservoirs recharge the shallow groundwater aquifers through water percolation (iii) Springs are recharging the surrounding wells throughout the year and (iv) Deeper groundwater from the bore-wells and hand-pumps

used for agriculture, constitutes the return flow for recharging the shallow groundwater aquifers. With this background of groundwater recharge pattern, a further emphasis is given to augment the recharge by proposing appropriate structures at suitable locations in Khapri watershed.

Groundwater recharging structures such as percolation tanks, check dams, nalabunds, gully plugs, gabions, necklace trenches and recharging ponds are proposed at sub-watershed level by considering the terrain characteristics (Lineaments, Drainage, Slope, Land use and Geomorphology), groundwater potential zones, groundwater quality and the existing groundwater recharge patterns. These structures are expected to increase the water table in very poor to moderate groundwater potential zones of Khapri watershed.

10.2 Conclusions

The Khapri watershed of district Dangs receives very high average annual rainfall, yet faces severe water scarcity during non-rainy periods on account of high runoff and less infiltration in the watershed. This is primarily due to presence of less transmissible basaltic rocks, high drainage density, fine drainage texture, rugged trappean highlands, moderate to very steeply sloping surfaces and well drained soils.

The frequent failures of groundwater structures, silted check-dams/percolation tanks and their position clearly indicate that parameters governing groundwater occurrences and recharge are overlooked. To overcome this, the geo-environmental parameters (GEPs) (geology, geomorphology, lineament, slope, drainage, land use and soil) are considered for deriving the groundwater potential zones in the Khapri watershed by using remote sensing and GIS techniques.

The groundwater potential zones are classified into five categories viz. Very good, Good, Moderate, Poor and Very poor. The maximum area (154.28 km^2) of Khapri watershed is occupied by the moderate category of groundwater potential zone, while the category of very good groundwater potential zone covers the minimum area of 38.81 km^2. The comprehensive assessment of geo-environmental parameters indicate the groundwater potential zones of Khapri watershed are dominantly governed by geomorphology, lineament and slope.

To augment the very poor to moderate groundwater potential categories, the recharging structures such as percolation tanks, check dams, nalabunds, gully plugs, gabions, necklace trenches and recharging ponds have been proposed by considering the groundwater quality and recharge patterns.

In addition to proposed recharge structures the several recommended measures such as aafforestation, de-siltation of existing check-dams, sheltering the wells through solar panel and restoration of the existing contaminated as well as unused dug wells will be useful for sustainable development of groundwater.

Thus, the approach used for sustainable development of groundwater resource in Khapri watershed of Deccan Volcanic Province, is promising and can be used in other hilly terrains of DVP with suitable modifications.