Generation of Groundwater Quality Index Map – A Case Study

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Abstract

Reliance on groundwater has been rapidly increasing, especially in the arid and semiarid regions, resulting in its overexploitation leading to deterioration of quality. Kurmapalli Vagu basin of Andhra Pradesh, a semi-critical region with respect to the stage of groundwater development is a good example. Its monitoring and assessment is imperative for devising preventive measures against health hazards. Groundwater samples from twenty five locations were collected and analyzed for various physico-chemical parameters in terms of Water Quality Index (WQI) to determine its suitability for drinking purposes. Seven locations were found to have WQI value within the limits. High values of WQI were mostly due to high content of Fluorides. WQI Contour map was generated to study spatial distribution of quality of groundwater. Suitable remedial measures and groundwater augmenting structures are proposed in the study area to improve the quality of groundwater.

Keywords: Groundwater, WQI, Fluorosis, Groundwater augmenting structures.

1. Introduction

Water is the most essential and one of the prime necessities of life. Rising demand of water for irrigation, agriculture, domestic consumption and industry is forcing stiff competition over the allocation of scarce water resources among both, areas and types of use. To meet the increasing water demands, reliance on groundwater has been rapidly increasing, especially in the arid and semiarid regions.

During past several decades, groundwater quality has emerged as one of the important and confronting environmental issues (Ravi Chandra Babu et al. 2006). Attention on water contamination and its management has become a need of the hour because of far reaching impact on human health (Mahadevaiah and Sanjeevi 2006, Sinha and Kumar 2008). The utility of groundwater available is dependent on its physical, chemical and bacteriological properties. Spatial and temporal distribution of groundwater quality is a function of climate (precipitation and evaporation), topography (slope which affects the residence time of groundwater), geology of the area (mineralogical and chemical composition of rocks and soils with which groundwater is in contact) etc. (Aswathanarayana 2002).

Kurmapalli Vagu basin is not served by irrigation projects except a few tanks that are also hardly get filled up. In the study area groundwater is the only source of drinking water (Rajani et al. 2006). Attempt has been made to evaluate the groundwater quality focusing on drinking water. Groundwater samples from twenty five locations were collected within the basin and were analyzed for various physico-chemical parameters. WQI was evaluated for determining suitability of water for drinking.

2. Study Area

The Kurmapalli Vagu basin, 108.09 sq.km. in extent, is located at about 55 km south east of Hyderabad (Figure 1). It lies between $78^0 40'$ - $78^0 50' 45''$ E longitude and $16^0 50'$- $17^0 0'$ N latitude. It was categorised as semi-critical with respect to the stage of groundwater development (Pradeep Kumar and Srinivas 2011).

In the present study IRS P6 - LISS III & IRS 1D - PAN merged RS data acquired on 27^{th} April 2008, geocoded at the scale of 1:50,000 and Survey of India (SOI) toposheet nos. 56 L/9, 56 L/13 have been used for preparation of various thematic maps. The base map of the study area is shown in Figure 2.

3. Water Quality Index

Water Quality Index, indicating the water quality in terms of a number, offers a useful representation of overall quality of water. Horton (1965) defined Water Quality Index as a reflection of composite influence of individual quality characteristics on the overall quality of water. WQI is used to assess water quality trends for management purpose. (Srivastava et al. 2007). For calculation of WQI, selection of parameters has great importance (Chatterjee and Raziuddin 2007). Since, selection of many number of parameters widen the water quality index and importance of various parameters depends on the intended use, twelve physico-chemical parameters namely pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Alkalinity, Total Hardness, Fluoride, Chloride, Nitrate, Sulphate, Iron, Calcium and Magnesium were used to calculate WQI.

4. Determination of Water Quality Index

To determine the suitability of groundwater for drinking purpose, Water Quality Index was computed using Eq. (1).

$$\text{WQI} = \left(\sum_{i=1}^{n} q_i W_i \Big/ \sum_{i=1}^{n} W_i \right) \qquad (1)$$

where, W_i is a Weightage factor computed using Eq.(2).

$$W_i = K / S_i \qquad (2)$$

where, S_i = Standard value of the i^{th} water quality parameter, K is a proportionality constant, which is taken as 1.0 (Ravi Chandra Babu et al. 2006), n is the total number of water quality parameters.

Quality rating (q_i) is computed using Eq.(3).

$$q_i = \{[(V_a - V_i)/(S_i - V_i)] \times 100\} \quad (3)$$

where, q_i = Quality rating for the i^{th} water quality parameter, V_a = Actual value of the i^{th} water quality parameter obtained from laboratory analysis, V_i = Ideal value of the i^{th} water quality parameter obtained from standard tables, V_i for pH = 7 and for other parameters it is equivalent to zero.

5. Water Quality Analysis

Table 1 presents values of twelve water quality parameters, determined as per APHA 1995, of groundwater samples collected from 25 different locations (Figure 3). WHO standard values (WHO 1971), ideal values and weightage factors of water quality parameters are listed in Table 2. Status of water quality based on WQI is given in Table 3.

6. Results and Discussion

6.1 Results and Discussion on Various Water Quality Parameters

6.1.1 pH

pH of drinking water is normally between 6.5 to 8.5 while that of natural water is between 4 to 9. The analysis showed that the pH values range between 6.4 to 8.2 (Table 1), indicating that the water is neutral. Minimum pH was observed at Mal village while maximum value was at Sakali Seripalli village. pH value of samples at six locations lie between 6 and 7, seventeen locations lie between 7 and 8 and remaining two locations between 8 and 9.

6.1.2 Electrical Conductivity

Electrical conductivity is the ability of water to allow electric current through it and is expressed in micro mhos per centimeter (µ mhos/cm). Conductivity value of fresh waters is in the range of 5 to 500 µ mhos/cm. Maximum value of 2863 µmhos/cm (Table 1) was observed at Venkatesh nagar village while minimum value was 842 µmhos/cm at Polepalli Main road. Water samples at eleven locations were having electrical conductivity value between 1000 to 2000 µmhos/cm and at ten locations in the range of 2000 to 3000 µ mhos/cm and at the remaining four locations below 1000 µ mhos/cm.

6.1.3 Total Dissolved Solids

Concentration of dissolved solids in groundwater decides its applicability for drinking, irrigation or industrial purposes. Concentration of dissolved matter in water is given by the weight of the material on evaporation of water to dryness up to a temperature of 180 ^{0}C. The values are expressed in mg/l. Major constituents of TDS include Bicarbonates (HCO_3^-), Sulphates (SO_4^{2-}) and Chlorides (Cl^-) of Calcium, Magnesium, Sodium and Silica. Groundwater containing more than 1000 mg/l of total dissolved solids is generally referred as brackish water. In the study area, TDS in groundwater ranges from 574 to 1975 mg/l (Table 1) with minimum from bore well location near Polepalli Main road and maximum value from bore well location at Mal. Water samples at seventeen locations were having total dissolved solids values between 1000 to 2000 mg/l and at remaining eight locations have values below 1000 mg/l.

6.1.4 Total Alkalinity

Alkalinity is caused due to the presence of carbonates, bicarbonates and hydroxides of calcium, magnesium, potassium and sodium. Calcium carbonate is the most usual constituent that causes alkalinity. Alkalinity is expressed in mg/l and the limit for drinking water is 200 mg/l. Total alkalinity in the groundwater in the basin ranges between 208 mg/l to 974 mg/l (Table 1). Minimum value of 208 mg/l was observed at Kishanpalli village of Yacharam mandal in Ranga Reddy district while the maximum value of 974 mg/l was observed at Madanapuram village of Nalgonda district.

6.1.5 Total Hardness

Hardness in water is caused primarily by the presence of carbonates and bicarbonates of calcium and magnesium, sulphates, chlorides and nitrates. Total hardness is a measure of calcium (Ca^{2+}) and magnesium (Mg^{2+}) content in water and is expressed as equivalent of $CaCo_3$. Water with a hardness of less than 75 mg/l is considered as soft. Hardness of 75-150 mg/l is not objectionable for most purposes. Minimum total hardness of 127 mg/l (Table 1) was observed at Battugudem and maximum value of 858 mg/l was at Godkondla village.

6.1.6 Fluoride

Fluorine is one of the most common elements in the earth's crust and is most electro-negative of all elements. It occurs in water as fluoride. It is expressed in mg/l. It is found in both igneous and sedimentary rocks in flat topography and semi arid regions. The formation of high fluoride in groundwater is governed by composition of bedrock and hydrogeology. High fluoride in groundwater may also be formed as a result of evapotranspiration along the groundwater flow path. Fluoride concentration in groundwater of the study area ranges from 0.9 to 12.7 mg/l. Fluoride of drinking water should ideally be between 1.0 to 1.5 mg/l. Minimum concentration of 0.9 mg/l was observed at Lambadi tanda while maximum of 12.7 mg/l at Madanapuram. Highest values of Fluoride were found in middle part of the study area and are related to the occurrence of fluoride rich rocks and their chemical kinetic behavior with groundwater (Mondal et al. 2009).

6.1.7 Chloride

Major sources of chloride in groundwater are the constituents of igneous and metamorphic rocks like sodalite and chlorapatite etc. Because of sewerage waste disposal and leaching of saline residues in the soil, abnormal chloride concentrations may occur. Water quality analysis of the samples collected indicates that the chloride concentration ranges from 78 mg/l to 694 mg/l. Minimum value of 78 mg/l was observed at Battugudem village and the maximum value of 694 mg/l at Godkondla village.

6.1.8 Nitrate

Nitrate enters groundwater through nitrogen cycle. 1 mg/l of nitrogen equals to 4.5 mg/l of nitrate. Natural nitrate concentration in groundwater ranges from 0.1 mg/l to 10 mg/l. In the study area, the nitrate concentration ranges from 9 mg/l to 58 mg/l. Minimum value was observed at Ummapur and maximum value was observed at both Godkondla and Takallapalli respectively. The desirable limit of nitrates in drinking water is 50 mg/l.

6.1.9 Sulphate

Abnormal concentrations of sulphate may be due to the presence of sulphide ore bodies like pyrite, lignite and coal. Sulphate concentration ranges from 37 mg/l to 216 mg/l observed at Kurmapalli and Vinjamur villages respectively.

6.1.10 Iron

The presence of iron in groundwater can be attributed to the dissolution of rock and minerals (pyroxenes, pyrite, magnetite and haematite (Sandhya 2005)), acid mine drainage, sewage and industrial effluents. Water quality analysis of the samples collected indicates that the Iron concentration ranges from 0.1 mg/l to 0.5 mg/l at various locations.

6.1.11 Calcium

Calcium occurs in water mainly due to the presence of limestone, gypsum, dolomite and gypsiferrous minerals. Permissible limit of calcium is 75 mg/l. Calcium concentration ranges from 21 mg/l to 124 mg/l observed in water sample locations at Venkatesh nagar and Annebainapalli villages respectively.

6.1.12 Magnesium

Magnesium occurs in water mainly due to the presence of olivine, biotite, augite and talc minerals. Permissible limit of magnesium is 30 mg/l. Water quality analysis of the samples collected indicates that the magnesium concentration ranges from 12 mg/l to 46 mg/l. Minimum value of 12 mg/l was observed at Godkondla village and the maximum value of 46 mg/l at Badvanagudem village.

6.2 Evaluation of Water Quality Index

Using the values of different water quality parameters for the samples as listed in Table 1, WHO standard values, ideal values and weightage factors as listed in Table 2, the computed values of WQI are listed in Table 4. These values of WQI were compared with standard values of WQI (as listed in Table 3) and accordingly quality of water was categorized as listed in Table 4. It may be observed from the values of WQI, that

- WQI values range from 44 - 217.
- Two locations have the value in the range of 25-50.
- Four locations have the value in the range of 50-75.
- Only one sample has the value in the range of 75-100.
- All other samples have the WQI values more than 100 making them unsuitable for drinking purpose.

It may be observed that high values of WQI were due to high content of Fluorides. Only one location was having less than 1.0 mg/l, seven locations were found to have 1.0 to 1.5 mg/l and the rest of 17 locations were having fluoride more than 1.5 mg/l. In Madanapuram the WQI value was 217 and the corresponding Fluoride content was 12.7 mg/l. In Polepalli Main road, Khandunayak Tanda and Sakali seripalli also the WQI values were above 150 and the fluoride contents were greater than 6.5. As the WQI is far above the permissible limits, it is suggested to take necessary precautions before the water is used for drinking purpose.

6.3 Fluorosis and Defluoridation

Since the study area is known for endemic fluorosis, ill effects of high fluoride concentration in drinking water are described briefly.

A small amount of fluoride (0.8 - 1.0 mg/l) in groundwater is necessary as it helps for bone development. Concentrations of fluoride more than 3.0 mg/l cause abnormalities in bone structure, calcification of spines and stiffening of joints and ligaments known as “Skeletal fluorosis”. Skeletal fluorosis is not easily identifiable until the disease has developed to an advanced stage. Presence of fluoride greater than 5 mg/l in drinking water causes neurological problems.

Defluoridation, process of removing excess fluoride in drinking water, can be carried out through precipitation and ion exchange method. In precipitation method, lime and alum in appropriate proportion are added to the raw water, which results in formation of precipitation, which will then be removed. In ion exchange method, strong base anions exchange resins are used to remove fluoride ion. Deflouridation of potable water can also be achieved by Nalgonda technique developed by National Environmental Engineering Research Institute, Nagpur. Nalgonda technique involves addition of aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation, sedimentation, filtration and disinfection. Using any one of the above methods, fluorosis can be prevented.

6.4 Generation of WQI Contour Map

Using the spatial data of location of different bore wells and the corresponding WQI values, WQI contour map was developed as shown in Figure 4. This was generated using SURFER 9 package. This map can be used as a ready reckoner for suggesting suitable and economic water treatment measures. It can also be used for suitable crop selection and for planning conjunctive use.

6.5 Groundwater Augmenting Structures

Based on the subsurface information derived from electrical resistivity data and thematic information from Remote Sensing data, groundwater augmenting structures like Check dams, Percolation tanks and Subsurface dykes were recommended as shown in Figure 5 (Pradeep Kumar et al. 2011). These structures enable artificial recharge of groundwater and finally results in improving groundwater quality.

7. Conclusions

Analysis of experimental investigation on quality of groundwater, using twelve physic-chemical parameters of Kurmapalli Vagu basin indicate that in general, the water quality was poor and unsuitable for drinking purpose. Fluorosis was found to be predominant. This study infers immediate attention towards the improvement of water quality. Suitable measures as suggested have to be taken up on war footing. In order to assist the planners, designers and executors of water quality treatment in the study area, WQI map has been developed. In order to improve the quality of groundwater through artificial recharge, suitable locations for groundwater augmentation structures are suggested.

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Sample Number	Location	pH	Electrical Conductivity (µmhos/cm)	Total Dissolved Solids (mg/l)	Total Alkalinity (mg/l)	Total Hardness (mg/l)	Fluoride (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Sulphate (mg/l)	Iron (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
1	Kottapalli	7.1	1962	1734	214	365	2.4	372	34	143	0.4	48	26
2	Kishanpalli	7.4	2675	1690	208	380	2.6	390	28	195	0.5	36	22
3	Mal	6.4	2420	1975	236	527	2.3	325	48	62	0.2	29	14
4	Venkateshnagar	6.7	2863	1742	314	605	1.5	431	42	84	0.4	21	28
5	Godkondla	7.2	2268	1875	457	858	2.6	694	58	136	0.3	48	12
6	Polepalli	7.3	996	786	428	273	3.6	96	21	82	0.5	34	16
7	Polepalli Main Road	7.8	842	574	782	180	6.7	128	28	78	0.4	23	32
8	Khandunayak Tanda	7.3	2134	1483	892	612	9.6	491	18	114	0.2	32	16
9	Madanapuram	7.2	2254	1862	974	548	12.7	520	43	148	0.3	26	28
10	Tirgandlapalli	6.9	1385	894	683	426	3.2	248	21	124	0.1	57	14
11	Sakali Seripalli	8.2	2643	1821	547	298	7.4	142	34	86	0.3	41	29
12	Takkallapalli	7.9	1492	829	486	374	2.5	193	58	172	0.4	72	26
13	Ummapur	7.7	2357	1735	652	450	4.8	245	09	134	0.2	64	35
14	Gollapalli	7.8	1126	925	421	438	1.9	296	18	108	0.5	67	18
15	Saireddigudem	6.8	1438	1264	528	342	4.7	224	15	48	0.2	48	23
16	Kurmed	8.1	2719	1014	496	264	1.4	164	38	122	0.2	52	26
17	Mallepalli	7.4	1895	1128	682	514	1.5	428	45	136	0.1	87	35
18	Kurmapalli	7.1	864	910	450	496	1.8	138	16	37	0.5	108	23
19	Kurmapalli Road	7.7	1548	1284	384	515	1.4	298	54	198	0.4	78	34
20	Badvanagudem	7.4	1256	894	558	196	2.7	124	12	44	0.4	52	46
21	Annebainapalli	7.1	864	1045	329	326	1.5	275	46	173	0.2	124	28
22	Battugudem	7.8	1369	928	742	127	4.6	78	26	42	0.3	67	43

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Table 1 Water Quality Parameters Values for Collected Groundwater Samples at Various Locations in Kurmapalli Vagu Basin

24	Lambadi Tanda	7.3	2168	1426	338	643	0.9	260	42	118	0.2	83	17
25	Varkal	6.9	1926	1578	392	726	1.1	379	31	67	0.4	112	34

Table 2 Water Quality Parameters, WHO Standard Values, Ideal Values and Weightage Factors of Water Quality Parameters

Sl. No	Parameter	Standard Value (S_i)	Ideal Value (V_i)	Weightage Factor (W_i)
1	pH	8.5	7	0.1176
2	Electrical Conductivity (µmhos/cm)	300	0	0.0033
3	Total Dissolved Solids (mg/l)	1000	0	0.0010
4	Total Alkalinity (mg/l)	120	0	0.0083
5	Total Hardness (mg/l)	300	0	0.0033
6	Fluoride (mg/l)	1.5	0	0.6666
7	Chloride (mg/l)	250	0	0.0040
8	Nitrate (mg/l)	50	0	0.0200
9	Sulphate (mg/l)	250	0	0.0040
10	Iron (mg/l)	0.3	0	3.3333
11	Calcium (mg/l)	75	0	0.0133
12	Magnesium (mg/l)	30	0	0.0333

Table 3 Status of Water Quality based on WQI

Sl. No	Water Quality Index	Status
1	0-25	Excellent
2	26-50	Good
3	51-75	Poor
4	76-100	Very Poor
5	100 and above	Unsuitable For Drinking (U.F.D.)

Table 4 Water Quality Index Values for Collected Groundwater Samples

Sample Number	Location	WQI	Status
1	Kottapalli	133	U.F.D.
2	Kishanpalli	162	U.F.D.
3	Mal	78	Very Poor
4	Venkateshnagar	123	U.F.D.
5	Godkondla	110	U.F.D.
6	Polepalli	172	U.F.D.
7	Polepalli Main Road	180	U.F.D.
8	Khandunayak Tanda	157	U.F.D.
9	Madanapuram	217	U.F.D.
10	Tirgandlapalli	62	Poor
11	Sakali Seripalli	162	U.F.D.
12	Takkallapalli	136	U.F.D.
13	Ummapur	108	U.F.D.
14	Gollapalli	155	U.F.D.
15	Saireddigudem	104	U.F.D.
16	Kurmed	72	Poor
17	Mallepalli	46	Good
18	Kurmapalli	153	U.F.D.
19	Kurmapalli Road	124	U.F.D.
20	Badvanagudem	137	U.F.D.
21	Annebainapalli	71	Poor
22	Battugudem	132	U.F.D.
23	Vinjamur	44	Good
24	Lambadi Tanda	65	Poor
25	Varkal	120	U.F.D.

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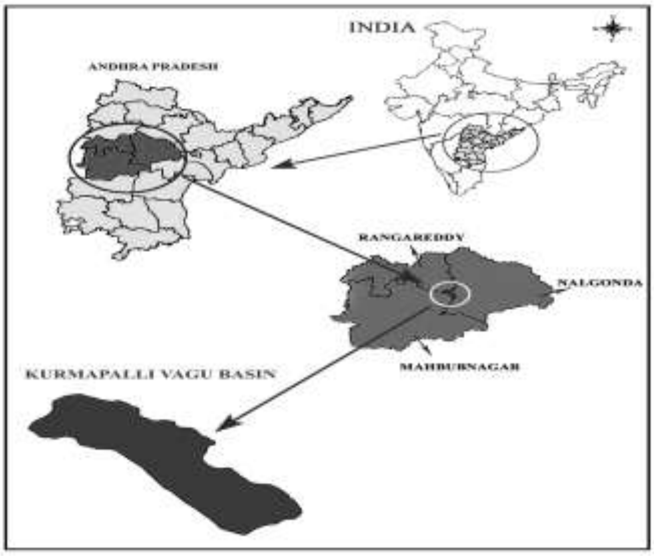

Figure 1 Location Map of Kurmapalli Vagu Basin

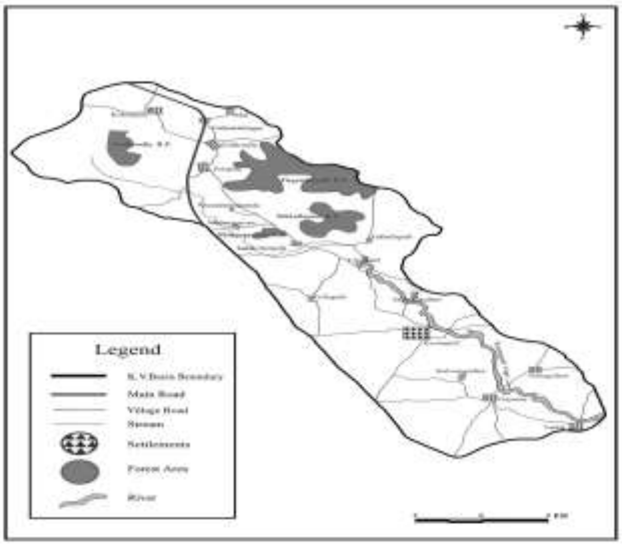

Figure 2 Base Map of Kurmapalli Vagu Basin

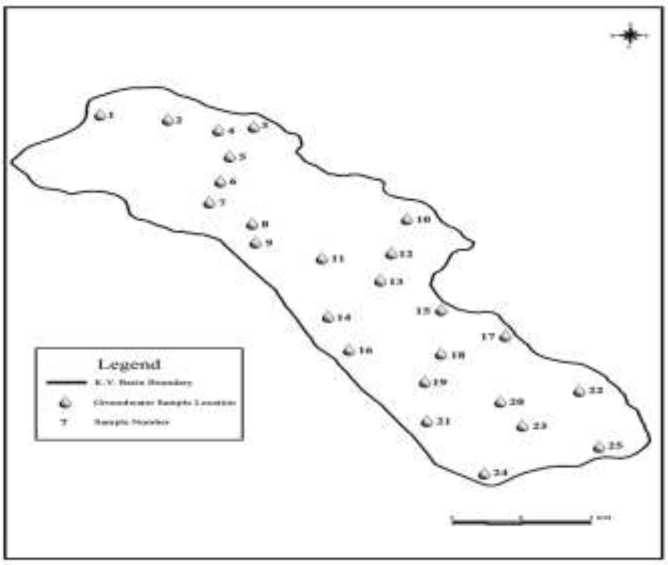

Figure 3 Location Map of Groundwater Samples in Kurmapalli Vagu Basin

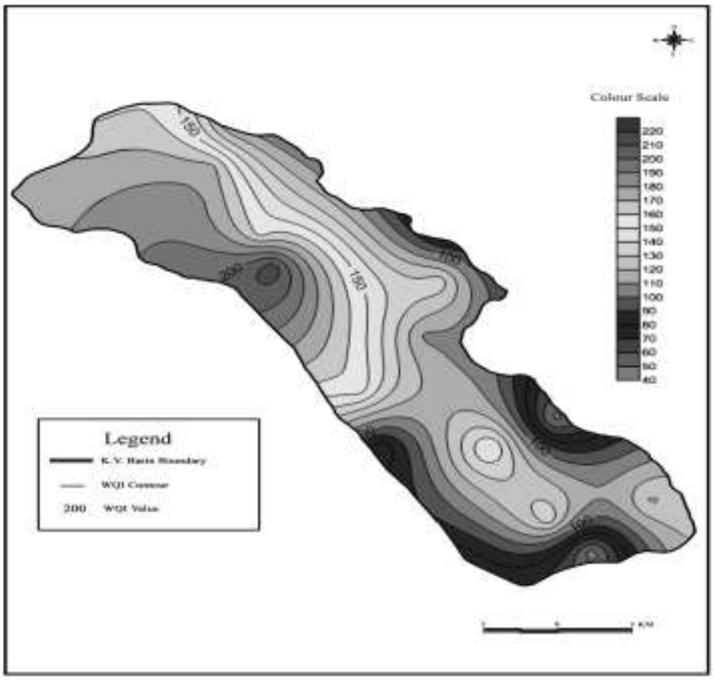

Figure 4 Water Quality Index Contour Map of Kurmapalli Vagu Basin

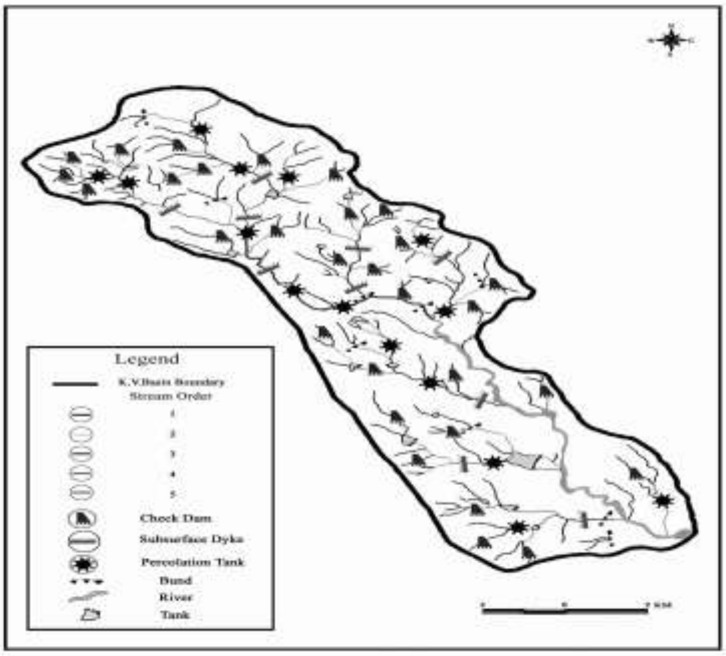

Figure 5 Location Map of Groundwater Augmenting Structures in Kurmapalli Vagu Basin