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ASSESSMENT OF GROUNDWATER QUALITY AND ITS SUITABILITY FOR AGRICULTURAL USAGE IN AND AROUND RANGAMPETA AREA, ANDHRA PRADESH, SOUTH INDIA

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The aim of this study is to assess the groundwater quality of Rangampeta area for irrigation and domestic purposes. The groundwater samples were analyzed for distribution of chemical elements Ca, Mg, Na, K, Si, HCO₃, CO₃, Cl and SO₄. It also includes pH, electrical conductivity, total hardness, non carbonate hardness and total alkalinity. The parameters like sodium absorption ratio, adjusted sodium absorption ratio, sodium percentage, potential salinity, permeability index and residual sodium carbonate were calculated. The dominant hydrochemical facies of groundwater are Ca-Mg-Cl and Na-Cl Water Types. The Gibbs's diagram plots suggest that the chemical weathering of rock forming minerals is the major driving force controlling water chemistry in this area. The positive chloro-alkaline indices revealed that the groundwater has suffered ion exchange between Na and K of water with Ca and Mg of soil during its flow.

Keywords: groundwater quality, physico chemical parameters, rangampeta, south India.

Introduction

Groundwater is an important natural resource especially for drinking and irrigation uses. Water quality assessment is essential for human health and the definition of water quality depends on the desired use of water [1]. The variations of water quality are essentially the combination of both anthropogenic and natural contributions [2]. Natural variations in groundwater hydrochemistry should be considered when assessing water quality data from groundwater monitoring programmers, as elevated concentrations for certain parameters might be influenced by the aquifer lithology [3]. The groundwater chemistry is subject to continuous modifications in any given hydrogeological

environment. Groundwater chemistry is largely a function of the mineral composition of the aquifer through which it flows. As the groundwater moves along its path from recharge to discharge areas, a variety of hydrogeochemical processes altered its chemical composition. The hydrogeochemical processes and hydrogeochemistry of the groundwater vary spatially and temporally, depending on the geology and chemical characteristics of the aquifer.

Groundwater contains minerals carried in solution, the type and concentration of which depends upon several factors like soluble products of rock weathering and decomposition in addition to external polluting agencies and changes in space and time. Geogenic sources are one of the causes for the variation in chemical composition of groundwater which changes with space and time [4, 5]. Hence, it is important to study and understand the different hydrogeochemical characteristics of water quality parameters. The appraisal of water chemistry attains significance, more so for a contaminated aquifer, so as to facilitate understanding the process of pollution and ability of the groundwater to assimilate extraneous elements [6].

Hence, the present study is undertaken to study the groundwater quality assessment around Rangampeta area. This area is located on north latitude from 13° 36' 05" to 13° 37' 10" N and east longitude from 79° 15' 00" to 79° 17' 60" E in Chandragiri mandal, Chittoor district, in Andhra Pradesh. This area is included in the survey of India toposheet No. 57 O/6.

Experimental

Groundwater samples were collected from 30 locations from Rangampeta area. The collected water samples were transferred into precleaned polythene container for analysis of chemical characters. To know the suitability of waters for irrigation, chemical parameters like pH, electrical conductivity (EC), Ca, Mg, Na, K, Si, Cl, HCO₃, CO₃, SO₄, and various chemical index such as total dissolved solids (TDS), total hardness (TH), non carbonate hardness (NCH), total alkalinity (TA), sodium absorption ratio (SAR), adjusted SAR (adj.SAR), sodium percentage (SP), residual sodium carbonate (RSC), and permeability index (PI) were analyzed by adopting the standard procedures of water analysis. The availability of data on field parameters such as EC, pH were measured. The major cations and anions were determined adopting the analytical techniques, which are based on the methods proposed by APHA [7]. The diagrams viz., Chadha's, Wilcox and Gibbs were constructed to study the genesis and water quality of the study area.

Results and discussion

Groundwater chemistry. The major ion chemistry of groundwater from studied area was statistically analyzed and the results summarized by minimum, maximum, mean in a Table. Various methods and graphs were used to study and interpret the water analyses data Fig. 1 to 3.

Minimum, maximum, average and standard deviation values of different constituents of water samples of Rangampeta area

Constituents	Min	Max	Average	St. dev.
Ca, mg/L	7,0	52,0	25,8	14,0
Mg, mg/L	7,0	60,0	29,4	14,6
Na, mg/L	8,0	138,0	66,4	37,4
K, mg/L	2,0	168,0	28,1	48,6
HCO ₃ , mg/L	10,0	327,0	113,0	67,0
CO ₃ , mg/L	2,0	72,0	19,4	16,0
SO ₄ , mg/L	10,0	61,0	31,2	14,1
Cl, mg/L	39,0	306,0	148,1	69,3
Si, mg/L	3,0	11,0	7,2	2,1
pH	7,9	8,6	8,3	0,2
Specific conductance, μ S/m	23000	119000	68300	243
Total dissolved solids, mg/L	150	774	444	158
Hardness as CaCO ₃ , mg/L	71	291	171	57
Non-carbonate hardness as CaCO ₃ , mg/L	-54	179	61	73
Alkalinity as CaCO ₃ , mg/L	44	232	125	49
Sodium adsorption ratio	0,3	4,9	2,2	1,3
Adjusted SAR	0,4	8,2	3,8	2,2
Sodium percentage, %	16,8	68,9	46,9	16,0
Potential salinity, meqL ⁻¹	1,3	8,9	4,5	2,0
Residual sodium carbonate, meqL ⁻¹	-3,5	1,1	-1,2	1,5
Permeability index (PI), %	41,0	92,3	63,5	13,0
Kelly's ratio	0,2	2,2	0,9	0,6
Magnesium ratio, %	19,4	87,9	64,1	18,5
Gibb's ratio I	0,38	0,98	0,68	0,15
Gibb's ratio II	0,31	0,93	0,70	0,18

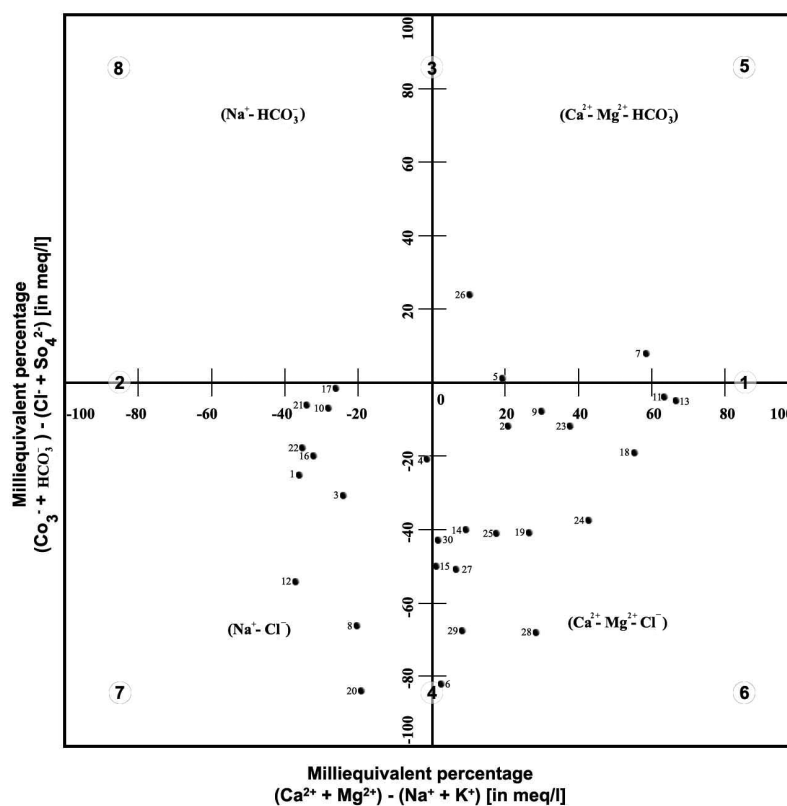


Fig. 1. Chadha's diagram (modified Piper diagram).

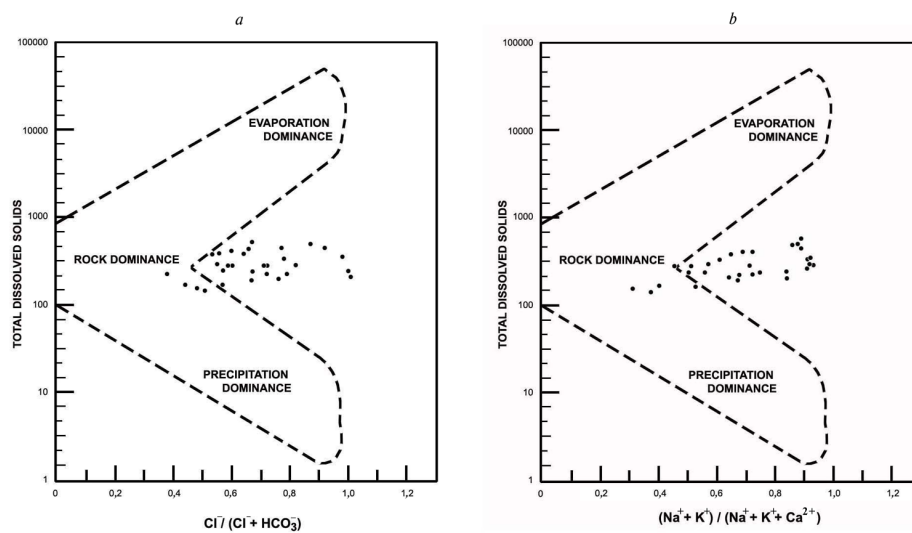


Fig. 2. Mechanism controlling the chemistry of groundwater (after Gibbs 1970): a – dominant anionis Cl^- and HCO_3^- , b – dominant cationis Na^+ , K^+ and Ca^{2+} .

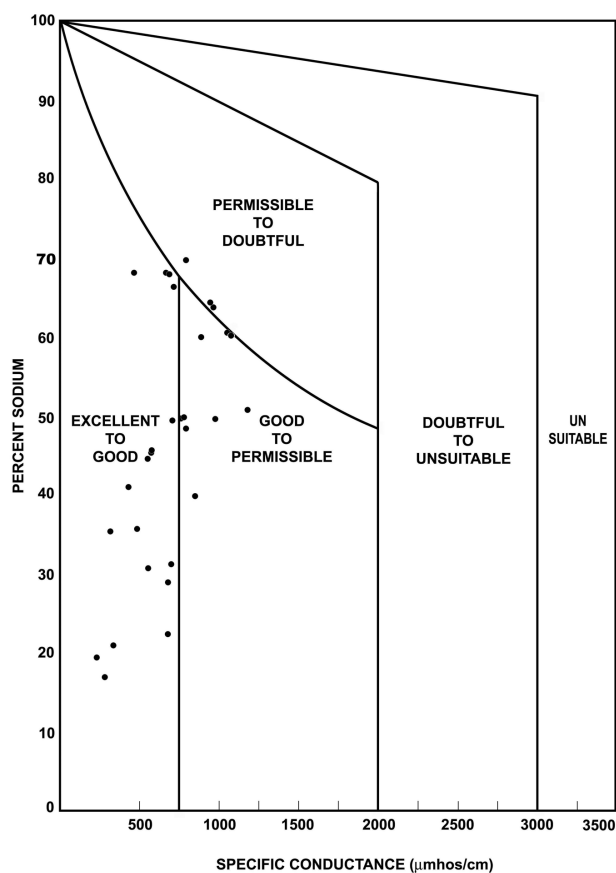


Fig. 3. The quality of water in relation to electrical conductivity and percent sodium (Wilcox diagram).

Hydrogeochemical facies. In the present study, the groundwater of the study area has been classified as per Chadha's diagram [8] in order to identify the hydrochemical processes. The proposed diagram is a modification of Piper diagram [9] with a view to extend its applicability in representing water analysis. This can be also used to study various hydro-chemical processes such as base cation exchange, actual ion concentration, mixing of natural waters and sulphate reduction and other related hydro-chemical problems. Results of analyses were plotted on the proposed diagram to test its applicability for geochemical classification of groundwater and to study hydrochemical processes (see Fig. 2, a, b). It is evident from the results, that about 53% samples fall in Group 6 (Ca-Mg-Cl Water Type) and 37% samples fall in Group 7 (Na- Cl Water Type) and remaining 3 water samples (5,7 and 26) fall in Group Ca-Mg-HCO₃ Water Type.

Mechanisms controlling groundwater chemistry. Gibbs diagrams are widely used to assess the functional sources of dissolved chemical constituents, such as precipitation-dominance, rock-dominance and evaporation dominance [10]. In this diagram the ratio of dominant anions and cations are plotted against the value of TDS. These diagrams are widely employed to assess the functional sources of dissolved chemical constituents, such as precipitation, rock, and evaporation dominance. In the present study area, the dominant anions (Cl and HCO₃) and cations (Na, K and Ca) are plotted against their respective total dissolved solids (see Fig. 3). The Gibbs plot suggest that most of the samples falls in weathering zone, which indicates the groundwater interaction between rock chemistry. Gibbs diagrams suggest that chemical weathering of the rock, which forms minerals. Gibbs ratio I values in the present study varies from 0.38 to 0.98 with an average value of 0,68 and Gibbs ratio II values varies from 0.31 to 0.93 with an average value of 0,70.

Water quality evaluation for irrigation purpose. The most important characteristics of irrigation water in determining its quality are: (i) Total concentration of soluble salts; (ii) Relative proportion of sodium to other principal cations; (iii) Concentration of boron or other element that may be toxic, and (iv) under some condition, bicarbonate concentration as related to the concentration of calcium plus magnesium. These have been termed as the salinity hazard [11, 12], sodium hazard, boron hazard and bicarbonate hazard. In the present study, the following observations were made for assessing the suitability of the ground waters for irrigation purpose.

pH. The pH is a measure of the hydrogen ion concentration in water. The pH value of water indicates whether the water is acidic or alkaline. In the study area, the concentration of hydrogen ion (pH) ranged from 7,9 to 8,6, with a mean value of 8,3. Most of the water samples (87%) have concentration within the safe limit of standard set (6 – 8,5) for irrigation purpose [13].

Salinity hazard. It is well known that EC is a good measure of dissolved solids in water. TDS generally reflects the amount of minerals content that dissolved in the water, and this controls its suitability for use. High concentration of total dissolved solid may cause deleterious effects on plant growth and soil quality. Highly mineralized water may also deteriorate domestic plumbing and appliances. In present investigation, the electrical conductivity of water samples varies from 23000 to a maximum of 119000 $\mu\text{S}/\text{m}$ with an average value of 68300 $\mu\text{S}/\text{m}$. Also, the concentration value of TDS ranged from 150 to 774 mg/L with the mean value of 444 mg/L. As per Wilcox [12] EC grading classification, in the present study about 63,3% of the water samples are classified as good, 33,3% as permissible, and 3,3% as excellent waters category.

Potential salinity (PS). Doneen [14] explained that the suitability of water for irrigation is not dependent on soluble salts. Doneen [15] is of the opinion that the low solubility salts precipitate in the soil and accumulate with each successive irrigation, whereas the concentration of highly soluble salts increase the soil salinity. Potential salinity is defined as the chloride concentration plus half of the sulphate concentration as showed below:

$$PS = Cl^{-} + \frac{1}{2}SO_4^{2-}$$

All ionic concentration is in meq^l⁻¹.

The potential salinity of the water samples ranged from 1,3 to 8,9 with an average value of 4,5 meq^l⁻¹. It suggests that the potential salinity in the groundwater of the studied area nearly is high, thus, making the water salinity hazard in soil of studied area. High values of potential salinity in the area can be ascribed to high chloride and sodium content that may derived from the human activities in the studied area.

Total hardness. The hardness is the measure of the capacity of water to react with soap and hard water requiring considerably more soap to produce lather. Hard water minerals primarily consist of calcium (Ca²⁺), and magnesium (Mg²⁺) metal cations, and sometimes other dissolved compounds such as iron. Calcium usually enters the water as either calcium carbonate (CaCO₃), in the form of limestone and chalk, or calcium sulfate (CaSO₄), in the form of other mineral deposits. In the present study, the predominant source of calcium is from granitic rocks. In the present study, hardness values are ranging from 71 to 291 with an average value of 171 mg/L as CaCO₃. Based on McGowan [16] water with hardness below 75 mg/L as CaCO₃, is generally considered as soft, 75 – 150, moderately hard, 150 – 300, hard and more than 300, very hard. Based on this classification, 3% of the surveyed water samples fall on soft category, 40% fall on moderately hard category and the rest of samples (57%) fall on hard category. In general, water with hardness more than 200 mg/L as CaCO₃ will lead to scale deposits in the piping system [17]. Thus, the result suggests that most of the water samples (73%) can safe for plumbing of irrigation systems.

Total alkalinity. Alkalinity is a measure of the ability of a solution to neutralize acids to the equivalence point of carbonate or bicarbonate. On the other word, alkalinity is closely related to the acid neutralizing capacity of a solution. In the natural environment carbonate alkalinity tends to make up most of the total alkalinity due to the common occurrence and dissolution of carbonate rocks and presence of carbon dioxide in the atmosphere. Alkalinity is important because

it buffers pH changes that occur naturally during photosynthetic cycles, water exchanges, etc. From the Table, it is clear that the alkalinity ranges from 44 to 232 with a mean value of 125 mg/L as CaCO₃ in the studied area.

Non-carbonate hardness (NCH). Hardness of water relates to the reaction with soap, since Ca and Mg ions precipitate soap. Hardness is expressed as mg/L of CaCO₃. If the hardness as CaCO₃ exceeds the difference between the alkalinity as CaCO₃ and hardness as CaCO₃, it is termed as NCH. Non carbonate hardness is also called permanent hardness. From the Table, it can be delineated that the NCH values ranged from – 54 to 179 with an average value of 61 mg/L as CaCO₃.

Sodium hazard. Excess sodium in waters produces the undesirable effects on soil structure and growth and development of plants. Hence, the assessment of sodium concentration is necessary while considering the suitability for irrigation. Plants are detrimentally affected; both excess absorption of sodium and immobilize of nutrient ions particularly Ca²⁺, Mg²⁺ and K⁺ by sodium in soil. Sodium replacing adsorbed calcium and magnesium is a hazard as it causes damage to the soil structure. Soils with an accumulation of exchangeable sodium are often characterized by poor till and low permeability making them unfavorable for plant growth [18 – 22]. In the past, the sodium hazard has been expressed as percent sodium of total cations. A better measure of the sodium hazard for irrigation is the SAR which is concentration of sodium relative to the concentrations of calcium and magnesium in water. It is directly related to the amount of sodium that is absorbed by soils. On the other word, the degree to which the irrigation water tends to enter into cation exchange reaction in soil can be indicated by the SAR [23]. Since sodium replaces adsorbed calcium and magnesium in soil, hence it is expressed as:

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{(\text{Ca}^{2+} + \text{Mg}^{2+})}{2}}}$$

All ionic concentration is in meq l⁻¹.

The SAR values of the groundwater samples in the studied area varied from 0,3 to 4,9 with an average value of 2,2 (see Table). As per classification of Wilcox [12], water with SAR ≤ 10 is considered as an excellent quality, between 10 to 18 is good; between 18 to 26 is fair and greater than 26 is said to be unsuitable for irrigation purpose in its natural form. As evident from Table. The SAR values of all the water samples of the study area to be less than 10, and are classified as excellent for irrigation.

From the Table, it is observed that the sodium percentage values of the studied area samples vary from 16,78 to 68,95% with an average value of 46,88%. Sodium percentage is plotted against conductivity, which is designated as Wilcox diagram and is illustrated in Fig. 3. The classification of groundwater was grouped based sodium in the water is increased in the form of sodium on sodium percentage as excellent (<20%), good (20 – 40%), permissible (40 – 60%), doubtful (60 – 80%) and unsuitable (>80%) [24]. In this study, water samples fall into the categories of "excellent to good" (60%), "good to permissible" (27%) and "permissible to doubtful" (13%).

Carbonate and bicarbonates hazard. The relative abundance of sodium with respect to alkaline earths and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence irrigation water quality. This excess is denoted by RSC and determined as suggested by Richards [25]. Because in waters having high concentration of bicarbonate and carbonate, there is tendency for calcium and magnesium to precipitate as calcite and magnesite, which increases sodium hazard and its related problems such as reducing soil permeability, soil aeration, high pH, inhibit root penetration, etc. [20, 21, 26].

According to the U.S. Salinity Laboratory [23], a RSC value less than 1,25 meq^l⁻¹ is safe for irrigation; a value between 1,25 and 2,5 meq^l⁻¹ is marginal quality and a value greater than 2,5 meq^l⁻¹ is unsuitable for irrigation. From the Table, it can be interpreted that the groundwater in the studied area shows RSC values of –3,5 to 1,1 with a mean value of –1,2 meq^l⁻¹. Based on RSC values, over 30 samples have values less than 1,25, which elucidates that all the groundwater in the studied area are safe for irrigation.

Doneen [27], Ayers and Wescot [13] have also determined the hazardous effect of excessive amount of bicarbonate and carbonate on water quality for irrigation usage in terms of permeability index (PI) and adjusted sodium adsorption ratio (adj.SAR), respectively. Permeability index and adj.SAR are computed as:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{(Ca^{2+} + Mg^{2+} + Na^+)} \cdot 100; \quad (1)$$

$$adj.SAR = SAR[1 + (8,4 - pH_c)]; \quad (2)$$

$$pH_c = (pK_2 - pK_c) + p(Ca + Mg) + p(Alk),$$

where pK_2 – negative logarithm of the second dissociation constant for carbonic acid, pK_c – solubility constant for calcite, p – negative logarithm of ion concentration. All ionic concentration is in meq^l⁻¹

Waters can be classified as Class I, Class II and Class III orders with regard to PI. Class I and Class II waters are categorized as good for irrigation with 75% or more of maximum permeability. Class III waters are unsuitable with 25% of maximum permeability [27]. From the Table, it can be demarcated that the PI values vary from 40,1 to 92,3 with an average of 63,5. Eighty-three percent of water samples fall into the Class I Category of Doneen's chart and are categorized as good for irrigation.

Concerning adj.SAR the water samples ranged from 0,4 to 8,2 with a mean value of 3,8 (see Table). Based on Ayers and Tanji [28] classification, 46,6% of samples have adj.SAR values less than 3 and are safe for irrigation and remained samples (53,4%) of samples have adj.SAR values between 3 and 9 are increasing problem for irrigation due to sodium hazard.

In general, the obtained results from the calculation of RSC, PI and adj. SAR suggest that nearly the water samples are suitable for irrigation with regard to carbonate and bicarbonates hazard.

Chloro-alkaline indices. The ion exchange between the groundwater and its host environment during residence or travel is well understood by studying the chloro-alkaline indices. The ion exchange of Na and K from water with Ca and Mg, the indices is positive while if the exchange is reverse then the indices are negative [29]. The statistics of chloro-alkaline indices 1, 2 of the study indicates 73% of the groundwater samples have positive and 27% negative values. It simply implies that the groundwater of Rangampeta area has suffered ion exchange between alkali and alkaline earth metals.

Conclusion

Interpretation of analytical data showed that the abundance of the major ions is as follows: $\text{Na} > \text{Mg} \approx \text{K} > \text{Ca} > \text{Si}$ and $\text{Cl} > \text{HCO}_3 > \text{SO}_4 > \text{CO}_3$. The groundwater quality variations are mainly related to groundwater-rock interaction. The chemical composition of groundwater of the study area is strongly influenced by rock water interaction, dissolution and deposition of silicates group of minerals present in granites. The Gibbs diagrams support these analysis results and suggest that chemical weathering of the rock forming minerals are the main controlling mechanisms of groundwater quality. Chemical dissolution of bed rock/minerals plays an important role in determining the geochemistry of natural waters. The major source of dissolved species to natural water is the rocks forming in contact with water, water rock interactions starts and moves forward towards equilibrium by dissolving or leaching bedrock minerals in to the solution.

The results obtained from Chadhas diagram that about 53% samples fall in Group 6 (Ca-Mg-Cl Water Type) and 37% samples fall in Group 7 (Na- Cl-Water Type). Most of the samples fall under Class I in PI calculation, revealing that most of the stations are suitable for irrigation. The Wilcox classification shows that majority of samples from most of the stations fall under "excellent to good" and "good to permissible limits". The study reveals that most of the stations require special type of irrigation methods to control the high salinity that will improve the yield of crop production. But, the water can be used safely for irrigation with special circumstances for salinity control such as leaching requirement or cropping of salt tolerant plants.

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