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Water quality guidelines for the management of pond fish culture

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ABSTRACT

The Optimum fish production is totally dependent on the physical, chemical and biological qualities of water to most of the extent. Hence, successful pond management requires an understanding of water quality. Water quality is determined by variables like temperature, transparency, turbidity, water colour, carbon dioxide, pH, alkalinity, hardness, unionised ammonia, nitrite, nitrate, primary productivity, BOD, plankton population etc. In the present chapter water quality management principles in fish culture have been reviewed to make aware the fish culturist and environmentalist about the important water quality factors that influence health of a pond and are required in optimum values to increase the fish yields to meet the growing demands of present day scenario of the world, when the food resources are in a state of depletion and the population pressure is increasing on these resources.

Keywords: Assessment and Monitoring, Culture, Fish productivity, Parameters, Water quality

1. Introduction

Fish is an inexpensive source of protein and an important cash crop in many regions of world and water is the physical support in which they carry out their life functions such as feeding, swimming, breeding, digestion and excretion (Bronmark and Hansson, 2005). Water quality is determined by various physico-chemical and biological factors, as they may directly or indirectly affect its quality and consequently its suitability for the distribution and production of fish and other aquatic animals (Moses, 1983). Many workers have reported the status of water bodies (lentic and lotic) after receiving various kinds of pollutants altering water quality characteristics (physical, chemical and biological). All living organisms have tolerable limits of water quality parameters in which they perform optimally. A sharp drop or an increase within these limits has adverse effects on their body functions (Davenport, 1993: Kiran, 2010). So, good water quality is very essential for survival and growth of fish. As we know fish is an important protein rich food resource and there has been sharp increase in demand of fish products due to increasing population pressure in this century. Thus to meet the demand of present food supply, water quality management in fish ponds is a necessary step that is required to be taken up.

In most of the countries, fishes are cultivated in ponds (lentic water) but unfortunately such culturists are not so aware of importance of water quality management in fisheries. If they are properly guided and make aware about water quality management practices, they can get maximum fish yield in their ponds to a greater extent through applying low input cost and getting high output of fish yield. The role of various factors like temperature, transparency, turbidity, water colour, carbon dioxide, pH, alkalinity, hardness, ammonia, nitrite, nitrate, primary productivity, biochemical oxygen demand (BOD), plankton population etc. can't be overlooked for maintaining a healthy aquatic environment and for the production of sufficient fish food organisms in ponds for increasing fish production. Therefore, there is the need to ensure that, these environmental factors are properly managed and regulated for good survival and optimum growth of fish. The objective of the present chapter is to review and present a concise opinion regarding the optimum levels of water quality characteristics required for maximum fish production.

2. Discussion

Fish do not like any kind of changes in their environment. Any changes add stress to the fish and the larger and faster the changes, the greater the stress. So the maintenance of all the factors becomes very essential for getting maximum yield in a fish pond. Good water quality is characterised by adequate oxygen, proper temperature, transparency, limited levels of metabolites and other environmental factors affecting fish culture. The initial studies of water quality of a fish pond in India were probably conducted by Sewell (1927) and Pruthi (1932). After that many workers have studied the physico-chemical condition of inland waters either in relation to fish mortality or as part of general hydrological survey (Alikunhi *et al*., 1952: Upadhyaya, 1964). The details of various pond ecosystems also have been studied by workers (Mumtazuddin *et al*., 1982: Delince, 1992: Garg and Bhatnagar, 1999: Bhatnagar, 2008). Bhatnagar and Singh (2010) studied the pond fish culture in relation to water quality in Haryana. However, the present chapter would provide the basic guidelines, parameter wise for the fish farmers in obtaining high fish yield in low input via maintaining water quality of their ponds.

Temperature is defined as the degree of hotness or coldness in the body of a living organism either in water or on land (Lucinda and Martin, 1999). As fish is a cold blooded animal, its body temperature changes according to that of environment affecting its metabolism and physiology and ultimately affecting the production. Higher temperature increases the rate of bio-chemical activity of the micro biota, plant respiratory rate, and so increase in oxygen demand. It further cause decreased solubility of oxygen and also increased level of ammonia in water. However, during under extended ice cover, the gases like hydrogen sulphide, carbon dioxide, methane, etc. can build up to dangerously high levels affecting fish health.

Desirable limits

According to Delince (1992) 30-35^{0}C is tolerable to fish, Bhatnagar *et al.* (2004) suggested the levels of temperature as 28-32^{0}C good for tropical major carps; <12^{0}C – lethal but good for cold water species; 25-30^{0}C – ideal for *Penaeous monodon* culture; < 20^{0}C – sub lethal for growth and survival for fishes and > 35^{0}C- lethal to maximum number of fish species and according to Santhosh and Singh (2007) suitable water temperature for carp culture is between 24 and 30^{0}C.

Remedies

1. By water exchange, planting shady trees or making artificial shades during summer's thermal stratification can be prevented.

2. Mechanical aeration can prevent formation of ice build-up in large areas of the pond.

Turbidity

Ability of water to transmit the light that restricts light penetration and limit photosynthesis is termed as turbidity and is the resultant effect of several factors such as suspended clay particles, dispersion of plankton organisms, particulate organic matters and also the pigments caused by the decomposition of organic matter.

Desirable limits

Boyd and Lichtkoppler (1979) suggested that the clay turbidity in water to 30 cm or less may prevent development of plankton blooms, 30 to 60 cm and as below 30 cm - generally adequate for good fish production and there is an increase in the frequency of dissolved oxygen problems when values above 60 cm, as light penetrates to greater depths encourage underwater macrophyte growth, and so there is less plankton to serve as food for fish. According to Bhatnagar *et al*. (2004) turbidity range from 30-80 cm is good for fish health; 15-40 cm is good for intensive culture system and < 12 cm causes stress. According to Santhosh and Singh (2007) the secchi disk (fig.1) transparency between 30 and 40 cm indicates optimum productivity of a pond for good fish culture.

Remedies

Addition of more water or lime (CaO, alum $Al_2(SO_4)_3 14H_2O$ at a rate of 20 mg L^{-1} and gypsum on the entire pond water at rate of 200 Kg/ $1000m^3$ of pond can reduce turbidity

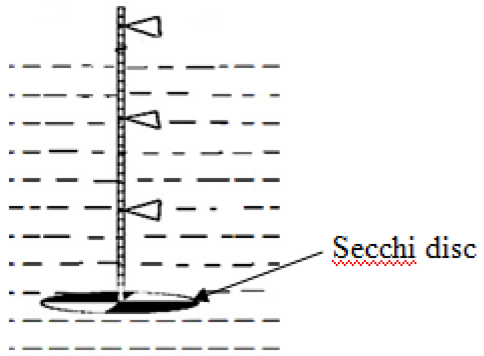

Figure 1: Measurement of turbidity using Secchi disc.

Water Colour

The colour of an object is defined by the wavelengths of visible light that the object reflects.

Desirable limits

National Agricultural Extension and Research (1996) states pale colour, light greenish or greenish waters suitable for fish culture and according to Bhatnagar *et al*. 2004 dark brown colour is lethal for fish/shrimp culture, light green colour- good for fish/shrimp culture, dark green colour is not ideal for fish/shrimp culture and clear water is unproductive for fish/shrimp culture. Delince (1992) stated that the abundance of phytoplankton and zooplankton is responsible for the determination of colour of an aquatic body and Green, bluish green/ brown greenish colour of water indicates good plankton population hence, good for fish health.

Remedies

Application of organic and inorganic fertilizers in clear water ponds may increase productivity.

Dissolved Oxygen (DO)

Dissolved oxygen affects the growth, survival, distribution, behaviour and physiology of shrimps and other aquatic organisms (Solis, 1988). The principal source of oxygen in water is atmospheric air and photosynthetic planktons. Obtaining sufficient oxygen is a greater problem for aquatic organisms than terrestrial ones, due to low solubility of oxygen in water and solubility decreases with factors like- increase in temperature; increase in salinity; low atmospheric pressure, high humidity, high concentration of submerged plants, plankton blooms. Oxygen depletion in water leads to poor feeding of fish, starvation, reduced growth and more fish mortality, either directly or indirectly (Bhatnagar and Garg, 2000).

Indication of low Dissolved oxygen

If fish comes to the surface of water (figure 2) and secchi disk reading falls below 20 cm, fish swim sluggishly and are weakened.

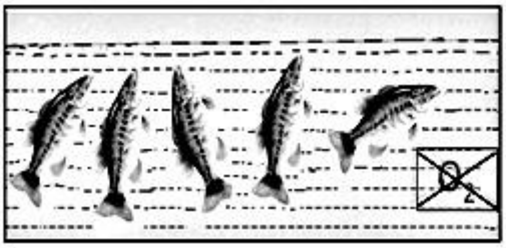

Figure 2: Stressed fishes due to low DO levels at surface of water

Desirable limits

According to Banerjea (1967) DO between 3.0-5.0 ppm in ponds is unproductive and for average or good production it should be above 5.0 ppm. It may be incidentally mentioned that very high concentration of DO leading to a state of super saturation sometimes becomes lethal to fish fry during the rearing of spawn in nursery ponds (Alikunhi *et al*., 1952) so for oxygen, the approximate saturation level at 50° F is 11.5 mg L^{-1}, at 70° F., 9 mg L^{-1}, and at 90° F., 7.5 mg L^{-1}. Tropical fishes have more tolerance to low DO than temperate fishes. According to Bhatnagar and Singh (2010) and Bhatnagar *et al*. (2004) DO level >5ppm is essential to support good fish production. Bhatnagar *et al*. (2004) also suggested that 1-3 ppm has sublethal effect on growth and feed utilization; 0.3-0.8 ppm is lethal to fishes and >14 ppm is lethal to fish fry, and gas bubble disease may occur. DO less than 1- Death of Fish, Less than 5 -Fish survive but grow slowly and will be sluggish, 5 and above- Desirable. According to Santhosh and Singh (2007) Catfishes and other air breathing fishes can survive in low oxygen concentration of 4 mg L^{-1}. Ekubo and Abowei (2011) recommended that fish can die if exposed to less than 0.3 mg L^{-1} of DO for a long period of time, minimum concentration of 1.0 mg L^{-1} DO is essential to sustain fish for long period and 5.0 mg L^{-1} are adequate in fishponds.

<u>Remedies</u> (i) Avoid over application of fertilizers and organic manure to manage DO level (ii) Physical control aquatic plants and also management of phytoplankton biomass (iii) Recycling of water and use of aerators. (iv) Artificially or manually beating of water. (v)

Avoid over stocking of fishes. (vi) Introduction of the hot water gradually with pipes to reduce if DO level is high.

Biochemical oxygen demand (BOD)

BOD is the measurement of total dissolved oxygen consumed by microorganisms for biodegradation of organic matter such as food particles or sewage etc. The excess entry of cattle and domestic sewage from the non point sources and similarly increase in phosphate in the village ponds may be attributed to high organic load in these ponds thus causing higher level of BOD.

Desirable limits

Clerk (1986) reported that BOD range of 2 to 4 mg L^{-1} does not show pollution while levels beyond 5 mg L^{-1} are indicative of serious pollution. According to Bhatnagar *et al*. (2004) the BOD level between 3.0-6.0 ppm is optimum for normal activities of fishes; 6.0-12.0 ppm is sublethal to fishes and >12.0 ppm can usually cause fish kill due to suffocation. Santhosh and Singh (2007) recommended optimum BOD level for aquaculture should be less than 10 mg L^{-1} but the water with BOD less than 10-15 mg L^{-1} can be considered for fish culture. Bhatnagar and Singh (2010) suggested the BOD <1.6mg L^{-1} level is suitable for pond fish culture and according to Ekubo and Abowei (2011) aquatic system with BOD levels between 1.0 and 2.0 mg L^{-1} -considered clean; 3.0 mg L^{-1} fairly clean; 5.0 mg L^{-1} doubtful and 10.0 mg L^{-1} definitely bad and polluted.

Remedies

1. Add lime/more, suspending use of fertilizers, removal of nonbiodegradable / floating organic matter from the pond surface, aeration, screening or skimming to reduce BOD level.
2. Before stocking, pondwater may be allowed to stabilize for few days (5-15 days).
3. Add safe quantities of manure accordingly local conditions of pond in terms of differences in type of manure, water temperature and normal dissolved oxygen.

Carbon-dioxide (CO_2)

Free carbon dioxide, highly soluble gas in water, main source of carbon path way in the nature, is contributed by the respiratory activity of animals and can exist in water as bicarbonate or carbonates in the dissolved or bound form in earth crust, in limestone and coral reefs regions.

$$CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^- \Leftrightarrow 2H^+CO_3^-$$

When dissolved in water it forms carbonic acid which decrease the pH of any system, especially insufficiently buffered systems, and this pH drop can be harmful for aquatic organisms.

Desirable limits

According to Boyd and Lichtkoppler (1979) fish avoid free CO_2 levels as low as 5 mg L^{-1} but most species can survive in waters containing up to 60 mg L^{-1} carbon dioxide, provided DO concentrations are high. Swann (1997) suggested that fish can tolerate concentrations of 10 ppm provided DO concentrations are high and water supporting good fish populations normally contain less than 5 ppm of free CO_2. According to Ekubo and Abowei (2011) tropical fishes can tolerate CO_2 levels over 100 mg L^{-1} but the ideal level of CO_2 in fishponds is less than 10 mg L^{-1}. Bhatnagar *et al*. (2004) suggested 5-8 ppm is essential for photosynthetic activity; 12-15 ppm is sublethal to fishes and 50-60 ppm is lethal to fishes. The free carbon dioxide in water supporting good fish population should be less than 5 mg L^{-1} (Santhosh and Singh, 2007).

Remedies

1. Proper aeration can "blow" off the excess gas
2. Check organic load and reduce the same by adding more water (no fish) and add Muriatic acid (swimming pool acid) to adjust the pH to about 5 or if possible remove the matter by repeated nettings.
3. Use of lime ($CaCO_3$) or sodium bicarbonate ($NaHCO_3$) (iv) Application of potassium permanganate at the rate 250 g for 0.1 hectare.

pH

pH is measured mathematically by, the negative logarithm of hydrogen ions concentration. The pH of natural waters is greatly influenced by the concentration of carbon dioxide which is an acidic gas (Boyd, 1979).

Desirable limits

Fish have an average blood pH of 7.4, a little deviation from this value, generally between 7.0 to 8.5 is more optimum and conducive to fish life. pH between 7 to 8.5 is ideal for biological productivity , fishes can become stressed in water with a pH ranging from 4.0 to 6.5 and 9.0 to 11.0 and death is almost certain at a pH of less than 4.0 or greater than 11.0 (Ekubo and Abowei, 2011). According to Santhosh and Singh (2007) the suitable pH range for fish culture is between 6.7 and 9.5 and ldeal pH level is between 7.5 and 8.5 and above and below this is stressful to the fishes. Ideally, an aquaculture pond should have a pH between 6.5 and 9 (Wurts and Durborow, 1992: Bhatnagar *et al*., 2004). Bhatnagar *et al*. (2004) also recommended that <4 or >10.5 is lethal to fish/shellfish culture; 7.5-8.5 is highly congenial for *P.monodon*; 7.0-9.0 is acceptable limits; 9.0 -10.5 is sublethal for fish culture.

Figure 3: Suitable pH range for pond fish culture.

Remedies

1. Add gypsum ($CaSO_4$) or organic matter (cowdung, poultry droppings etc.) and initial pre-treatment or curing of a new concrete pond to reduce pH levels.
2. Use of quicklime (CaO) to rectify low pH of aquatic body.

Alkalinity

Alkalinity is the water's ability to resist changes in pH and is a measure of the total concentration of bases in pond water including carbonates, bicarbonates, hydroxides, phosphates and borates, dissolved calcium, magnesium, and other compounds in the water. Lime leaching out of concrete ponds or calcareous rocks, photosynthesis, denitrification and sulphate reduction is mainly responsible for increasing alkalinity while respiration, nitrification and sulphide oxidation decrease or consume alkalinity (Stumn and Morgan, 1981: Cook *et al.*, 1986) and to a lesser degree it increases due to evaporation and decomposing organic matter. But if the alkalinity is low, it indicates that even a small amount of acid can cause a large change in our pH.

Desirable limits

Moyle (1946) gave the range of total alkalinity as 0.0 - 20.0 ppm for low production, 20.0 - 40.0 ppm- low to medium, 40.0 - 90.0 ppm- medium to high production and above 90.0 ppm- productive. Boyd and Lichtkoppler (1979) suggested that water with total alkalinities of 20 to 150 mg L^{-1} contain suitable quantities of carbon dioxide to permit plankton production for fish culture. According to Wurts and Durborow (1992) alkalinity between 75 to 200 mg L^{-1}, but not less than 20 mg L^{-1} is ideal in an aquaculture pond. Swann (1997) recommended total alkalinity values of at least 20 ppm for catfish production and for good pond productivity. Bhatnagar *et al*. (2004) suggested that <20ppm indicates poor status of waterbody, 20-50 ppm shows low to medium, 80-200 ppm is desirable for fish/prawn and >300 ppm is undesirable due to non- availability of CO_2. Stone and Thomforde (2004) suggested 50-150 mg L^{-1} ($CaCO_3$) as desirable range; an acceptable range of above 20 mg L^{-1} and less than 400 mg L^{-1} for ponds and above 10 mg L^{-1} for hatchery water. According to Santhosh and Singh (2007) the ideal value for fish culture is 50-300 mg L^{-1}.

Remedies

1. Fertilize the ponds to check nutrient status of pondwater
2. Alkalinity can be increased by calcium carbonate, concrete blocks, oyster shells, limestone, or even egg shells depending upon soil pH and buffering capacity.

Hardness

Hardness is the measure of alkaline earth elements such as calcium and magnesium in an aquatic body along with other ions such as aluminium, iron, manganese, strontium, zinc, and hydrogen ions. Calcium and magnesium are essential to fish for metabolic reactions such as bone and scale formation.

Desirable limits

The recommended ideal value of hardness for fish culture is at least 20 ppm (Swann, 1997) and a range of 30-180 mg L^{-1} (Santhosh and Singh, 2007). According to Stone and Thomforde (2004) the desirable Range is 50-150 mg L^{-1} as $CaCO_3$ and acceptable Range is above 10 mg L^{-1} as $CaCO_3$. According to Bhatnagar *et al*. (2004) hardness values less than 20ppm causes stress, 75-150 ppm is optimum for fish culture and >300 ppm is lethal to fish life as it increases pH, resulting in non-availability of nutrients. However, some euryhaline species may have high tolerance limits to hardness.

Remedies

1. Add quicklime/alum/both and add zeolite to reduce hardness.
2. During heavy rainfall avoid the runoff water to bring lot of silt into the fish pond.

Calcium

Calcium is generally present in soil as carbonate and most important environmental, divalent salt in fish culture water. Fish can absorb calcium either from the water or from food.

Desirable limits

Wurts and Durborow (1992) recommended range for free calcium in culture waters is 25 to 100 mg L^{-1} (63 to 250 mg L^{-1} $CaCO_3$ hardness) and according to them Channel catfish can tolerate minimum level of mineral calcium in their feed but may grow slowly under such conditions. Water with free calcium concentrations as low as 10 mg L^{-1} if pH is above 6.5 can be tolerated by Rainbow trout, 40 to 100 mg L^{-1} range (100 to 250 mg L^{-1} as $CaCO_3$ hardness) are desirable for striped bass, red drum or crawfish.

Conductivity

Conductivity is an index of the total ionic content of water, and therefore indicates freshness or otherwise of the water (Ogbeibu and Victor, 1995). Conductivity can be used as indicator of primary production (chemical richness) and thus fish production. Conductivity of water depends on its ionic concentration (Ca^{2+}, Mg^{2+}, HCO_3^-, CO_3^-, NO_3^- and PO_4^-), temperature and on variations of dissolved solids. Distilled water has a conductivity of about 1 µ mhos/cm and natural waters have conductivity of 20-1500 µ mhos/cm (Abowei, 2010). Conductivity of freshwater varies between 50 to 1500 hs/cm (Boyd, 1979), but in some polluted waters it may reach 10,000 hs/cm and seawater has conductivity around 35,000 hs/cm and above.

Desirable limits

As fish differ in their ability to maintain osmotic pressure, therefore the optimum conductivity for fish production differs from one species to another. Sikoki and Veen (2004) described a conductivity range of 3.8 -10 hs/cm as extremely poor in chemicals, Stone and Thomforde (2004) recommended the desirable range 100-2,000 mSiemens/cm and acceptable range 30-5,000 mSiemens/cm for pond fish culture.

Salinity

Salinity is defined as the total concentration of electrically charged ions (cations – Ca^{++}, Mg^{++}, K^+, Na^+ ; anions – CO_3^-, HCO_3^-, SO_4^-, Cl^- and other components such as NO_3^-, NH_4^+ and PO_4^-). Salinity is a major driving factor that affects the density and growth of aquatic organism's population (Jamabo, 2008).

Desirable limits

Fish are sensitive to the salt concentration of their waters and have evolved a system that maintains a constant salt ionic balance in its bloodstream through the movement of salts and water across their gill membranes. According to Meck (1996) fresh and saltwater fish species generally show poor tolerance to large changes in water salinity. Often salinity limits vary species to species level. Garg and Bhatnagar (1996) have given desirable range 2 ppt for common carp; however, Bhatnagar *et al*. (2004) gave different ideal levels of salinity as 10-20 ppt for *P. monodon*; 10-25 ppt for euryhaline species and 25-28 ppt for *P. indicus*. Barman *et al*. (2005) gave a level of 10 ppt suitable for *Mugil cephalus* and Garg *et al*. (2003) suggested 25 ppt for *Chanos chanos* (Forsskal)

Remedies

1. Salinity is increased or diluted by replenishment of water.
2. Aeration is essential to equalise the water salinity all over the water column.

Chloride

Chlorine (Cl^-) is a gas which is added in water as a disinfectant to control harmful bacteria and Chloride is the same element found in the form of a salt, both have dramatically different chemical properties. Chloride is a common component of most waters and is useful to fish in maintaining their osmotic balance**.**

Desirable limits

According to Stone and Thomforde (2004) the desirable range of chlorides for commercial catfish production is above 60 mg L^{-1} and acceptable range is 10 times the nitrite concentration. Chloride (in the form of salt) is required at a minimum concentration of 60 mg L^{-1} and a ratio of chloride to nitrite of 10:1 reduces nitrite poisoning as catfish are susceptible to "brown blood" disease (caused by excess nitrite in the water). It becomes a matter of concern if chloride levels become high as above 100 mg L^{-1} in the waters because even in very small concentrations, it burns the edges of the gills with long term after effects and its acceptable range is 0. However, chloride content of water is also dependent on Salinity level.

Ammonia (NH_3)

Ammonia is the by-product from protein metabolism excreted by fish and bacterial decomposition of organic matter (fig- 4) such as wasted food, faeces, dead planktons, sewage etc. The unionized form of ammonia (NH_3) is extremely toxic while the ionized form (NH_4^+) is not and both the forms are grouped together as "total ammonia".

Effect

Ammonia in the range >0.1 mg L^{-1}1tends to cause gill damage, destroy mucous producing membranes, "sub- lethal" effects like reduced growth, poor feed conversion, and reduced disease resistance at concentrations that are lower than lethal concentrations, osmoregulatory imbalance, kidney failure. Fish suffering from ammonia poisoning generally appear sluggish or often at the surface gasping for air.

Desirable limits

The toxic levels for un-ionized ammonia for short-term exposure usually lie between 0.6 and 2.0 mg L^{-1} for pond fish, and sublethal effects may occur at 0.1 to 0.3 mg L^{-1} (EIFAC, 1973; Robinette, 1976). Maximum limit of ammonia concentration for aquatic organisms is 0.1 mg L^{-1} (Meade, 1985: Santhosh and Singh, 2007). According to Swann (1997) and OATA (2008) the levels below 0.02 ppm were considered safe. Stone and Thomforde (2004) stated the desirable range as Total NH_3-N: 0-2 mg L^{-1} and Un-ionized NH_3-N: 0 mg L^{-1} and acceptable range as Total NH_3-N: Less than 4 mg L^{-1} and Un-ionized NH_3-N: Less than 0.4 mg L^{-1}. Bhatnagar *et al*. (2004) suggested 0.01-0.5 ppm is desirable for shrimp; >0.4 ppm is lethal to many fishes & prawn species; 0.05-0.4 ppm has sublethal effect and <0.05 ppm is safe for many tropical fish species and prawns. Bhatnagar and Singh (2010) recommended the level of ammonia (<0.2 mg L^{-1}) suitable for pond fishery.

Control and treatments

1. Increase pond aeration.
2. Addition of liming agents such as hydrated lime or quick lime decreases ammonia and this technique is effective only in ponds with low alkalinity.
3. Formaldehyde and zeolite treatment. A dosage of 50 ml per 100 gallons to chemically bind up to 1 ppm of ammonia, can be useful and but also check the manufacturer's directions before use.
4. Regular water change out.

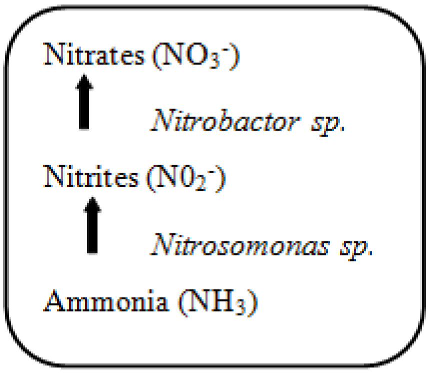

Figure 4: *Nitrobacter* and *Nitrosomonas* helps in conversion of NH_3 to NO_3.

Nitrite (NO_2^-)

Nitrite is an intermediate product of the aerobic nitrification bacterial process, produced by the autotrophic *Nitrosomonas* bacteria combining oxygen and ammonia (fig.4).

Effects

Nitrite can be termed as an invisible killer of fish because it oxidizes haemoglobin to methemoglobin in the blood, turning the blood and gills brown and hindering respiration also damage for nervous system, liver, spleen and kidneys of the fish.

Desirable limits

The ideal and normal measurement of nitrite is zero in any aquatic system. Stone and Thomforde (2004) suggested that the desirable range 0-1 mg L^{-1} NO_2 and acceptable range less than 4 mg L^{-1} NO_2. According to Bhatnagar *et al*. (2004) 0.02-1.0 ppm is lethal to many fish species, >1.0 ppm is lethal for many warm water fishes and <0.02 ppm is acceptable. Santhosh and Singh (2007) recommended nitrite concentration in water should not exceed 0.5 mg L^{-1}. OATA (2008) recommended that it should not exceed 0.2 mg L^{-1} in freshwater and 0.125 mg L^{-1} in seawater.

Reducing the level of Nitrite

1. Reduction of stocking densities, Improvement of feeding, biological filtration and general husbandry procedures, Increase aeration to maximum, Stop feeding.
2. Addition of small amounts of certain chloride salts, regular water change out.
3. Use of biofertilizers to accelerate nitrification.

Nitrate (NO_3)

Where ammonia and nitrite were toxic to the fish, Nitrate is harmless and is produced by the autotrophic *Nitrobacter* bacteria combining oxygen and nitrite (fig.4). Nitrate levels are normally stabilized in the 50-100 ppm range.

Desirable limits

Meck (1996) recommended that its concentrations from 0 to 200 ppm are acceptable in a fish pond and is generally low toxic for some species whereas especially the marine species are sensitive to its presence. According to Stone and Thomforde (2004) nitrate is relatively nontoxic to fish and not cause any health hazard except at exceedingly high levels (above 90 mg L^{-1}). Santhosh and Singh (2007) described the favourable range of 0.1 mg L^{-1} to 4.0 mg L^{-1} in fish culture water. However, OATA (2008) recommends that nitrate levels in marine systems never exceed 100 mg L^{-1}.

Reducing the level of Nitrate

Dilution by water change (ensure water used for change has a lower nitrate level), Use of ion exchange materials, Increase plant density and by the use of denitrifying biological filtration nitrate concentration can be reduced.

Phosphorus

Almost all of the phosphorus (P) present in water is in the form of phosphate (PO_4) and in

surface water mainly present as bound to living or dead particulate matter and in the soil is found as insoluble $Ca_3(P0_4)_2$ and adsorbed phosphates on colloids except under highly acid conditions. It is an essential plant nutrient as it is often in limited supply and stimulates plant (algae) growth and its role for increasing the aquatic productivity is well recognized.

Desirable limits

Soil phosphorus (unit- mg of P_2O_5 per 100gm of soil) level below 3 might be considered indicative of poor production, between 3 and 6 of average production and ponds having available phosphorus above 6 are productive (Banerjea, 1967). According to Stone and Thomforde (2004) the phosphate level of 0.06 mg L^{-1} is desirable for fish culture. Bhatnagar *et al*. (2004) suggested 0.05-0.07 ppm is optimum and productive; 1.0 ppm is good for plankton / shrimp production.

Remedies

Use inorganic fertilizers to increase phosphorus level (N: P=15:30).

Primary productivity

This is the rate at which photosynthesis takes place. The most commonly used index of productivity is the DO content of the water. Primary productivity may be reported as net or gross. Net primary productivity represents the total amount of new organic matter synthesized by photosynthesis less the amount the organic matter used for respiration. Primary productivity by light and dark bottles is possible methods of measuring phytoplankton abundance.

Desirable limits

Bhatnagar *et al*. (2004) recommended 1.60-9.14 mg C L^{-1} D^{-1} (GPP)—as optimum status and <1.6 or >20.3 mg C L^{-1} D^{-1} (GPP)—as poor productivity of a pond culture. Santhosh and Singh (2007) has given the ideal value of primary productivity is 1000-2500 mg C $M^{-3}d^{-1}$ (=1.0-2.0 mg C L^{-1} d^{-1}). A fish pond can be considered good in productivity if it is slight green in colour, with no scum on the surface and having a transparency of about one foot. According to Trifonova (1989) primary productivity can be estimated by measuring the chlorophyll (ch) 'a' from the algal biomass. If the productivity value is less than 0.5 g m^{-3} (<1.5 mg ch'a'm^{-3}) it was considered- oligotrophic, 1-5 g m^{-3} (1.5-10 mg ch'a'm^{-3}) - mesotrophic, 5-10 gm^{-3} (10-25 mg ch'a'm^{-3}) - eutrophic and >10 g m^{-3} (>25 mg ch'a'm^{-3}) as highly eutrophic.

Remedies

1. Productivity can be improved by use of organic/inorganic fertilizers in ponds.
2. In case of plankton bloom / swarm; feed/manure application can be suspended for some time.

Plankton

Those aquatic pelagic organisms, which are carried about by the movement of the water rather than their own ability to swim are called planktons. The plant components are called as phytoplankton and animal components as zooplanktons and they serve as fish food organisms (fig. 5). For enumeration they are collected using plankton net (fig. 6). As plankton is at the base of the food web, there is a close relationship between plankton abundance and fish production (Smith, and Swingle, 1938).

Plankton blooms and fish kill

Fertilization may not be the only reason for eutrophication or excessive growth of planktons in pond water surface. The growth of certain species of blue green algae form dense scums in surface waters, cause shallow thermal stratification, less availability of soluble phosphate in the top layer and prevents the penetration of light for photosynthesis to depths below 1m so leading to anoxic conditions in the deep areas (lack of oxygen and high concentration of free carbon dioxide) resulting in fish kills.

Desirable limits

Bhatnagar and Singh (2010) suggested the optimum plankton population (approximately 3000-4500 Nos. L^{-1}) in pond fish culture.

Significance

1. The main objective to maximise the plankton production in optimum quantity is to maintain the standing crop and optimum fertilisation also reduce the probability of algal crash.
2. Dense phytoplankton helps in producing 10 times more oxygen than it consumes, so have an important role in compensating for respiratory loss without adding further energy expenditure.
3. Exploiting primary production is a cheap method of producing fish. Planktons also prevent the development of macrophytes that are undesirable for fish.

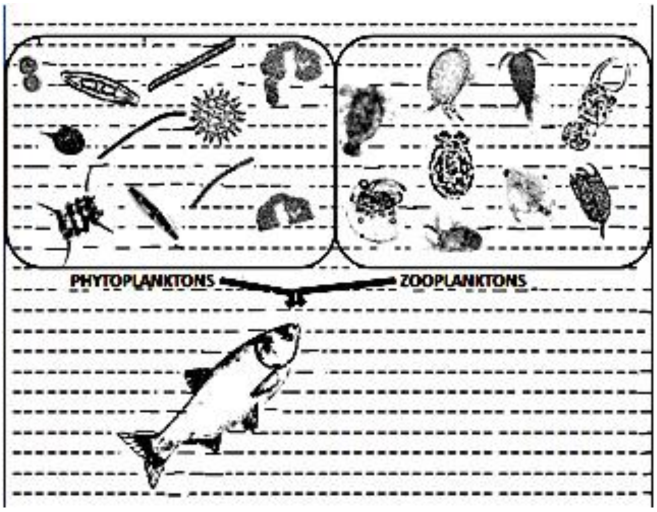

Figure 5: Planktons as fish food organisms

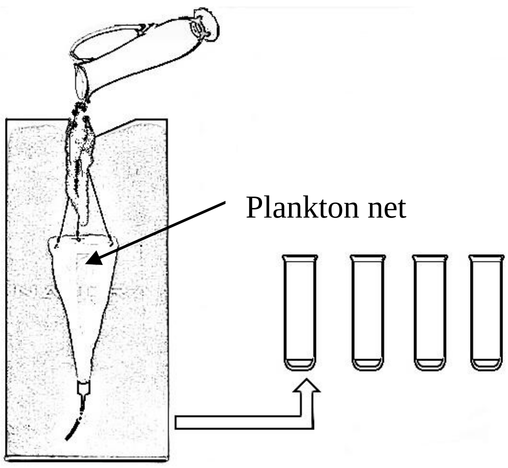

Figure 6: Method of plankton collection

Control and treatment

1. Water circulation should be proper to avoid the appearance of anaerobic microzones and large sized inedible phytoplankton species.
2. Biological control of phytoplankton scum using herbivores (plankton feeding fishes such as silver carp) that reduces the blue green algae and total phytoplankton biomass appear more promising.
3. When plankton scums appear, DO should be measured daily to ensure that oxygen is present in depths below 1.3 m. Light penetration and distribution of DO in ponds can be facilitated with copper tetraoxosulphate ($CuSO_4$) in one or two applications, a week. The quantity of $CuSO_4$ in waters with 25ppm hardness is 800 g/ha surface area.

   Disadvantage is that, it adds to the total Biochemical Oxygen Demand (BOD) in the water. Nutrients may later recycle and may cause heavy scum.

How to detect pond water of poor quality

The following guidelines are given to a fish farmer to know when pond water is deteriorating in quality and therefore not suitable for fish growth.

1. Clear water indicates very low or absence of biological production- not fertile enough and fish will not grow well in it.

2. Muddy water (that is a lot of clay particles are present), fish can have their gills blocked by the soil particles and this can result in death - not good for fish culture.
3. Deep green water indicates over-production of planktons that serve as food for fish but occur as a result of application of more than enough fertilizers, manure or nutrient rich feeds to a pond.
4. When a fish pond gives an offensive odour, it indicates pollution of pond water. Sources of pollution include application of excess food stuff to the pond, or inflow of water from polluted rivers. Pollution can also result from application of chemicals to arable crops around the pond site.
5. In an already stocked fishpond, if a farmer noticed the fish always struggling at the pond water surface to get oxygen, then there is low DO content in the water (fig. 2).

The optimum range of various water quality parameters are summarised in Table-1.

Table 1: Suggested water-quality criteria for pond water fishery for getting high yield via applying minimum input.

Sr.No	Parameter	Acceptable range	Desirable range	Stress
1.	Temperature (^{0}C)	15-35	20-30	<12, >35
2.	Turbidity (cm)		30-80	<12,>80
3.	Water colour	Pale to light green	Light green to light brown	Clear water, Dark green &Brown
4.	Dissolved oxygen (mg L^{-1})	3-5	5	<5, >8
5.	BOD (mg L^{-1})	3-6	1-2	>10
6.	CO_2 (mg L^{-1})	0-10	<5, 5-8	>12
7.	pH	7-9.5	6.5-9	<4, >11
8.	Alkalinity (mg L^{-1})	50-200	25-100	<20, >300
9.	Hardness (mg L^{-1})	>20	75-150	<20,>300
10.	Calcium (mg L^{-1})	4-160	25-100	<10, >250
11.	Ammonia (mg L^{-1})	0-0.05	0- <0.025	>0.3
12.	Nitrite (mg L^{-1})	0.02-2	<0.02	>0.2
13.	Nitrate (mg L^{-1})	0-100	0.1-4.5	>100, <0.01
14.	Phosphorus (mg L^{-1})	0.03-2	0.01-3	>3
15.	H_2S (mg L^{-1})	0-0.02	0.002	Any detectable level
16.	Primary productivity (C $L^{-1} D^{-1}$)	1-15	1.6-9.14	<1.6, >20.3
17.	Plankton (No. L^{-1})	2000-6000	3000-4500	<3000, >7000

These precautions and above mentioned guidelines if taken will not only raise productivity and economic benefits but will also help the farmers in maintaining ecofriendly ponds environment required for sustainable fish culture / aquaculture.

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Karnal district (Latitude: $29^0$25’05”- $29^0$59’20” N and Longitude: $76^0$27’40” - $77^0$13’08” E) falls in the north-east part of the Haryana State. The river *Yamuna*, which marks the eastern boundary of the Haryana State as well as Karnal district, provides the major drainage in the area. About 70% of the net irrigated area is covered through ground water, with rice- wheat being the major crop rotation. The district is characterized by semiarid climate and is a part of Indo- Gangetic alluvial plains which contribute a large share of food grains to national buffer stock. The overexploitation of hitherto fresh groundwater in the district is leading to not only alarming decline in watertable but also deterioration in quality in certain pockets. The current average water table depth in the district is about 20 m and deep submersible tubewells at 50-100 m depth have replaced the centrifugal pumps in almost entire district.Water samples were collected from 67 locations during pre and post-monsoon seasons of the year 2011, and were subjected to analysis for chemical characteristics. The type of water that predominates in the study area was of sodium-calcium bicarbonate and magnesium bicarbonate type during pre and post-monsoon seasons of the year 2011 respectively, based on hydro-chemical facies. Based on chemical analysis, the pre and post monsoon water samples were classified as per different standard irrigation criteria to study the chemical changes resulting due to rain and natural recharge.

Keywords: Groundwater, chemical characters, chemical classification, SAR, RSC, USSL diagram.

1. Introduction

Water quality analysis is one of the most important aspects in groundwater studies. Determination of physico-chemical characteristics of water is essential for assessing the suitability of water for various purposes like drinking, domestic, industrial and irrigation. The groundwater quality may also vary with seasonal changes and is primarily governed by the extent and composition of dissolved solids. Water quality is influenced by natural and anthropogenic effects including local climate, geology and irrigation practices. A number of techniques and methods have been developed to interpret the chemical data. Zaporozee (1972) has summarized the various modes of data representation and has discussed their possible uses. Presentation of chemical analysis in graphical form makes understanding of complex groundwater system simpler and quicker. Methods of representing the chemistry of water like Collin’s bar diagram, radiating vectors of Maucha (1940), and parallel and horizontal axes of Stiff(1940), have been used in many parts of the world to show the proportion of ionic concentration in individual samples. Subramanian (1994) followed a series of methods to interpret and classify the chemistry of groundwater in hard rock, including coastal zones in the southern parts of India.

In India about 50 per cent of the total cultivated area under irrigation is dependent upon groundwater and of this, about sixty per cent of irrigated food production depends on groundwater wells (Shah *et al.*, 2000; CWC, 2000). In the present study, the area, i.e. Karnal District of Haryana state also uses mostly groundwater through shallow tube wells. Ground water contributes 95 % of the total need for agriculture. CGWB (2007) reported that chemical analysis of water samples from shallow aquifers indicates that ground water is alkaline in nature and is moderately saline. The ground water is mixed Cation-HCO3 type. The stage of ground water development for the district is 137% and all the six blocks fall in over-exploited categories. That means that the ground water is under stress and the ground water level is declining. There is no scope for further ground water development. Only measures should be taken to reduce on the dependence on ground water and to enhance the ground water resources. Though some discrete, hydro chemical data are available for the region, comprehensive seasonal variation of groundwater quality has never been studied so far. In this paper an attempt has been made to study the affect of monsoon on groundwater quality for irrigation.

2. Materials and method

2.1 Study area

Karnal is located in the northwestern corner of Haryana state between North latitudes $29^0$25'05" and $29^0$59'20" and East longitudes $76^0$27'40" and $77^0$13'08" covering an area of 2520 sq.km. The district covers 5.69% area of the state. The district is one of the most densely populated districts of the state. The total population of the district as per 2001 census is 12, 74,183. The population density is 506 persons per sq.km against the State average of 478 persons per sq.km. The district falls in the Upper Yamuna Basin. The river Yamuna which marks the eastern boundary of the Haryana State as well as Karnal district provides the major drainage in the area. Irrigation in the district is done by surface water as well as ground water. 70% of the net irrigated area is covered through ground water

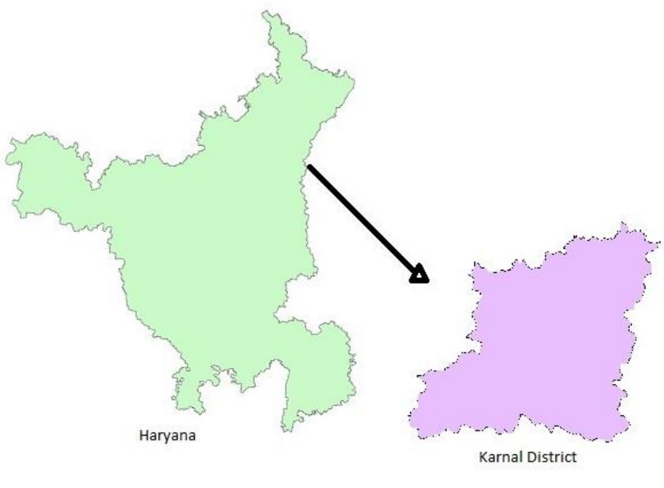


Figure 1: Study area

2.2 Collection of water samples

Groundwater samples were collected from 67 tubewells located in different parts of the district during pre-monsoon (May/June 2011) and post-monsoon (October/November 2011) period. The collected water samples were transferred into precleaned polythene container for analysis of chemical characters. Chemical analyses were carried out using the standard procedures (APHA-2002). Each of ground water samples were analyzed for pH, electrical conductivity (EC), major cations and major anions. Among variable parameters, pH and EC were measured immediately by using portable meters (Eutech, ECTestr11+). Total hardness and calcium were determined by ethylenediaminetetraacetic acid titimetric method. Magnesium was estimated as difference in Total Hardness and Calcium. Total alkalinity, carbonate and bicarbonate and chloride were estimated by using titimetric method. Sodium and Potassium were estimated by flame photometer.Sulphate was estimated by gravimetric method. Total dissolved solids, RSC, % Sodium, SAR were determined by calculation. The analytical data was used to classify the utilitarian purpose of water and for ascertaining various factors on which the chemical characteristics of water depend. In this paper Piper, Back and Hanshaw, Wilcox, Eaton, Todd and USSL (US Salinity Laboratory) classification have been used to characterize the hydrochemical characteristics of groundwater of Karnal District.

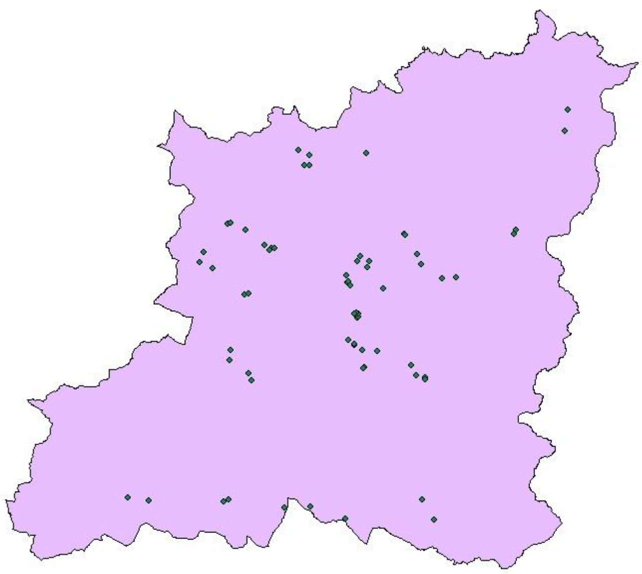
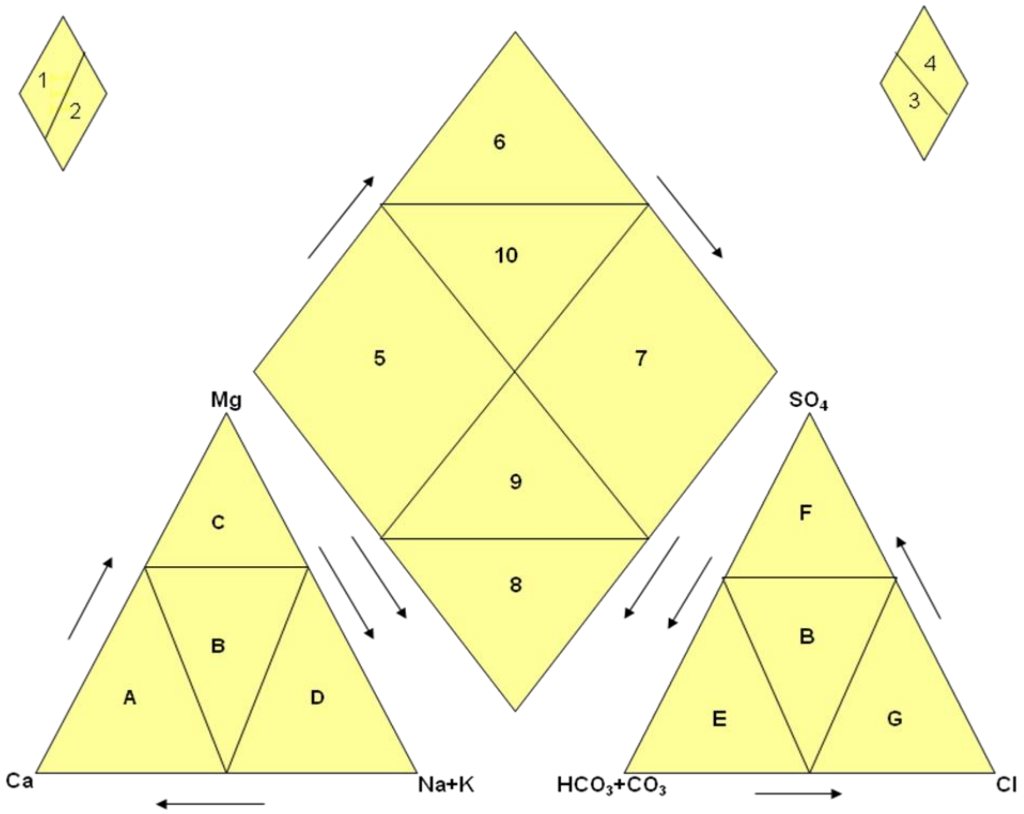


Figure 2: Sampling location map

2.3 Piper diagram

The Piper-Hill diagram (1953) is used to infer hydro-geochemical facies. These plots include two triangles, one for plotting cations and the other for plotting anions (figure 3). The cations and anion fields are combined to show a single point in a diamond-shaped field, from which inference is drawn on the basis of hydro-geochemical facies concept. These tri-linear diagrams are useful in bringing out chemical relationships among groundwater samples in more definite terms rather than with other possible plotting methods. Chemical data of representative samples from the study area is presented by plotting them on a Piper-tri-linear diagram for pre-and post-monsoon (figures 4 and 5).These diagrams reveal the analogies, dissimilarities and different types of waters in the study area. The concept of hydrochemical facies was developed to understand and identify the water composition in different classes.

Facies are recognizable parts of different characters belonging to any genetically related system. Hydrochemical facies are distinct zones that possess action and anion concentration categories. To define composition class, Back and co-workers (1965) suggested subdivisions of the tri-linear diagram (figure 3). The interpretation of distinct facies from the 0 to 10% and 90 to 100% domains on the diamond shaped cation to anion graph is more helpful than using equal 25% increments. It clearly explains the variations or domination of cation and anion concentrations during pre-monsoon and post-monsoon.



Legend

- **A-** Calcium type,B-No Dominant type,C- Magnesium type,D- Sodium and potassium type,E- Bicarbonate type,F- Sulphate type,G- Chloride type

Figure 3: Classification diagram for anion and cation facies in the form of major-ion percentages **(**Piper, 1953; Back and Hanshaw, 1965; Sadashivaiah et al., 2008)

Wilcox (1995) classified groundwater for irrigation purposes based on per cent sodium and Electrical conductivity. Eaton (1950) recommended the concentration of residual sodium carbonate to determine the suitability of water for irrigation purposes. The US Salinity Laboratory of the Department of Agriculture adopted certain techniques based on which the suitability of water for agriculture is explained. The sodium in irrigation waters is usually denoted as per cent sodium and can be determined using the following formula.

$$\% Na = (Na^{+}) \times 100 / (Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})$$

Where the quantities of Ca^{2+} Mg^{2+} Na^{+} and K^{+} are expressed in milliequivalents per litre (meq/l).

In waters having high concentration of bicarbonate, there is tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. As a result, the relative proportion of sodium in the water is increased in the form of sodium carbonate. RSC is calculated using the following equation.

$RSC = (HCO_3^{-} + CO3^{2-}) – (Ca^{2+} + Mg^{2+})$

Where all ionic concentrations are expressed in equivalent per mole.

According to the US Department of Agriculture, water having more than 2.5 epm of RSC is not suitable for irrigation purposes.

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, sodium hazard, boron hazard and bicarbonate hazard. In the past, the sodium hazard has been expressed as per cent sodium of total cations. A better measure of the sodium hazard for irrigation is the SAR which is used to express reactions with the soil.

SAR is computed as

$$SAR = \frac{Na^{+}}{\left\{\frac{Ca^{2-} + Mg^{2+}}{2}\right\}^{1/2}}$$

Where all ionic concentrations are expressed in equivalent per mole.

For the purpose of diagnosis and classification, the total concentration of soluble salts (salinity hazard) in irrigation water can be expressed in terms of specific conductance.Thematic maps of Electrical Conductivity (EC) and Residual Sodium Carbonate (RSC) were created for both Pre-monsoon and Post-monsoon seasons using Arc GIS 10.0 software.

3. Results and discussion

Piper diagrams are an example of water quality diagrams which are probably the most frequently used today. The subdivisions of the trilinear or piper diagram depict that Na-Ca-HCO_3 type of water was dominated during pre-monsoon. The percentage of samples falling under NaCa-HCO_3 type of water was 45% in pre-monsoon season(Table 1). Mg-HCO_3 type of water was predominated during post-monsoon with 57% water samples. For anion concentration, HCO_3-type of water was predominated in pre-monsoon with 83.6% samples while in post monsoon season 94% samples were of HCO_3–type water. The appreciable change in the hydro-chemical facies was noticed during the study period (pre- and post-monsoon), which was might be due to the leaching of alkali salts through precipitation.Thussu (2004) reported that in Karnal, the water in general is Ca-Mg- HCO_3 type. The changes in chemical composition have taken place along the present day palaeobank of Yamuna river and Chautang nala. Primary saline water with conspicuous primary salinity occurs at Jalmana, while the water with secondary salinity occurs at Kinana. Changes have taken place in the waters, which were CaMg HCO_3 to Na-Ca-HCO_3 type at Assand, and to $NaHCO_3$ at Nisang; $NaHCO_3$ to mixed to NaCI at Munak and mixed to $CaMgHCO_3$ at Shahpur. The geology of Karnal district is alluvium in nature having appreciable content of sand in underground layers and water is generally found in the sandy zone.

Table 1: Characterization of groundwater of Karnal District of Haryana on the basis of Piper tri-linear diagram

Subdivision of the diamond	Characteristics of corresponding subdivisions of diamond-shaped fields	Percentage of samples in this category	
		Pre-Monsoon	Post-Monsoon
1	Alkaline earth (Ca+Mg) Exceed alkalies (Na+K)	37.3	58.2
2	Alaklies exceeds alkaline earths	62.7	41.8
3	Weak acids (C03+HCO3) exceed Strong acids (SO4+Cl)	83.6	91
4	Strong acids exceeds weak acids	16.4	9
5	Magnesium bicarbonate type	40.3	56.7
6	Calcium-chloride Type	-	-
7	Sodium-chloride Type	13.4	6
8	Sodium-Bicarbonate Type	1.5	1.5
9	Sodium calcium-Bicarbonate type	44.8	35.8
10	Calcium Magnesium-Chloride Type	-	-

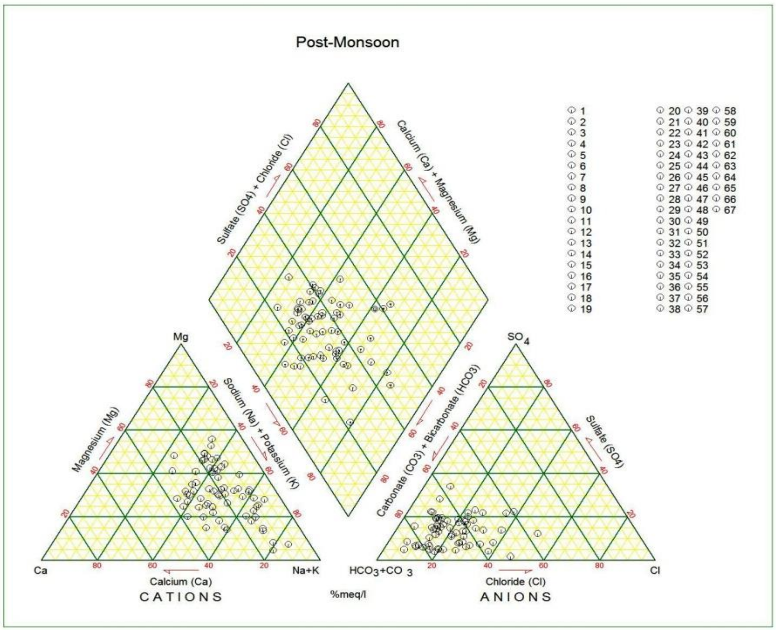


Figure 4: Post-monsoon Groundwater Samples Plotted in Piper-Trilinear diagram

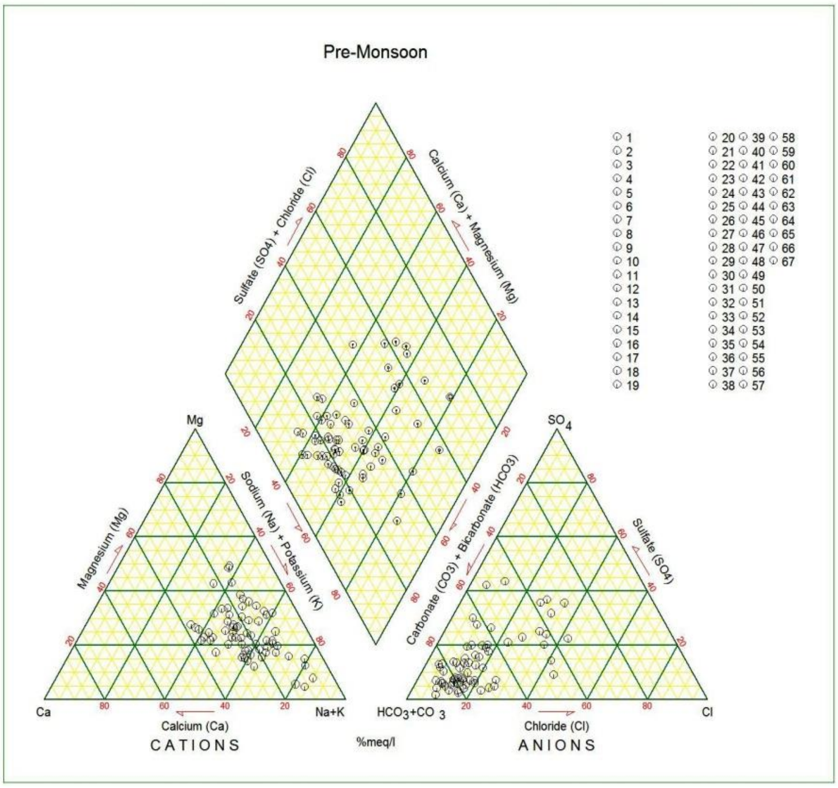


Figure 5: Pre-monsoon Groundwater Samples Plotted in Piper-Trilinear diagram

The classification of groundwater samples with respect to per cent sodium is shown in Table 2. It is observed that about 89.6% of samples fall under permissible to doubtful category during premonsoon while 85.1% samples are reported in this category during post- monsoon. Similarly, 7.5% and 4.5% samples fall under unsuitable category during pre and post monsoon season respectively.

Table 2: Sodium percent water class

Sodium (%)	Water class	Pre-monsoon Samples	Post-monsoon samples
<20	Excellent	-	-
20-40	Good	38.98-39.17 (2 samples)	21.54-38.89 (7 samples)
40-60	Permissible	40.32-59.22 (35 samples)	40.55-59.80 (42 samples)
60-80	Doubtful	60.16-77.50 (25 samples)	61.55-76.66 (15 samples)
>80	Unsuitable	81.83-88.07 (5 samples)	80.37-87.18 (3 samples)

Groundwater of the study area is classified on the basis of RSC and the results are presented in Table 3 for both pre- and post-monsoon seasons. Based on RSC values, water can be classified as good (<1.25mEq/l), marginally suitable (1.25-2.5mEq/l), and unsuitable (>2.5mEq/l).During Pre monsoon season it is observed that 13.4% samples are of good quality,19.4 % of samples are of marginal suitable and 67% samples are unsuitable for irrigation use.

Table 3: Groundwater quality based on RSC (Residual sodium carbonate)

RSC (epm)	*Remark on quality*	*Pre-monsoon samples*	*Post-monsoon samples*
<1.25	Good	0.01-1.04 (9 samples)	0.01-1.22 (18 samples)
1.25-2.5	Doubtful	1.53-2.48 (13 samples)	1.40-2.43 (23 samples)
>2.5	Unsuitable	2.52-6.92 (45 samples)	2.59-7.35 (26 samples)

While in post monsoon season 26.86% samples are of good quality, 34.32 % are marginally suitable and 38.80% are unsuitable for irrigation. The spatial distribution of RSC in groundwater of the area during pre and post monsoon seasons is illustrated in figure 8 & 9. The figure clearly indicates that natural recharge with rainwater improved the groundwater quality in some parts of the district.

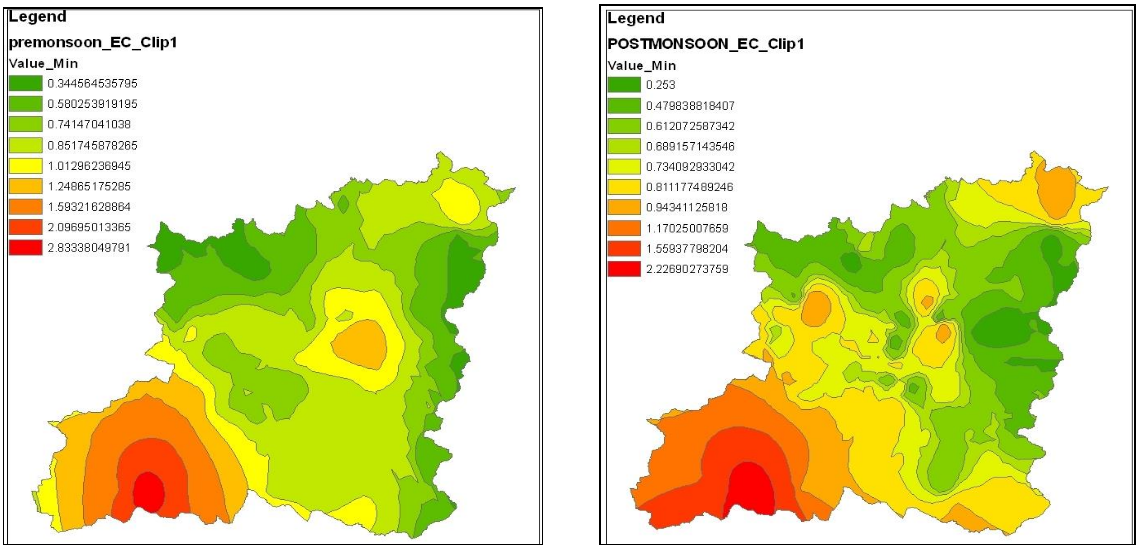


Figure 8: Spatial Distribution of EC and RSC during Pre-monsoon Season(May, 2011)

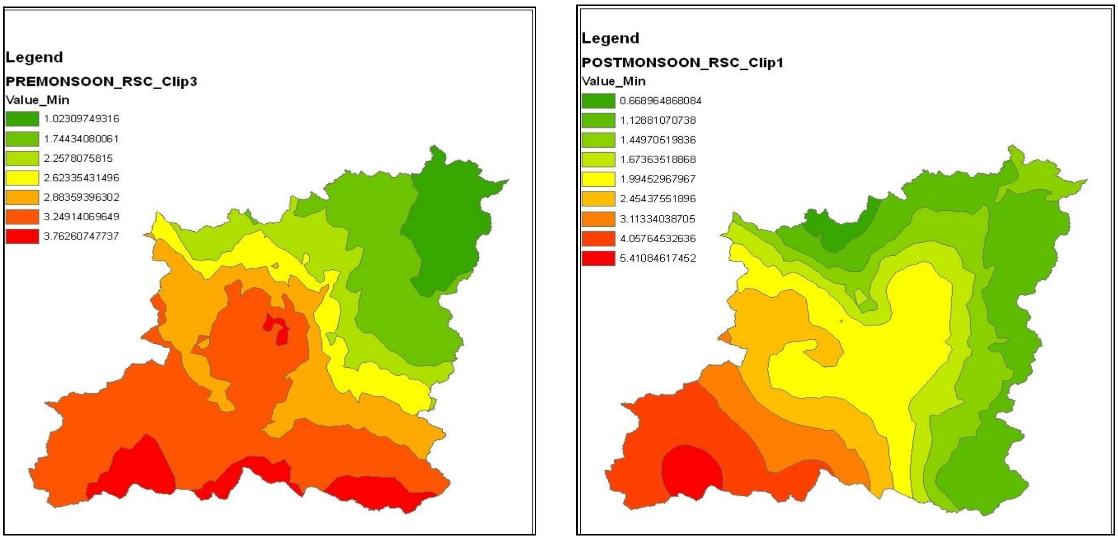


Figure 9: Spatial Distribution of EC and RSC during Post-monsoon Season(Oct, 2011)

The classification of groundwater samples from the study area with respect to SAR is represented in Table 4. The SAR value of about 98.5%of pre-monsoon samples and 100% of post-monsoon samples is classified as excellent to good for irrigation. In order to characterize water for irrigation the value of SAR and specific conductance were plotted on the US salinity (USSL) diagram (figure 6 & 7).About 76.1% of the pre-monsoon samples and 88% post-monsoon samples are grouped within C2S1 and C3S1 classes (figure 6 & 7).

Table 4: Sodium hazard classes based on USSL classification

Sodium Hazard class	*SAR in Equivalents per mole*	*Remark on quality*	*Premonsoon samples*	*Postmonsoon samples*
			(Alkalinity)	
S1	10	Excellent	1-6 (51 samples)	1-6 (59 samples)
S2	10-18	Good	5-11	6-15

			(15 samples)	(8 sample)
S3	18-26	Doubtful	18-19 (1 samples)	-
S4 and S5	>26	Unsuitable	-	-

Classification of groundwater based on salinity hazard is presented in table 5.EC value indicates that about 67.16% samples were unsuitable for irrigation during pre-monsoon while 49.25% samples during post-monsoon were found to be unsuitable for irrigation purposes. The spatial variation in electrical conductivity of groundwater of the area during pre and post monsoon seasons is illustrated in figure 8 & 9, which clearly indicates improvement in groundwater quality in post monsoon samples.

Table 5: Salinity hazard classes

Salinity hazard class	*EC in (micromohs/cm)*	*Remark on quality*	*Pre-monsoon samples*	*Post-monsoon samples*
C1	100-250	Excellent	220 (1 sample)	-
C2	250-750	Good	380-720 (20 samples)	253-739 (33 samples)
C3	750-2,250	Doubtful	760-2030 (45 samples)	704-1615 (33 samples)
C4 & C5	>2,250	Unsuitable	3910 (1 samples)	3372 (1 sample)

4. Conclusions

Hydro chemical evaluation of groundwater indicates that Na-Ca-HCO_3 type water dominates during pre monsoon and Mg-HCO_3 during post monsoon seasons of the year 2011 .NaHCO_3 waters shows high sodacity with high soluble sodium percentage and residual sodium carbonate. The change in water type from Na-CaHCO_3 to MgHCO_3 indicates the dilution of alkalinity hazard. Because of the monsoon rainfall of 425 mm during 2011, the % samples grouped under C_2S_1 (EC: 250- 750 micro siemen/cm, SAR<10) increased from 31 % during pre monsoon to 48 % during post monsoon, while of C_3S_1 class (EC: 750- 2250 micro siemen/ cm, SAR < 10) decreased from 45 to 40 %. The monsoon rain also improved the groundwater quality in terms of RSC and percent sodium as reflected by the reduction in number of unsuitable samples from 67 to 39 % (RSC > 2.5) and from 8 to 5 % (% Sodium > 80). High Bicarbonate is observed in most of the samples which is believed to be due to the recharge from normal groundwater (Ca-Mg-HCO_3).Water that is not suitable based on the above classification may be suitable in well-drained soils.

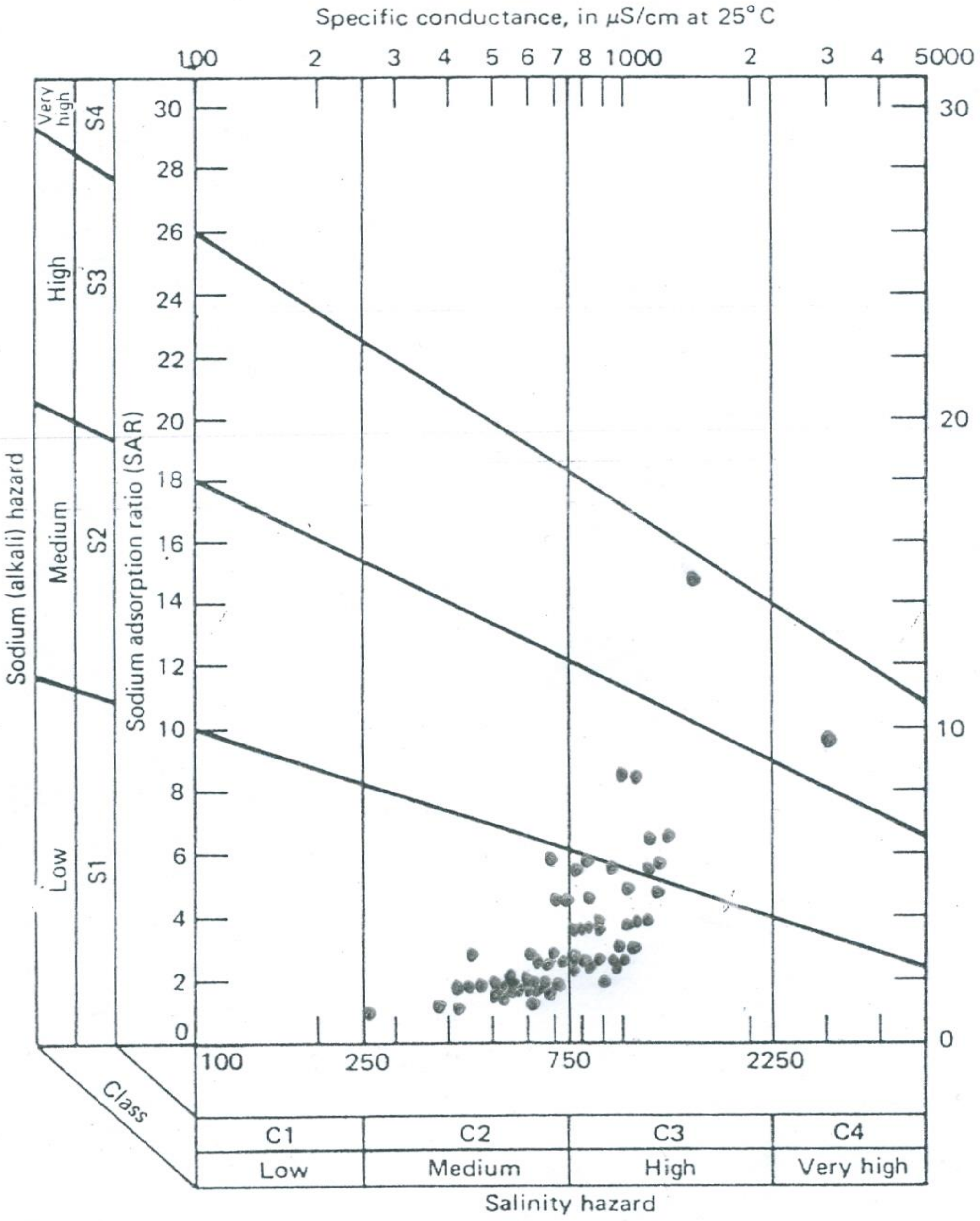


Figure 6: USSL classification of Groundwater during Post-monsoon

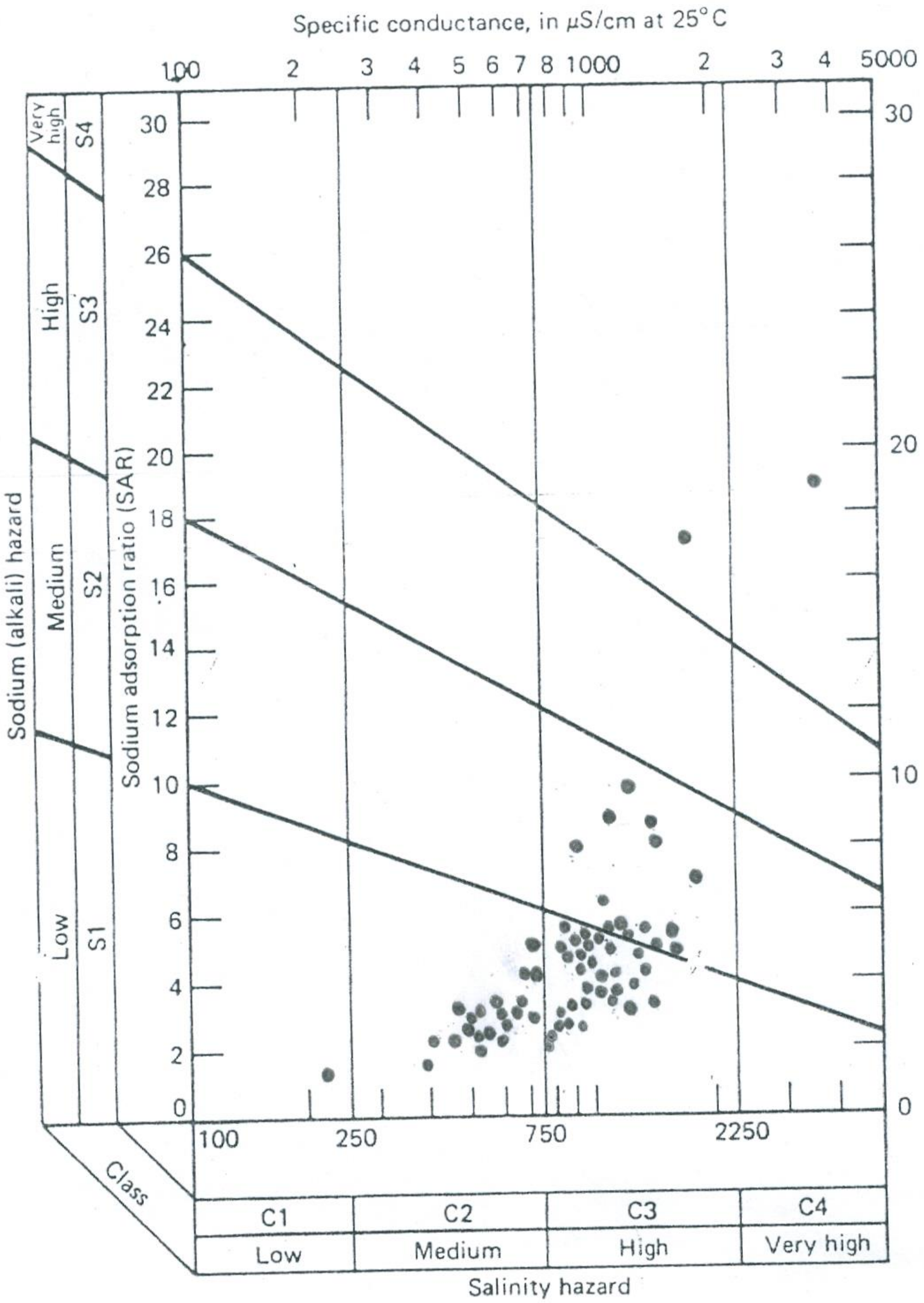


Figure 7: USSL classification of Groundwater during Pre-monsoon

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