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WQI to Monitor Water Quality for Irrigation and Potable Use

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Preface

In this era of water scarcity and water stress situation across the globe it is a privilege to present this bulletin for the researcher, agriculturist, policymakers and other stakeholders. The water quality index (WQI) developed under the project 'Suitability of the available poor quality water resources for agricultural use under different agro-climatic region' is presented after being tested and validated through ground truth. The increasing use of poor quality water in agriculture is adversely affecting the natural resources like soil, crop, groundwater and also posing threat to mankind and other living organisms. To prevent the negative impact of poor quality water/wastewater a measuring tool is required to assess the suitability for different uses which was addressed through development of this WQI. The index was validated using Central Groundwater Board data and found trustworthy and easy to compute. This index will be of immense use to the researcher, policy maker, users and other stakeholders in near future.

I congratulate the authors for their sincere effort in publishing the salient findings of the project in this bulletin. A brief discussion concerning the global status of wastewater treatment and water quality, two case studies implementing WQI and their classification is presented. Its applicability will help in decision making in reusing poor quality water safely for irrigation and also help in finding the causative factor responsible for contaminating the water.

September 2014 **(Ashwani Kumar)**

Director, Directorate of Water Management

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The authors put their sincere thanks in paper to their beloved family members whose constant encouragement and support made it happen successfully.

This bulletin is dedicated to all the stakeholders engaged in poor quality water use in agriculture and domestic sector.

September' 2014 **Authors**

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Background and Scope

Worldwide, the use of poor quality water in agriculture is growing due to the increasing shortage of fresh water. In India rapid urbanization, industrialization, energy generation, increased demand for food of the growing population generate wastewater without any proper treatment or re-use. Particularly, in low-income countries the wastewater collection and treatment facilities, which are often not operational and no effective regulations for wastewater use are in place, up to 90 percent of the wastewater flows untreated into the water bodies, threatening health, food security and access to safe drinking water (WWAP, 2012). The ratio of untreated to treated wastewater is higher in developing countries as projected in the global map.

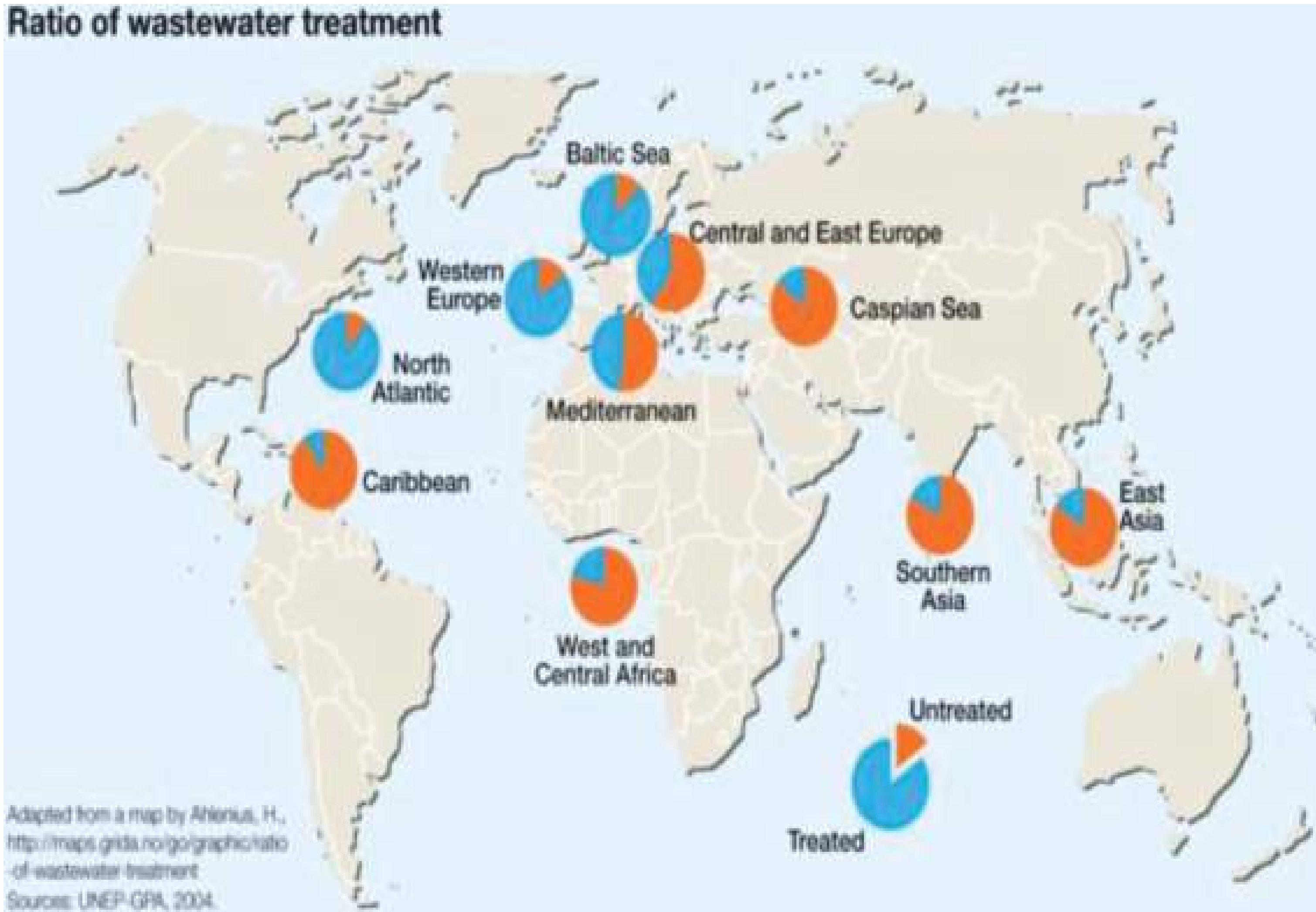
In urban India, especially metropolis with higher population density generates large quantities of wastewater (Table-1) that is discharged, untreated or partially treated due to lack of infrastructure to the environment contaminating land and water resources. This causes contamination of traditional water sources for irrigation and degradation of freshwater resources available for urban and peri-urban agriculture (Raschid-Sally and Jayakody, 2008)

In India, use of untreated wastewater or poor quality water in agriculture is a common practice without any regulation. That can aggravate health risks and deteriorate soil health. Guidelines/standards are available worldwide prescribing the permissible limits of contents in water for potable and irrigation use that needs to be integrated for better understanding of the problem and their control. Challenge is to identify the reuse options for agriculture and other sectors with proper utilisation of the nutrients contained in it. Wastewater is an important resource that requires some tools for its safe utilisation in agriculture.

Table 1 Water Supply, Sewage Generation and Treatment Capacity in urban areas of India

Category	No. of cities	Population	Total water Supply (in MLD)	Wastewater Genration (inMLD)	Treatment Capacity (in MLD)
Class-1 city	498	14,30,83,804	44,769	35,558	11,554
Class-II town	410	3,00,18,368	3,325	2,697	234
Total	908	25,77,54,640	48,094	38,254	11,787

Source : Adapted from CPCB (2009)



Source : UNEP - GPA, 2004

Introduction

Fresh water constitute about 2.5 % of the total volume of water on earth and less than 1 % of this resource is utilizable (UNEP, 2008). Fresh water scarcity already exists in many parts of the world at present and by 2025 about 1.8 billion people will be living with absolute water scarcity, two-thirds of the world's population will be living under water stressed condition (UNEP, 2008). In India, the total utilizable water resource is assessed as 1123 billion cubic meter (BCM). The per capita availability of water at national level has been reduced from about 5,177 cubic meters in 1951 to the estimated level of 1,820 cubic meters in 2000. Given the projected increase in population by the year 2025, the per capita availability is likely to drop to below 1,000 cubic metres, which could be labelled as a situation of water scarcity.

India receives 4000 BCM of annual rainfall with an average runoff generated is only 1869 BCM. The annual replenishable groundwater resource of the country is 431 BCM and net groundwater available for utilization is 396 BCM. Annual groundwater draft is 243 BCM out of which 221 BCM is used for irrigation and 22 BCM for domestic and industrial use (CGWB, 2013). In many countries like India groundwater is the main source of irrigation as well as for drinking purpose too. Groundwater is extensively used for irrigation in India and the status of groundwater development in India varies from 0.07 percent in the state of Arunachal Pradesh to 170 percent in Punjab. Other than availability it is the quality of the water that restricts its use for agriculture as well as domestic purpose. Due to injudicious and excessive use of fertilizers, discharge of untreated urban and industrial effluent in rivers and land deteriorates the surface water and groundwater quality. Once the groundwater is contaminated, its quality cannot be restored by discontinuing the contaminants from the origin. It therefore becomes imperative to frequently monitor the quality of groundwater and to device ways and means to protect it.

Conceptually, water quality refers to the characteristics of a water supply that will influence its suitability for a specific use, i.e. how well the quality meets the needs of the user. Quality is defined by certain physical, chemical and biological characteristics. Irrigation water quality is being evaluated based on the chemical and physical characteristics of the water and only rarely are any other factors considered important (FAO 1985). Irrigation and domestic uses have different quality needs and one water supply is considered more acceptable (of better quality) if it produces better results or causes fewer problems than an alternative water supply.

There is a number of different water quality guidelines associated with irrigated agriculture. Separately each is valuable but none is completely acceptable because of the wide variability in field conditions. The modified guideline by Ayers and Westcot, 1985 was found to be the most reliable to predict the water quality for irrigation. The suitability criterion of water for agriculture is determined not only by the total amount of salt present but also by the type of salt. Many soil and crop related problems are incurred as the total salt content increases. Special management practices may be required to maintain desirable crop yields. Water quality for use in agriculture is judged on the potential severity of problems that can be expected to be developed during long-term use. The process is slow and gradual so one must be very careful about the quality of water being used for domestic as well as for irrigation purpose.

Evaluating the quality of water for domestic purpose especially for potable use Water Quality Index (WQI) based on chemical characteristics is found to be one of the most effective tools. Water Quality Index (WQI) were formulated in many countries based on their National standards. Horton, 1965 proposed the first WQI to be used as a tool for assessing the overall quality of water. Cude 2001, improves the understanding of water quality issues by integrating complex data and generating a score that assess the appropriateness of the quality of water for a variety of uses. Sargaonkar and Deshpande, 2003 defined quality in terms of its physical, chemical and biological parameters and developed an overall index of pollution for surface water based on a general classification scheme in Indian context. Boyacioglu, 2007 developed the Universal Water Quality Index (UWQI) to provide a simpler method for describing the quality of the surface water used for drinking water supply. Most of the WQI proposed were based on the physical, chemical and biological parameters though the hydrogeology and groundwater flow influences the quality of water directly or indirectly. The mobile elements contaminate the groundwater quality either by surface or subsurface flow.

Water Quality Monitoring Programme

Every natural resources viz., air, water, soil, vegetation etc. has two dimensions quality and quantity which is the basis of their utilization for different purposes. Monitoring of quality is essential to evaluate the nature and extent of pollution and also to find out suitable measures to maintain the quality. Water quality in India is being monitored by Central Pollution Control Board (CPCB). The pollution control boards in India are responsible for restoration and maintenance of the wholesomeness of aquatic resources. To ensure that the water quality is being maintained or restored at desired level it is important that the pollution control boards regularly monitor the water quality. The water quality monitoring is performed to assess nature and extent of pollution control needed in different water bodies or their part and also for rational planning of pollution control strategies and their prioritisation with an understanding of the environmental fate of different pollutants.

Surface Water Monitoring Network

Monitoring helps in evaluating the nature and extent of pollution control required, and effectiveness of pollution control measures already in existence. It also helps in drawing the water quality trends and prioritising pollution control efforts. A network of monitoring stations on rivers across the country has been established by Central Pollution Control Board (CPCB). The present network comprises of 1700 stations in 27 States and 6 Union Territories spread over the country. The monitoring is done on monthly or quarterly basis in surface waters and on half yearly basis in case of groundwater (CPCB 2009).

The monitoring network covers 353 Rivers, 107 Lakes, 9 Tanks, 44 Ponds, 15 Creeks/Seawater, 14 Canals, 18 Drains and 490 Wells. Among the 1700 stations, 980 are on rivers, 117 on lakes, 18 on drains, 27 on canals, 9 on tank, 15 on creeks/seawater, 44 on pond and 490 are groundwater stations. Presently the inland water quality monitoring network is operated under a three-tier programme i.e. GEMS, Monitoring of Indian National Aquatic Resources System and Yamuna Action Plan. Water samples are being analyzed for 28 parameters consisting of physicochemical and bacteriological parameters for ambient water samples apart from the field observations. Besides this, 9 trace metals and 15 pesticides are analyzed in selected samples. Biomonitoring is also carried out on specific locations. In view of limited resources, limited numbers of organic pollution related parameters are chosen for frequent monitoring i.e. monthly or quarterly and major cations, anions, other inorganic ions and micro pollutants (Toxic Metals & POP's) are analyzed once in a year to keep a track of water quality over large period of time. The water quality data are reported in Water Quality Status Year Book.

The water quality management in India is performed under the provision of Water (Prevention and Control of Pollution) Act, 1974. The basic objective of this Act is to maintain and restore the wholesomeness of national aquatic resources by prevention and control of pollution. The Act does not define the level of wholesomeness to be maintained or restored in different water bodies of the country. The Central Pollution Control Board (CPCB) has tried to define the wholesomeness in terms of protection of human uses, and thus, taken human uses of water as base for identification of water quality objectives for different water bodies in the country.

With increasing use of untreated wastewater in agriculture water quality for irrigation is of concern which is not being addressed posing threats to human health. It therefore becomes imperative to regularly monitor the quality of groundwater and to device ways and means to protect it. WQI is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. It, thus, becomes an important parameter for the assessment and management of surface and groundwater. WQI is defined as a rating reflecting the composite influence of different water quality parameters.

Groundwater Monitoring Network

India is a vast country with varied hydro geological situations resulting from diversified geological, climatological and topographic settings. Water-bearing rock formations (aquifers), range in age from Archaean to Recent. The natural chemical composition of groundwater is influenced predominantly by type and depth of soils and subsurface geological formations through which groundwater passes. Groundwater quality is also influenced by contribution from the atmosphere and surface water bodies.

Quality of groundwater is also influenced by anthropogenic factors. For example, overexploitation of groundwater in coastal regions may result in sea water ingress and consequent increase in salinity of groundwater. Excessive use of fertilizers and pesticides in agriculture, and improper disposal of urban/industrial waste can also cause contamination of groundwater resources.

Groundwater contains a wide variety of dissolved inorganic chemical constituents in various concentrations, resulting from chemical and biochemical interactions between water and the geological materials. Inorganic contaminants including salinity, chloride, fluoride, nitrate, iron and arsenic are important in determining the suitability of groundwater for drinking purposes.

The International Standard Organization (ISO) has defined monitoring as, "The programmed process of samplings, measurements and subsequent recording or signalling or both, of various water characteristics, often with the aim of assessing, conformity to specified objectives." A systematic plan for conducting water quality monitoring is called Monitoring Programme, which includes monitoring network design, preliminary survey, resource estimation, sampling, analysis data management and reporting.

Monitoring groundwater quality is an effort to obtain information on chemical quality through representative sampling in different hydrogeological units. Groundwater is commonly tapped from phreatic aquifers through dug wells in a major part of the country and through springs and hand pumps in hilly areas. The main objective of groundwater quality monitoring programme is to get information on the distribution of water quality on a regional scale as well as create a background data bank of different chemical constituents in groundwater. Central Ground Water Board (CGWB) has been monitoring the chemical quality of groundwater in the country since 1974.

The chemical quality of shallow groundwater is being monitored by Central Ground Water Board once in a year (April / May) through a network of 15640 observation wells located all over the country. The state-wise distribution of observation wells being monitored by CGWB. The major sources for water pollution are presented in table 2.

Table 2. Pollution sources in water, effects and constituents of concern

Pollution type	Primary sources	Effect on natural resources	Constituents of concern
1 Organic matter	Industrial wastewater (such as food processing,distillery, paper and pulp, brewery, sugar, petrochemical, iron and steel manufacturing) and domestic sewage.	Depletion of oxygen from the water column as it decomposes, stress or suffocating aquatic life.	Biological Oxygen Demand (BOD), Dissolved Organic Carbon (DOC), Dissolved Oxygen (DO)
2 Pathogens and microbial contaminants	Domestic sewage, cattle and other livestock, natural sources.	Spreads infectious diseases through contaminated drinking water supplies leading to diarrhoeal disease and intestinal parasites, increased childhood mortality in developing countries.	Shigella, Salmonella, Cryptosporidium, Fecal coliform (Coliform), Escherichia coli (mammal faeces – E. Coli)
3 Nutrients	Principally runoff from agricultural lands and urban areas but also from some industrial discharge.	Over-stimulates growth of algae (eutrophication) which then decomposes, robbing water of oxygen and harming aquatic life. High levels of nitrate in drinking water lead to illness in humans.	Total N (organic + inorganic), total P (organic + inorganic) For eutrophication: (Dissolved Oxygen, Individual N species (NH_4, NO_2, NO_3, Organic N), Orthophosphate
4 Salinization	Leached from alkaline soils by over irrigation or by over-pumping coastal aquifers resulting in saltwater intrusion.	Salt build-up in soils which kills crops or reduces yields. Renders freshwater supplies undrinkable.	Electrical conductivity, Chloride (followed, post characterization by full suite of major cations (Ca, Mg), anions
5 Acidification (precipitation or runoff)	Sulphur, Nitrogen oxides and particulates from electric power generation, industrial stack and auto/truck emissions (wet and dry deposition). Acid mine drainage from tailings as well as mines.	Acidifies lakes and streams which negatively impacts aquatic organisms and leaches heavy metals such as aluminium from soils into water bodies.	pH

6 Heavy metals	Industries and mining sites (Mining, paper and pulp, electroplating, metallurgical, chemical, textile and leather industries, gas and coke plants, laundry, fertilizer application, municipal and industrial effluents, pesticides).	Persists in freshwater environments such as river sediments and wetlands for long periods. Accumulates in the tissues of ish and shellfish. Can be toxic to both aquatic organisms and humans who consume them.	Pb, Cd, Zn, Cu, Ni, Cr, Hg, As (particularly groundwater)
7 Toxic organic compounds and microorganic pollutants.	Wide variety of sources from industrial sites, automobiles, farmers, home gardeners, municipal wastewaters.	A range of toxic e≃ects in aquatic fauna and humans from mild immune suppression to acute poisoning or reproductive failure.	PAHs, PCBs, pesticides (lindane, DDT, PCP, Aldrin, Dieldrin, Endrin, Isodrin, hexachlorobenzene)
8 Thermal	Fragmentation of rivers by dams and reservoirs slowing water and allowing it to warm. Industry from cooling towers and other end-of-pipe above-ambient temperature discharges	Changes in oxygen levels and decomposition rate of organic matter in the water column. May shift the species composition of the receiving water body.	Temperature
9 Silt and suspended particles	Natural soil erosion, agriculture, road building, deforestation, construction and other land use changes.	Reduces water quality for drinking and recreation and degrades aquatic habitats by smothering them with silt, disrupting spawning and interfering with feeding.	Total suspended solids, turbidity
Other pollutants include Radioactivity, Fluoride, Selenium.			
Micro-organic pollutant list now includes a suite of endocrine disrupters, antioxidants, plasticizers, fire retardants, insect repellents, solvents, insecticides, herbicides, fragrances, food additives, prescription drugs and pharmaceuticals (e.g., birth control, antibiotics, etc.), non-prescription drugs (e.g., caffeine, nicotine and derivatives, stimulants).			

Source: UNESCO 2006

Water Quality

Among all the sectors of water use, agriculture is the most sensitive to water scarcity and water quality. Although the agricultural sector is sometimes viewed as a 'residual' user of water, after domestic and industrial sectors, it accounts for 70 percent of global freshwater withdrawals, and more than 90 percent of consumptive use. It is also the sector with the largest scope or potential for adjustment (FAO, 2012). Freshwater consumption is accounted in terms of green, blue and grey water footprints. Green water use is consumption from rainfall; blue water use is consumption from groundwater or surface water; and grey water use is the fresh water required to reduce pollutant concentrations to acceptable values through dilution. This distinction among green, blue, and grey water footprints recognizes that the consumptive use of rainfall, groundwater or surface water, and the water quality impacts have different economic costs and ecological impacts (http://edis.ifas.ufl.edu/ae484).

The quality of water depends on the concentration of different constituents in it. The concentrations of constituents depend on its sources of origin and interventions through living or dead organisms in the path of its flow. Water exists in different forms in the nature viz., surface water, groundwater and wastewater. Surface water may be defined as water available on the earth's surface in sea and also collected as runoffs from rainfall in ponds, lakes, rivers and streams. Groundwater is the inherent water in the earth's crust collected underground by seepage of rainwater and surface water through soil and occupies subterranean permeable layers. Wastewater is the waste produced after using fresh water by different industrial, agricultural and domestic activities. It contains various biological, organic and inorganic contaminants that pollute surface and groundwater when discharged without treatment.

Understanding water quality requires quantitative knowledge of physical, chemical and biological characteristics and comparing their levels with standards to support for different uses including potable and irrigation use. The physical quality refers to odor and colour, turbidity, temperature, suspended solids, dissolved solids, residue and floatable substances. Chemical quality refers to pH, conductivity, dissolved oxygen, total organic carbon, hardness and carbon dioxide. It also refers to trace elements viz., arsenic (As), boron (B), cadmium (Cd), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn), organic constituents viz., anionic surfactants, mineral oil, phenol content, hydrocarbons and pesticides and inorganic constituents viz., ammonia (NH_4), calcium (Ca), chloride (Cl), fluoride (F), iron (Fe), magnesium (Mg), manganese(Mn), nitrate (NO_3), sodium (Na), sulfate (SO_4), sulphide (SO_3), total nitrogen (N) and potassium (K).

Criteria and standards

Water quality requirements for different uses of water are scientifically termed as criteria and the permissible level of contaminants in water for different uses without any negative impact on environment and society are termed as Standards. These are legally enforced levels set up by a governmental or any international agency that have been arrived at after consideration of water quality criteria and the economic, social and political consequences of possible regulatory action.

As per Gupta and Gupta 2003 the characteristics of irrigation water that have been the most important in determining its quality, depends upon climatic condition, irrigation practices, soil water retention characteristics, crop tolerance, depth to water table and agronomic practices etc. are the following

i) Salinity hazard (Total concentration of soluble salts): Electrical conductivity (EC)

ii) Specific ion toxicity hazard (Ionic composition)

   a) Major constituents (Na^+, Mg^+, Cl^-, HCO_3^-, CO_3^{--}, Silica, NO_3^-)

   b) Minor constituents (B, Li, F and other micro toxicants).

iii) Sodicity hazard (Relative proportion of Na to other cations, sodium adsorption ratio (SAR), sodium to calcium activity Ratio (SCAR), adjusted SAR/SCAR.

iv) Alkalinity hazard (Bicarbonate concentration as related to the concentration of (Ca + Mg) or calcium alone; residual sodium carbonate (RSC) or residual sodium bicarbonate (RSBC).

In addition to above individual parameters combined evaluation of two parameters viz., 1) EC and SAR, 2) SAR and RSC is also of practical importance.

Electrical Conductivity

Salinity is estimated in terms of electrical conductivity (EC) and is obtained from the resistance recorded across a conductivity cell from the following relationship.

$$EC = K/R.$$

Where K is the cell constant and R is the resistance expressed in deci Siemens per meter (dSm^{-1}) according to SI units (from the system International units). EC of the soil extracts at saturation (EC_e) has been widely recognized as an index to evaluate the plant growth. In the field, the moisture content of the soil fluctuates between a lower limit represented by the permanent wilting percentage and the upper wet end of the available range. Ideally it would be inferred that EC of irrigation water should be as low as possible, but the water which is completely free of the soluble salts is never the best for irrigation. The water having EC less than 0.2 dS/m have no fertility value and are well known to create permeability problem in the soil. The irrigation water should however have EC preferably less than 1.5 dS/m so that the irrigated soil does not ever become saline and there is full choice to grow the crops (Gupta and Gupta 2003). Groundwater occurring in arid and semi arid region with less amount of rainfall is highly saline.

Specific ions

Magnesium

Magnesium is the second most abundant cation usually found in water with high salinity. However in low salinity water calcium dominates over magnesium ions. It can be stated that with an increase in EC of water Mg/Ca ratio tends to increase. It was believed that if the proportion of Ca + Mg is high, the sodicity hazard is low. If Na predominates the hazard is high. One of the most important criteria in determining quality of water for irrigation is the Mg content of the irrigation water. A harmful effect on soil appears when the ratio Mg: Ca + Mg exceeds 0.5. Occurrence of magnesium ions in higher proportion than calcium ions tends to increase the adverse effect due to sodicity.

Chloride

The occurrence of chloride ions in natural irrigation water increase with an increase in EC and sodium ions. Therefore high salinity water are dominated by these ions. Unlike the sodium ions, neither the chloride ions have any effect on the physical properties the soil nor they adsorbed by the soil. For this reason, the absolute or relative concentration of chloride ions has not found any importance as general criteria in the evaluation of quality of irrigation water.

Nitrate

Nitrate (NO_3) is a highly water soluble molecule made up of nitrogen and oxygen. It is formed when nitrogen for ammonia or other sources combines with oxygen dissolved in water. Nitrate is a natural constituent of plants and is found in vegetables in varying degrees depending on the amount of fertilizer applied and other growing condition. According to WHO most adults ingest 20-70 mg of nitrate -nitrogen per day with most of this coming from food. When food items containing nitrate are eaten as part of a balanced diet the nitrate exposure is not considered to be harmful.

In its natural form water contains less than 1 ppm of nitrate nitrogen and thus is not a main cause of nitrate exposure. High level of nitrate is an indication of contamination. The usual sources of nitrate contamination comprise of chemical fertilizers, animal wastes septic tanks, municipal sewage treatment plants and decomposed plant debris.

The ability of nitrate to enter water in well depends on the type of soil and bed rock and on the depth and structure of the well. Bureau of Indian Standard has set the maximum permissible level of nitrate-nitrogen in public drinking water at 20 mg /l or 20 ppm (parts per million) (BIS 2002) which is further revised in 2004 to maximum permissible level of 45 ppm. Infants who are fed water or formula made with water that is high in nitrate content can develop a condition called methemoglobinemia. This condition is also called blue baby syndrome because the skin appears blue-grey or lavender in colour. This colour change is caused by a lack of oxygen in the blood (http://www.co.adams.wi.gov).

Sodium Adsorption Ratio (SAR)

Qualitatively, soluble sodium percentage (SSP) indicated sodicity hazard but this has not been found satisfactory index to predict the sodicity hazard on quantitative basis. A better index called SAR was developed by United States Salinity Laboratory (USSL) (Richards, 1954). Gupta and Abichandani, 1970 reported that after rainfall there is significant improvement of quality of water on the basis of EC and SAR, but this fact is not borne by SSP values which remain nearly the same. Even when EC and SAR/ESP of the soil increases, SSP values remain nearly constant. The use of SSP as one of the criteria in evaluating the quality if irrigation water has therefore, become obsolete and SAR as expressed below (the concentration is in me/l) found effective.

$$SAR = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca+Mg}}{2}}}$$

Most annual crops are not so sensitive, but may be affected by higher concentration. Sodium sensitive crops included deciduous fruits, nuts, citrus and beans. These plants suffer injury as a result of sodium accumulation in the leaves. However, whereas low salinity water may be found dominant in sodium bicarbonate high salinity water will be found dominant in sodium chloride.

Sodium to calcium activity Ratio (SCAR)

In high saline irrigation water which have high Mg/Ca ratio there sodium hazard is calculated as sodium to calcium activity ratio (SCAR) and estimated as Na/Ca.

Residual Sodium Carbonate (RSC)

When the proportion of bicarbonate ions is higher than calcium ions the water quality deteriorates because after evaporation of irrigation water, bicarbonate ion tends to precipitate the calcium ions. The precipitation of calcium carbonate as a scale in distribution lines, boilers, water heaters etc. is highly undesirable. Eaton 1950 suggested an index called residual sodium carbonate (RSC) to assess the effect of bicarbonate along with carbonate using the expression below.

$$RSC = (CO_3 + HCO_3) - (Ca + Mg)$$

Residual Sodium Bi-Carbonate (RSBC)

Gupta 1984 suggested that residual sodium bi-carbonate (RSBC) index to be used to measure alkalinity hazards as carbonate occurs in trace amounts in natural water and is expressed using the equation below.

$$RSBC = HCO_3 - Ca$$

Adj Sodium adsorption ratio (adj R_{Na})

An alternative procedure that adjusts the calcium concentration of the irrigation water to the expected equilibrium value following an irrigation, and includes the effects of carbon dioxide (CO_2), of bicarbonate (HCO_3) and of salinity (EC_w) upon the calcium originally present in the applied water but now a part of the soil-water was found more accurate. The procedure assumes a soil source of calcium - from soil lime ($CaCO_3$) or other soil minerals such as silicates - and no precipitation of magnesium. The new term for this is adj RNa (adjusted Sodium Adsorption Ratio) and the calculation procedure is presented in the following example as an improvement on the older Sodium Adsorption Ratio (SAR). It can be used to predict more correctly potential infiltration problems due to relatively high sodium (or low calcium) in irrigation water supplies (Suarez 1981; Rhoades 1982) and can be substituted for SAR. The equation for calculation of adj RNa of the surface soil is very similar to the older SAR equation and is:

$$\text{adj } R_{Na} = \frac{Na}{\sqrt{\frac{Ca_x + Mg}{2}}}$$

where:

Na = sodium in the irrigation water reported in me/l

Ca_x = a modified calcium value taken from Table 11, reported in me/l. Cax represents Ca in the applied irrigation water but modified due to salinity of the applied water (ECw), its HCO_3/Ca ratio (HCO_3 and Ca in me/l) and the estimated partial pressure of CO_2 in the surface few millimetres of soil (P_{CO2} = 0.0007 atmospheres)

Mg = magnesium in the irrigation water reported in me/l

To use the Ca_x table (Annexure I), first determine the HCO_3 to Ca ration (HCO_3/Ca) and EC_w from the water analysis, using HCO_3 and Ca in me/l and the water salinity (EC_w) in deciSiemens per metre. An appropriate range of calculated HCO_3/Ca ratios appears on the left side of the table and the range of EC_w across the top. Find the HCO_3/Ca ratio that falls nearest to the calculated HCO_3/Ca value for the subject water and read across to the ECw column that most closely approximates the EC_w for the water being evaluated. The Cax value shown represents the me/l of Ca that is expected to remain in solution in the soil water at equilibrium and is to be used in equation for adj R_{Na}.

The impact of water quality parameters in toxic concentration on human health is presented in table 3. The prescribed limits of water quality parameters for different uses as per BIS 2002, 2004 and FAO recommendations for trace element in irrigation water are presented in Annexure II, III, IV and V respectively.

Table 3. Impact of water quality parameters in excess on health

Parameter	Impact on Health
pH	Bitter taste, corrosion, affects mucous membrane
Total dissolved solids	Gastrointestinal irritations, undesirable taste
Alkalinity	Boiled rice turns yellowish
Hardness (Calcium + Magnesium)	Scale forming, skin irritations
Nitrite	Forms nitrosamines which are carcinogenic
Nitrate	Blue baby disease (methemoglobineamia)
Sulphate	Laxative effect, Gastrointestinal irritation
Chloride	Corrosion
Fluoride	Dental and skeletal fluorosis
Trace and Heavy metals	
Arsenic	Bioaccumulation, central nervous system affected
Mercury	Highly toxic, causes minamata disease, neurological impairment, kidney problem, mutagenic
Cadmium	Causes itai itai disease, Hypertension, Cardiovascular and gastro intestinal disease
Lead	Kidney problem, bioaccumulation and neurological problems
Aluminium	Neurological disorders, Alzheimer's disease
Copper	Liver damage, mucosal irritation, renal damage and depression, restricts growth of aquatic plants
Zinc	Gastrointestinal, dehydration, abdominal pain, nausea and dizziness
Pesticide	Acute central nervous system problem

Water Quality Index (WQI)

WQI is a single score derived by considering different important parameters of water quality. It is an integration of the individual effect of all the parameters in right proportion in deiding the quality of water. WQI is generally computed in three steps by several researchers (Water programme, 2007, Ramkrishnaiah et al 2009). Here a different approach of assigning weightage was considered to identify and highlight the location specific reasons for contamination of water.

At first each parameter was assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes based on per cent of samples within the permissible limit as per the standards. Weights of 5, 4, 3, 2, 1 are assigned to the quality parameters when 0-20, 21-40, 41-60, 61-80 and 81-100 % of samples are within the permissible limit respectively (Raychaudhuri et al 2011).

Secondly, the relative weight (Wi) is computed from using the following equation:

$$\mathrm{Wi} = \frac{\mathrm{wi}}{\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{wi}} \qquad \text{.............................} (1)$$

where, Wi is the relative weight, wi is the weight of each parameter and n is the number of parameters.

Third step involves, assignment of a quality rating scale (qi) for each parameter by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS followed by multiplication with 100:

$$\mathrm{qi} = (\mathrm{Ci} \,/\, \mathrm{Si}) \times 100 \qquad \text{.............................} (2)$$

where qi denotes the quality rating, Ci denotes the concentration of each chemical parameter in each water sample in mg/L, and Si is the Indian drinking water or irrigation water standard for each chemical parameter in mg/L according to the guidelines of the BIS 10500, 1991 or FAO respectively.

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation

$$\mathrm{SIi} = \mathrm{Wi} \,.\, \mathrm{qi} \qquad \text{.............................} (3)$$

$$\mathrm{WQI} = \sum_{i=1}^{n} \mathrm{SIi} \qquad \text{.............................} (4)$$

SIi is the subindex of ith parameter; qi is the rating based on concentration of ith parameter and n is the number of parameters.

The computed WQI values are then categorised into five classes, “excellent” “good”, “poor”, “very poor” and “unsuitable” for drinking purpose and in four classes based on “none”, “slight”, “moderate” and “severe” restrictions for irrigation use.

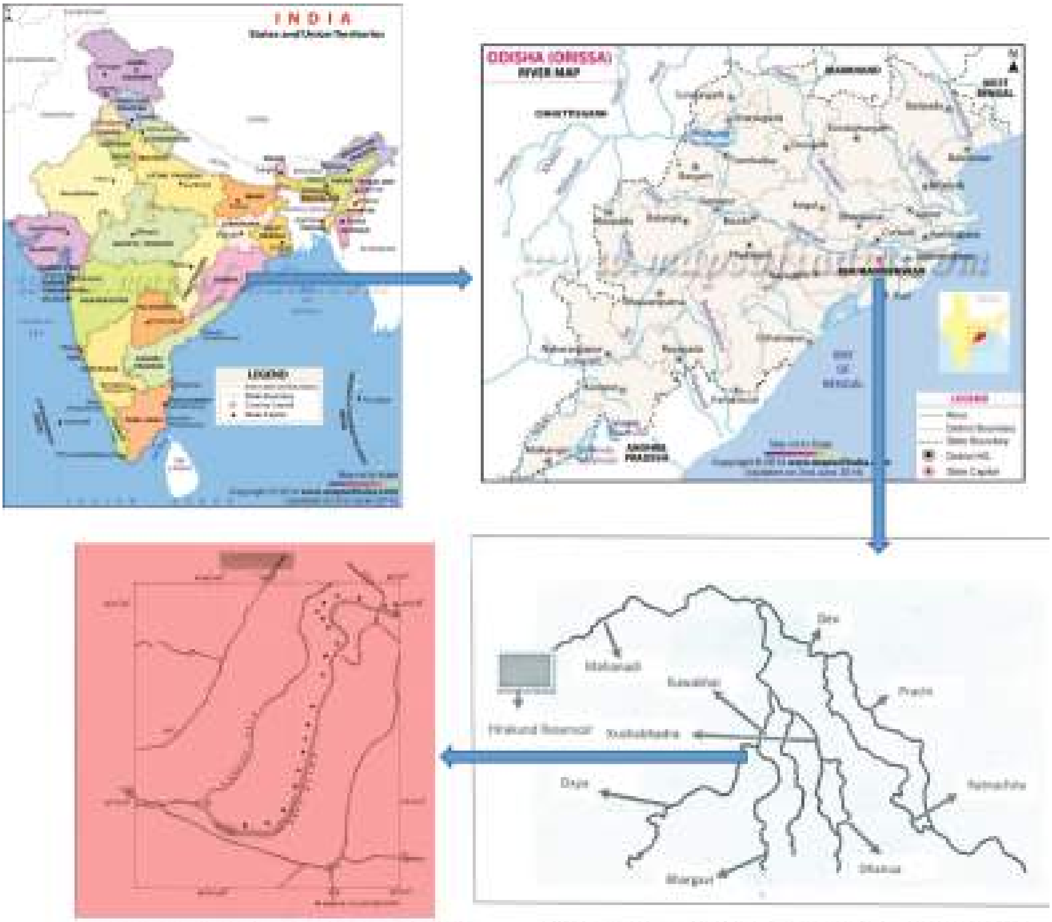
The WQI identifies the causative element or group of parameters responsible for the deteriorated quality so that appropriate measures can be implemented for its restoration. Further the WQI is computed with the methodology for groundwater for its irrigation and potable uses is validated through ground-truth check and is presented as case studies.

Case Study I : Assessment of Suitability of Groundwater along Daya River for Potable Use

Odisha (formerly Orissa) is located in the eastern part of India and spread over east coast plain; the middle mountainous and highland region; and the central plateaus agroclimatic zone. The largest river of Odisha, Mahanadi drains a basin area of 1, 43, 000 km^2 with a deltaic plain of 7000 km^2 built up by the main river and its six branches- Birupa, Chitrotpala, Kathjuri-Devi, Kusabhadra, Bhargavi and Daya as shown in Fig 1. Two barrages exist - one 100 km upstream of the river and the other barrage 20 km downstream. Water from these two barrages is used for irrigation covering an area of about 3000 km^2. The main drainage channel of Bhubaneswar city, the capital of Odisha is the Kuakhai River, a distributary of the Mahanadi river, which flows along the eastern edge of the city. The Kuakhai river is sub-divided into the Bhargavi and the Daya river in the extreme south eastern part of the city. The minor tributaries of the Kuakhai and Daya rivers flows through the city mostly in easterly and south easterly direction.

The study area extends in and around Daya River that lies between 20 ° 12 ' 39 " N to 20° 5 ' 8.33 " N latitude and 85 ° 51 ' 35 " E to 85 ° 48 ' 3.66 " E longitude (Fig 1). Studies conducted along the 20 km stretch of Daya river from its origin from the Kuwakhai river (Lingipur water supply station from where water is being supplied to the entire city of Bhubaneswar) to the point where Ganguanala carrying load from nine drains meets Daya river at Barimullah village where the Daya River water is extensively used for irrigation. The villages covered and the major crops grown in this region is presented in table 4.

The climate of the study area is subtropical with summer season from March to middle of June followed by the rainy season from June to September and winter season from November till the end of February. Relative humidity is generally high throughout the year and varies from 62-85%. The mean monthly potential evapo-transpiration varies from 57mm. in January to 254 mm in May. The mean annual wind velocity is recorded as 14.8 km/hr. The rainfall in the study area falling in Khurda and Puri district is mostly governed by the southwest monsoon and the average annual rainfall of Khurda and Puri district is 1408.4 and 1408.8 mm respectively. The rainfall is uneven and data obtained for last 20 years (1987-2009) recorded maximum rainfall of 2058.9 in 2001 and 2099.2 mm in 1995 in Khurda and Puri districts respectively and minimum as 1044.0 in 2004 and 764.3 in 1996 mm in Khurda and Puri district respectively. June-September is the peak rainy season and floods are quite common in the site.



Sampling site along Daya River

Mahanadi River System of Odisha and its tributaries

Fig 1. Study area along Daya river

Physiographically the study area is in the upper part of the deltaic plains divided into three parts: lower, middle and upper with very gently slopes. This alluvial plain is characteristically flat. The altitude of the deltaic plain varies from 1 to 10 m above mean sea level. There are mainly three types of soils in the area, which are Alfisols, Aridsols and Entisols. However, Ultisols occur over a small patch. The study area is mostly dominated by Alfisols and are mostly acidic in nature generally deficient in P_2O_5 and N_2 and medium to high in K_2O content The soil pH ranges from 5.8 -6.4.

As per the Central Groundwater Development Report the geological formations are mostly the Tertiary and Quaternary formations consist of laterites and alluvium.

While the major parts are covered by alluvium of varying thickness. The average thickness of laterite is around 8 to 10 m. The younger alluvium is dominating in the area covering nearly 90% of the area, occuring as flood plain deposits along the course of Daya river. These sediments consist of an admixture of silt, sand, gravel and pebble in varying proportions.

The aquifer system in the area is mostly shallow. The thickness of shallow aquifers (near surface aquifer) varies widely due to salinity problem. The geological setup governs the occurrence and movement of groundwater. The unconsolidated sand and gravel layers of Tertiary and Quaternary age form the main repository of groundwater. Groundwater in shallow aquifers near the surface occurs under phreatic conditions, even to a depth of up to 135 m below ground level. The laterites occurring as capping over the country rocks are vesicular, ferruginous and highly porous, which support large number of domestic wells. The depth to water level of the study area varies from 0.16 m bgl to 5.96 mbgl as recorded during pre monsoon, 2006 and varied from 0.08 mbgl to 5.13 m bgl as recorded during post-monsoon, 2006. The fluctuation of depth to water level in 2006 between pre-monsoon and post-monsoon varied from 0.1 m to 3.51 m (CGWB 2010).

As per the Ministry of Water Resources, Water Management Wing, Orissa, the total area was under high and very high population density. Basically, agriculture is the main occupations of the large section of the society. Generally, agriculture is carried out in a primitive and traditional way in most part of this region. Business and trade is also a way of life for a minor section of the population. Water from various rivers flowing in this areas serve as a major source for irrigating the agricultural lands which help the farmer's in improving their living conditions with increased agricultural production. On the other hand, this area faces natural calamities like floods and cyclone every year, which worsen the socio-economic condition of the people living in these areas.

Samples were collected from selected sites following standard methods as described in APHA – AWWA-WEF 1995. The chemical parameters viz., pH, electrical conductivity (EC), hardness, alkalinity, cations and anions in the samples were estimated using standard methodology (APHA – AWWA-WEF 1995 and Tomar, 1999).

Table 4. Cropping pattern of the study area

Sampling Site		Major crops irrigated
Village	District	
Lingipur water supply	Khurdha	Groundnut, sugarcane, marigold, cauliflower, Cabbage
Lingipur	Khurdha	Brinjal, cucumber, sugarcane, pumpkin, paddy, tomato, bitter gourd.
Sardaipur	Khurdha	Groundnut, sugarcane marigold, cauliflower, cabbage
Nuagaon (Daya Bridge)	Khurdha	Brinjal, potato, paddy , sugarcane , other vegetables
Nathpur	Khurdha	Groundnut , sugarcane, marigold , cauliflower, cabbage
Dihapur	Khurdha	Paddy ,sugar cane, tomato ,brinjal , other vegetables'
Bikipur	Khurdha	Paddy ,sugarcane, tomato, brinjal
Jaypur	Khurdha	Paddy ,sugarcane, tomato, potato, etc.
Jaypur patna	Khurdha	Paddy ,sugar cane ,green gram
Itipur	Khurdha	Paddy, sugarcane
Palashpur	Khurdha	Brinjal ,potato ,sugar cane, green gram, black gram , ladies finger, paddy
Tikarpara	Khurdha	Paddy, black gram, brinjal, potato
Gangeshwarpur	Khurdha	Brinjal, paddy, sugarcane, blackgram, vegetables
Kalyanpur	Khurdha	Paddy, sugarcane, green gram, black gram, vegetables
Suabari	Khurdha	Brinjal, potato ,sugarcane, paddy, marigold
Arjungad	Khurdha	Ladies finger, potato, beans, onion, marigold, vegetables
Poparanga	Puri	Paddy, groundnut, brinjal, chili
Raghunathpur	Puri	Cucumber, ladiesfinger, sugarcane, rashi
Vindhyagarh	Puri	Paddy, groundnut
Dakshina Nuagaon	Puri	Paddy, groundnut, black gram

The chemical analyses of the groundwater and their quality ratings are presented in table 5A and 5B. The percent compliance with the Indian Standards are summarized in table 6. Calculated relative weight (Wi) values of each parameter are also given in Table 6. The subindex and WQI of groundwater for different village was estimated and presented in table 7 and Fig 2.

Table 5A. Chemical parameters of groundwater and their quality rating scale (q_i)

Village	pH	qi	TDS (mg/l)	qi	Ca	qi	Mg	qi	TH	qi	TA	qi	Fe	qi	Mn	qi
Lingipur WS	6.52	100.3	371.2	74.24	192.4	256.5	34.2	114	648.1	216.0	308.3	154.2	0.423	141.0	0.284	284
Lingipur	6.47	99.5	1363.2	272.6	120.2	160.3	38.9	129.7	455	151.7	242.8	121.4	0.398	132.7	0.153	153
Sardaipur	6.72	103.4	377.6	75.5	136.3	181.7	38.4	128.0	499.6	166.5	198.0	99.0	0.384	128.0	0.306	306
Nuagaon	6.64	102.2	409.6	81.9	120.2	160.3	41.2	137.3	461.1	153.7	268.4	134.2	0.329	109.7	0.286	286
Nathpur	6.87	105.7	588.8	117.8	136.3	181.7	51.1	170.3	533.5	177.8	324.8	162.4	0.468	156.0	0.490	490
Dihapur	6.65	102.3	979.2	195.8	136.3	181.7	124.3	414.3	745.3	248.4	138.7	69.4	0.864	288.0	0.513	513
Bikipur	6.58	101.2	1011.2	202.2	136.3	181.7	346.3	1154.3	1707.2	569.1	397.1	198.6	1.24	413.3	0.671	671
Jaypur	6.96	107.1	1664.0	332.8	192.4	256.5	41.2	137.3	630.5	210.2	487.2	243.6	7.31	2436.7	1.155	1155
Jaypur Patna	7.01	107.8	1363.2	272.6	136.3	181.7	160.9	536.3	849.8	283.3	255.2	127.6	2.45	816.7	1.356	1356
Itipur	6.98	107.4	793.6	158.7	56.1	74.8	141.5	471.7	598.4	199.5	208.8	104.4	3.41	1136.7	0.842	842
Palashpur Sashan	7.23	111.2	576.0	115.2	78.6	104.8	160.9	536.3	685	228.3	208.8	104.4	3.622	1207.3	0.321	321
Tikadpara	7.28	112.0	396.8	79.4	120.2	160.3	75.5	251.7	504.4	168.1	397.1	198.6	5.31	1770.0	0.252	252
Gangeshwar-pur Sashan	7.09	109.1	640.0	128.0	88.2	117.6	73.1	243.7	620.8	206.9	208.8	104.4	0.847	282.3	0.256	256
Kalyanpur Sashan	7.15	110.0	320.0	64.0	104.2	138.9	80.4	268.0	527.9	175.9	440.8	220.4	0.659	219.7	0.195	195
Suabarri	7.08	108.9	384.0	76.8	120.2	160.3	82.8	276.0	580.7	193.6	348.0	174.0	1.24	413.3	0.518	518
Arjungadh	7.3	112.3	256.0	51.2	96.2	128.3	51.1	170.3	413.2	137.7	301.6	150.8	0.459	153.0	0.264	264
Poparanga	7.22	111.1	268.80	53.8	88.2	117.6	34.1	113.7	294.0	98.0	185.6	92.8	0.84	280.3	0.32	316
Raghunathpur	7.17	110.3	339.2	67.8	88.2	117.6	21.8	72.67	338.4	112.8	139.2	69.6	1.868	622.7	0.114	114
Vindhyagarh	7.14	109.8	243.2	48.6	88.2	117.6	7.2	24	224.3	74.7	132.4	66.2	1.214	404.7	0.184	184
Dakshin Nayagarh	7.2	110.8	262.4	52.5	48.1	64.1	19.5	65	184.5	61.5	154.4	77.2	1.35	450.0	0.089	89
Barimullah	7.14	109.8	211.2	42.2	48.1	64.1	12.1	40.3	172.3	57.4	159.3	79.7	0.841	280.3	0.141	141

Table 5B Chemical parameters (anions) of groundwater and their quality rating scale (q_i)

Village	HCO_3 (mg/l)	qi	SO_4 (mg/l)	qi	Cl (mg/l)	qi	NO_3 (mg/l)	qi
Lingipur WS	324.2	132.9	7.8	3.92	362.0	144.8	123.8	275.1
Lingipur	255.4	104.7	11.8	5.88	321.4	128.6	104.5	232.2
Sardaipur	208.2	85.3	3.9	1.96	285.3	114.1	119.1	264.7
Nuagaon	282.3	115.7	78.4	39.2	435.4	174.2	84.3	187.3
Nathpur	341.6	140.0	235.2	117.6	234.3	93.7	127.6	283.6
Dihapur	145.9	59.8	125.4	62.7	291.5	116.6	117.5	261.1
Bikipur	417.6	171.1	54.9	27.4	176.7	70.7	69.9	155.3
Jaypur	512.4	210.0	70.6	35.3	163.3	65.3	169.6	376.9
Jaypur Patna	268.4	110.0	67.6	33.8	191.7	76.7	152.8	339.6
Itipur	219.6	90.0	78.4	39.2	234.3	93.7	140.4	312.0
Palashpur Sashan	219.6	90.0	53.9	26.9	205.9	82.4	134.2	298.2
Tikadpara	417.6	171.1	39.2	19.6	205.9	82.4	126.5	281.1
Gangeshwarpur Sashan	219.6	90.0	33.3	16.7	231.0	92.4	108.4	240.9
Kalyanpur Sashan	463.6	190.0	27.9	13.9	205.9	82.4	102.4	227.6
Suabarri	366	150.0	31.4	15.7	255.6	102.2	117.3	260.7
Arjungadh	317.2	130.0	40.2	20.1	177.5	71.0	92.4	205.3
Poparanga	195.2	80.0	50.9	25.5	163.3	65.3	85.2	189.3
Raghunathpur	146.4	60.0	19.6	9.8	149.1	59.6	76.1	169.1
Vindhyagarh	139.2	57.0	62.7	31.4	228.1	91.2	67.9	150.9
Dakshin Nayagarh	162.4	66.6	23.5	11.7	250.9	100.4	92.4	205.3
Barimullah	167.5	68.6	18.6	9.3	218.3	87.3	59.7	132.7

Table 6. Comparison of groundwater quality with drinking water standards, Bureau of Indian Standards (BIS 2004)

Parameters	Indian Standard (BIS 2004)	Percent compliance	Weight	Relative weight
pH	6.5-8.5	100	1	0.022727
Total dissolved solids	500	57.1	3	0.068182
Total hardness as $CaCO_3$, mg/l	300	19.05	5	0.113636
Total Alkalinity as $CaCO_3$ mg/l	200	33.33	4	0.090909
Bicarbonate, mg/l	244	47.6	3	0.045455
Chloride, mg/l	250	66.7	2	0.022727
Sulphate, mg/l	200	100	1	0.113636
Nitrate, mg/l	45	0	5	0.068182
Calcium, mg/l	75	14.29	5	0.113636
Magnesium, mg/l	30	19.05	5	0.113636
Iron, mg/l	0.3	0	5	0.113636
Manganese, mg/l	0.1	4.76	5	0.113636

Nitrate is assigned the maximum weight of 5 due to its major importance in water quality assessment as well as the entire sample has nitrate beyond the permissible limit. Magnesium which is given the minimum weight of 1 as magnesium by itself may not be harmful.

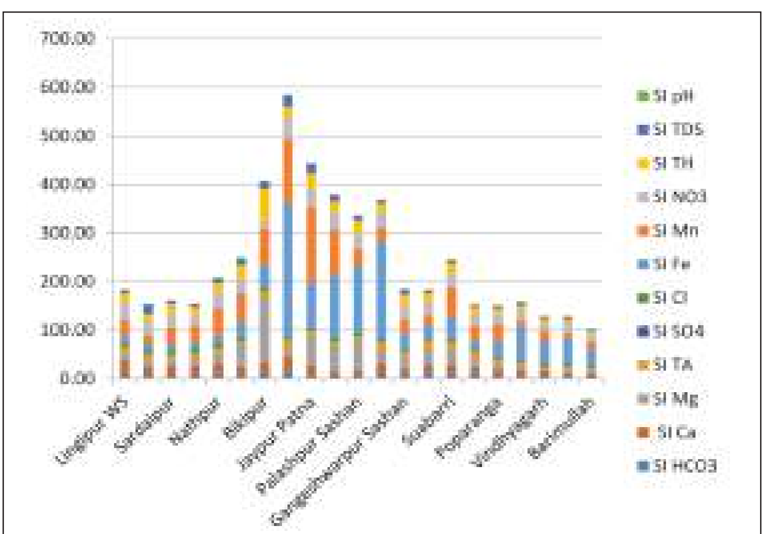


Fig 2. Water Quality Index of groundwater along Daya River

Table 7. SubIndex of all the parameters and Water Quality Index of groundwater from different villages

Village	SI HCO3	SI Ca	SI Mg	SI TA	SI SO_4	SI Cl	SI Fe	SI Mn	SI NO_3	SI TH	SI TDS	SI pH	WQI	Class
Lingipur WS	9.06	29.15	12.95	14.01	0.09	6.58	16.02	32.27	31.26	24.55	5.06	2.28	183.30	Poor
Lingipur	7.14	18.21	14.73	11.04	0.13	5.84	15.08	17.39	26.39	17.23	18.59	2.26	154.03	Poor
Sardaipur	5.82	20.65	14.55	9.00	0.04	5.19	14.55	34.77	30.08	18.92	5.15	2.35	161.06	Poor
Nuagaon	7.89	18.21	15.61	12.20	0.89	7.92	12.46	32.50	21.29	17.47	5.59	2.32	154.34	Poor
Nathpur	9.55	20.65	19.36	14.76	2.67	4.26	17.73	55.68	32.22	20.21	8.03	2.40	207.52	Very poor
Dihapur	4.08	20.65	47.08	6.30	1.43	5.30	32.73	58.30	29.67	28.23	13.35	2.33	249.44	Very poor
Bikipur	11.67	20.65	131.17	18.05	0.62	3.21	46.97	76.25	17.65	64.67	13.79	2.30	407.01	Unsuitable
Jaypur	14.32	29.15	15.61	22.15	0.80	2.97	276.89	131.25	42.83	23.88	22.69	2.43	584.97	Unsuitable
Jaypur Patna	7.50	20.65	60.95	11.60	0.77	3.49	92.80	154.09	38.59	32.19	18.59	2.45	443.66	Unsuitable
Itipur	6.14	8.50	53.60	9.49	0.89	4.26	129.17	95.68	35.45	22.67	10.82	2.44	379.11	Unsuitable
Palashpur Sashan	6.14	11.91	60.95	9.49	0.61	3.74	137.20	36.48	33.89	25.95	7.85	2.53	336.73	Unsuitable
Tikadpara	11.67	18.21	28.60	18.05	0.45	3.74	201.14	28.64	31.94	19.11	5.41	2.55	369.50	Unsuitable
Gangeshwar-pur Sashan	6.14	13.36	27.69	9.49	0.38	4.20	32.08	29.09	27.37	23.52	8.73	2.48	184.53	Poor
Kalyanpur Sashan	12.95	15.79	30.45	20.04	0.32	3.74	24.96	22.16	25.86	20.00	4.36	2.50	183.13	Poor
Suabarri	10.23	18.21	31.36	15.82	0.36	4.65	46.97	58.86	29.62	22.00	5.24	2.48	245.79	Very poor
Arjungadh	8.86	14.58	19.36	13.71	0.46	3.23	17.39	30.00	23.33	15.65	3.49	2.55	152.60	Poor
Poparanga	5.45	13.36	12.92	8.44	0.58	2.97	31.86	35.91	21.52	11.14	3.67	2.52	150.33	Poor
Raghunathpur	4.09	13.36	8.26	6.33	0.22	2.71	70.76	12.95	19.22	12.82	4.63	2.51	157.85	Poor
Vindhyagarh	3.89	13.36	2.73	6.02	0.71	4.15	45.98	20.91	17.15	8.50	3.32	2.50	129.21	Poor
Dakshin Nayagarh	4.54	7.29	7.39	7.02	0.27	4.56	51.14	10.11	23.33	6.99	3.58	2.52	128.73	Poor
Barimullah	4.68	7.29	4.58	7.24	0.21	3.97	31.86	16.02	15.08	6.53	2.88	2.50	102.83	Poor

The calculated WQI values are classified into five categories, “excellent” to “unsuitable” for drinking and presented in table 8. Electrical conductivity of water is directly proportional to its total dissolved salts. Hence it is an index to represent the total concentration of soluble salts in water.

Table 8. Classification of groundwater quality based on Water Quality Index

WQI Value	Water quality	% of water samples
<50	Excellent	0
50-100	Good	0
101-200	Poor	57.14
201-300	Very Poor	14.28
>300	Unsuitable	28.57

In this study, the computed WQI values ranges from 102.83 at Barimullah to 584.97 at Jaypur and therefore, can be categorized into five types “excellent” to “unsuitable” water for drinking. Table 15 shows the percentage of water samples that falls under different quality. The high value of WQI at these points has been found to be mainly due to the higher values of iron, manganese, magnesium, nitrate, hardness, calcium, alkalinity and bicarbonate in the groundwater.

The WQI for the 20 villages studied ranges from 102.8 to 584.9 (Table 8, Fig 2). All the samples collected exceeded 100, the upper limit for drinking water. About 57.1% of water samples are poor in quality. In this part, the groundwater quality may improve due to inflow of freshwater of good quality during rainy season. The analysis reveals that the groundwater of the area needs some degree of treatment before consumption, and it also needs to be protected from the perils of contamination.

Case Study II : Assessing the Suitability of Groundwater of Rushikuliya Command for Potable and Irrigation use

The present study aimed at assessing the water quality index (WQI) for the groundwater of Rushikulya Command area through a comprehensive chemical analysis by CGWB. For calculating the WQI, 10 to 15 parameters have been considered: pH, total hardness, calcium, magnesium, bicarbonate, chloride, nitrate, sulphate, total dissolved solids, sodium, potassium and fluorides.

Study Area

Rushikulya Irrigation System serves as a life line in the Ganjam district. It is a well planned integrated system comprising of four numbers of Anicuts (Sorismuli on Badanadi river, Madhaborida on Mahanadi river, Padma on the Padma river; and Janivilli on the Rushikulya river) and two medium sized reservoirs (Bhanjanagar reservoir on Borigam nala and Sorada reservoir on the Padma river)(Fig. 3). For Irrigation, the numerous distributaries, minors and sub-minors of Rushikulya Irrigation System plays a vital part. In addition number of Minor Irrigation schemes are also in operation in for of check weirs, ponds, tanks etc, which are also extensively utilized.

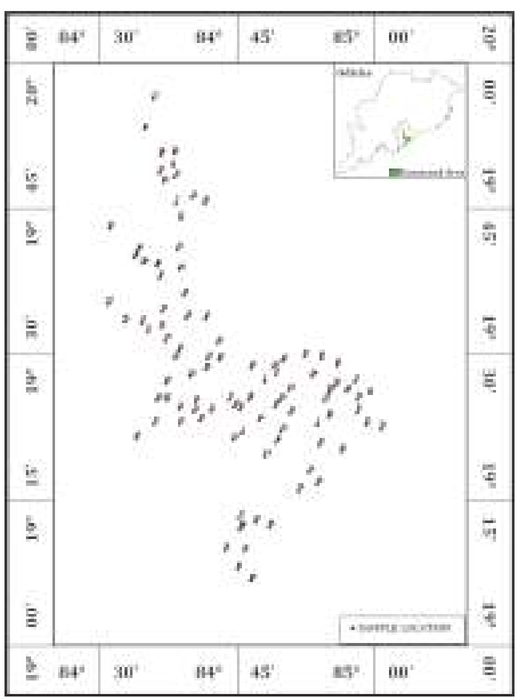


Fig 3. Location map of the study area

The major irrigation canal of the system is the Rushikulya Main canal, which off takes on the right of Janivillii Anicut and covers a total length of 87.417 Km. The canal has 16 numbers of distributaries off taking from it. Distributary number 3 and 4 have been abandoned and not excavated. The total length of distributaries with their minors and sub minors is 152 Kms. The Rushikulya Main Canal integrates 88 numbers of tanks and 11 numbers of channels through its canal system and was originally designed to command an area of 33,525 ha.

Climate : The area with sub tropical climate has high temperature and rainfall. Proximity to the sea results in an overall warm and humid climate. Temperature varies from 46C during May to 13C in January. The mean summer temperature is around 35C and that in winter is around 17C. The average annual rainfall is 1272 mm. The average monsoon and non-monsoon rainfall is 1006 mm and 266 mm respectively. Relative humidity is high and is about 75% throughout the year, particularly in the coastal areas and reduces down slightly in the interior parts of the district. Winds are fairly strong during summer and in monsoon months in the coastal part. For the rest of the year it usually remains moderate with mean wind speed around 15 km/h and the dominant wind direction is southerly. The potential evapotranspiration is maximum in the month of May (284 mm) and reduces to a minimum in the month of January (61.7 mm).

Geology : The major geomorphic units occurring in the area are Structural hills, denudational hills, residual hills, inselbergs, linear ridges, pediments, intermontane valleys, buried pediments, flood plains, coastal plains, sand dunes, mud flats etc. The slope of all categories of hills varies from 15% to 35%, whereas that of pediments varies from 3 to 15%. All the weathered units (Buried pediments and pediplains), flood plains show slope of less than 3%. The slope of coastal plain is around 1%. Major part of the Rushikulya Command area is underlain by the hard crystalline rocks of Archaean age. Sediments of recent to sub-recent age occur along the narrow coastal tract and as discontinuous patches along the Rushikulya river. Laterite also occurs in the area as capping over the older formations i.e. Khondalites. The generalized stratigraphic sequence of the study area is given below:

Recent to Sub-Recent	*Alluvium*	*Sand, Silt, Clay in varying proportions.*
	Laterite and Lateritic gravels	
~~ *UNCONFORMITY* ~~~~~~~~~~~~~~~~~~~~~		
Archaean	*Eastern Ghat Granitic Suite*	*Pegmatite and Quartz veins, Porphyritic and non porphyritic Granites, Granite Gneisses, Garnetiferous Granite Gneiss,*
	Charnockite Suite	*Hypersthene Granite Gneiss, Basic Pyroxene Granulites,*
	Khondalite Suite	*Quartz-garnet-sillimanite schists and gneisses, Quartzites, Calc-Silicate rocks*

The crystallines of Eastern Ghat Group comprises of granite, granite gneisses, Khondalites, Charnockites, Pegmatite and quartz veins.

Soils : Though the red loamy and red sandy soils form the major soil type in Ganjam district, within the command area, the alluvial soils is also a major soil type and covers the lower reaches of the command area. Few small patches of black soil too could be found in the study area.

Land Use : Arable irrigated area covers 1097 sq. km (90.3% of the total geographical extent of the command area) and arable un-irrigated category spreads around to 102.8 sq. km. (8.40% of the command area). Minor patches of forest land covering around 17.4 sq.km (roughly 1.43 % of the command area) and major and minor rural settlements as well as urban settlements are also present within the command area. Agriculture is the principal source of income of the people in the area. Cultivation is being practiced both in k*harif* and in *rabi* season. The existing cropping patterns of the area under low, midium and upland condition are shown in table 9 below.

Table 9. Cropping pattern of Rushikulya command area

Sl. No.	Land Class	Non-Irrigated	Irrigated
1.	High Land	Groundnut – Kulthi	Vegetable – Potato – Til
2.		Pulses – Til	Groundnut – Cold crop – Summer vegetable
3.		Ragi – Pulses	Paddy – Sugarcane
4.	Medium Land	Paddy – Pulses	Ragi – Paddy – Chilly
5.		Paddy – Mustard	Paddy – Potato – Til
6.			Paddy – Groundnut – Mung
7.	Low Land	Paddy – Pulses	Paddy – Chilly
8.		Til – Paddy – Pulses	Ragi – Paddy – Pulses

Methodology

The water quality data of groundwater from the Rushikulya command area from the established monitoring wells, exploratory wells and surface water body was obtained from Central Ground Water Board (CGWB). These samples were collected both during the pre-monsoon season (2005) for a comprehensive comparison and to document any distinct seasonal changes in groundwater quality. The samples collected were subjected to analysis for their pH, electrical conductivity (E.C.), carbonate (CO_3^{--}), bi-carbonate (HCO_3^{-}), chloride (Cl^{-}), sulphate (SO_4^{--}), nitrate (NO_3^{-}), phosphate (PO_4^{--}), fluoride (F^-), calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^+) and potassium (K^+). For the present study only the water samples collected from the dug wells (phreatic aquifers have been considered). The depth of these dug wells are in the range of 6 – 12 metres below the ground level. The maximum and minimum range of the analysed parameters are presented in table 10.

Table 10. Ranges of chemical quality of groundwater in Rushikuliya command area

Parameters	Units	Minimum	Maximum
pH	-	7.34	9.26
Electrical Conductivity	µS/cm	92.00	5618.00
Total Hardness	mg/l	40.00	1580.00
Carbonate (CO_3)	mg/l	0.00	15.00
Bi-Carbonate (HCO_3	mg/l	18.00	866.48
Chloride (Cl)	mg/l	14.00	1687.42
Sulphate (SO_4)	mg/l	1.10	400.00
Nitrate (NO_3)	mg/l	0.00	420.15
Calcium (Ca)	mg/l	4.00	456.91
Magnesium (Mg)	mg/l	4.00	207.00
Sodium (Na)	mg/l	5.00	839.50
Potassium (K)	mg/l	0.80	556.90
Fluoride (F)	mg/l	0.00	1.79
Phosphate (PO_4)	mg/l	0.00	1.90

Source: Central Ground Water Board, Regional Station, Bhubaneswar

Water Quality Index

The chemical analyses of the groundwater and the percent compliance with the FAO guidelines/Indian Standards were estimated. The WQI was computed using the standard methodology developed in three steps. In the first step, each of the parameters has been assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes as well as per cent deviation from the standards. In the second step, the relative weight (Wi) is computed using eqn 1 and in the third step, a quality rating scale (qi**)** for each parameter is assigned using eqn 2. according to the guidelines laid down in the BIS/FAO (BIS 10500, 1991/2002/2004 or FAO 1985). Using eqn 2 and 3 SI and WQI was computed.

For irrigation use the computed WQI values are classified into four categories based on the restrictions viz., none, slight, moderate and severe with WQI ranging as <150, 151-300, 301-450 and > 450 respectively (Raychaudhuri et al. 2014). For potable use the computed WQI values are classified into five categories viz., excellent, good, poor, very poor and unsuitable with WQI ranging as <50, 51-100, 101-200, 201-300 and > 300 respectively.

Groundwater Quality for Irrigation Use

WQI was determined following three steps as described above. In the first step, weight was assigned to each parameter (w_i) according to its relative importance in the overall quality of water for drinking purposes as well as per cent deviation from the FAO standards (Table 11). The maximum weight of 5 has been assigned to the parameter K due to its importance in water quality assessment as well as 80 % or more than 80 % of the samples are beyond the permissible limit. The pH, carbonate, bicarbonate, chloride, sulphate, phosphate and fluoride are given the minimum weight of 1 as >= 80 % of the samples are within the permissible limit and of no harm for irrigation use. The second step was followed and relative weight was assigned accordingly (Table11). The WQI computed as per the methodology ranges from 31.74 at Narayanpur to 5596.4 at Nimina (Fig 4). Majority of the samples (39.4 %) are of good quality followed by severe restrictions (30.3 %) with WQI ranging from 458.3 to 5596.4 (Table 12). The high value of WQI at these locations has been found to be mainly from the higher values of potassium content in the groundwater due to sea water intrusion.

Indiscriminate use of irrigation water and low level of groundwater development, construction of roads, embankments, expansion of inhabitations has aggravated the process of bringing the groundwater level to the surface or near to the surface, which in turn enhanced the extent of waterlogged areas. This may further increase the degree of mineralisation in groundwater as well as soil salinity.

Table 11. Weightage assigned to individual parameters for irrigation use

Parameters	Units	FAO Standards	% compliance	Weight	Relative weight
pH	-	6.0-8.5	80.8	1	0.038462
EC	µS/cm	1000*	36.4	4	0.153846
SAR	-	3	67.7	2	0.076923
CO_3	mg/l	60	100	1	0.038462
HCO_3	mg/l	610	92.0	1	0.038462
Cl	mg/l	1065	96.0	1	0.038462
NO_3-N	mg/l	45**	52.5	3	0.115385
SO_4	mg/l	1920	100.0	1	0.038462
F	mg/l	1.5	85.8	1	0.038462
PO_4-P	mg/l	2	100.0	1	0.038462
T.H	mg/l	712	85.8	1	0.038462
Ca	mg/l	400	98.9	1	0.038462
Mg	mg/l	60	68.7	2	0.076923
Na	mg/l	920	100.0	1	0.038462
K	mg/l	2	13.1	5	0.192308
			Total	**26**	

*Full yield potential is obtained for nearly all crops when using irrigation water less than 1.0 dSm^{-1}.

**Mostly Indian soils are low in N content so the permissible limit for drinking water quality parameter is considered.

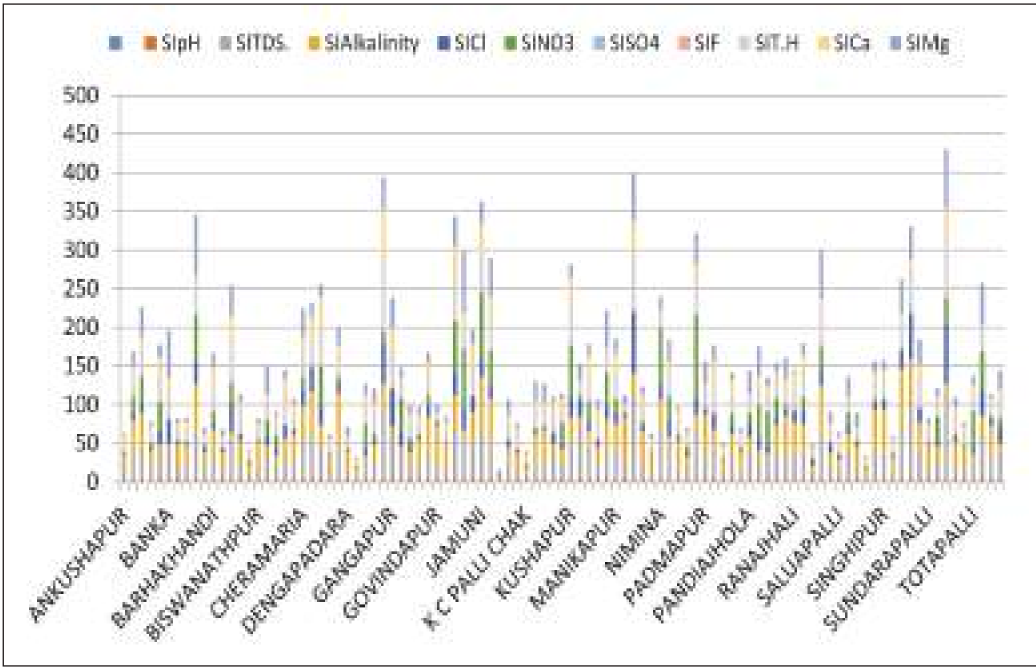


Fig 4. WQI estimated for Rushikuliya command area for potable Use

Table 12. Classification of groundwater quality for irrigation use based on WQI

WQI	Class	Restriction	% of water samples
< 150	I	None	39.4
150-300	II	Slight	22.2
300-450	III	Moderate	10.1
>450	IV	Severe	30.3

Salinity in the samples could be attributable to a number of factors – There is an effect of sea water interference in the extreme lower reaches of the command area in the Surala – Jagapur – Sunapurpentha patch. Overall the area suffers from appreciable water logging condition, even in the pre monsoon period. Over time because of this water logging, a considerable amount of soil salinity has developed in patches, which are reflected in the analysed water samples.

Potassium - another element that contributes to poor water quality could be attributed to the applications of nitrogen-phosphorus-potassium (NPK) fertilizers by the farmers as well as may be from the nature of soil and sub-surface formations.

Groundwater Quality for Potable Use

WQI was determined following three steps as described above. In the first step, weight was assigned to each parameter (w_i) according to its relative importance in the overall quality of water for drinking purposes as well as per cent deviation from the standards (Table 13). The maximum weight of 4 has been assigned to the parameter TDS, alkalinity and total hardness due to its importance in water quality assessment as well as 60 % or more than 60 % of the samples are beyond the permissible limit. The pH, sulphate and fluoride is given the minimum weight of 1 as >= 80 % of the samples have the pH within the permissible limit and of no harm for potable use. The second step was followed and relative weight was assigned accordingly (Table 13). The WQI computed as per the methodology ranges from 17.23 at Jatrasuni to 430.42 at Surala (Fig 5 and Fig 6). Majority of the samples (45.5 %) are of poor quality with WQI ranging from 100.98 to 196.32 (Table 14). The high value of WQI at these locations has been found to be mainly from the higher values of hardness, alkalinity, magnesium and nitrate content in the groundwater.

Magnesium in the lower reaches is attributable to the influence of sea water. In the upper reaches and other parts, it may be either due to the effect of the transported soil from the bottom scrapings of the local ponds or due to the presence of calcrete nodules in the soil horizon affected by extensive leaching. This is further substantiated by an alkaline water of Bi-Carbonate type.

Table -13 : Weightage assigned to individual parameters for potable use

Analytical Parameters	BIS Standards (2002)	% compliance	Weight	Relative weight
pH	6.5-8.5	80.8	1	0.038462
TDS	500	24.2	4	0.153846
Alkalinity	200	22.2	4	0.153846
Cl	250	55.6	3	0.115385
NO_3	20	52.5	3	0.115385
SO_4	400	100	1	0.038462
F	1.5	85.9	1	0.038462
T.H	300	38.4	4	0.153846
Ca	80	48.5	3	0.115385
Mg	24	42.4	3	0.115385
		Total	**27**	

In this part, the groundwater quality may improve due to inflow of freshwater of good quality during rainy season. The analysis reveals that the groundwater of the area needs some degree of treatment before consumption, and it also needs to be protected from the perils of contamination. The results were well accepted through ground truthing. The overall problem in quality may be that most of these dug wells are redundant in terms of their usage or used very meagerly – only for certain restricted non-potable purpose. For drinking water use, most villagers depend on the hand pumps as well as on the water supply schemes of Govt. of Odisha.

Table 14. Classification of Groundwater quality for potable Use based on WQI

WQI	Class	Quality	% water samples
<50	I	Excellent	7.1
51-100	II	Good	24.2
101-200	III	Poor	45.5
201-300	IV	Very Poor	14.1
>300	V	Unsuitable	9.1

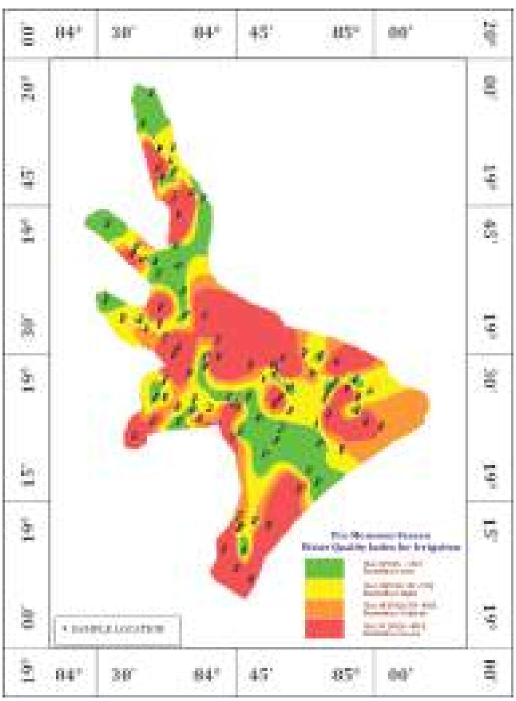


Fig 5. Variation in irrigation water quality of Rushikuliya command area based on FAO guidelines

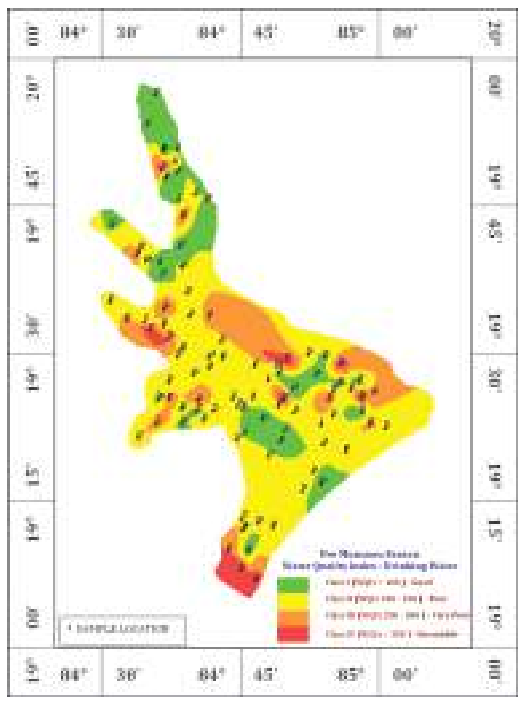


Fig 6. Variation in drinking water quality of Rushikuliya command area based on BIS guidelines

Conclusion

In India groundwater is the main source of irrigation and potable use. Injudicious and excessive use of fertilizers, discharge of untreated urban and industrial effluent in rivers and land deteriorates the groundwater quality. Most of the wastewater/ effluent are being discharged directly in the River through drains that contaminate both the surface water and groundwater. Agriculture is the largest sector for fresh water use followed by domestic sector in India. Due to water scarcity poor quality water are being used in agriculture that poses threat to soil, crop and human health. The WQI developed is an integration of different parameters important for maintaining water quality. It was found to be an important tool in assessing the suitability of poor quality water for irrigation or potable use. It will also help in identifying the causative factor and its level of contamination which in turn will help in resolving the contaminants through proper treatment.

The WQI based on chemical characteristics implemented in two sites were found effective in classifying the groundwater for irrigation and potable use and was validated through ground truth. Water quality index (WQI) is found to be one of the most effective tools. The WQI developed was validated through a case study along Daya River the drainage point of entire Bhubaneswar city, the capital city of Odisha State located in the eastern part of the country. Based on the WQI five classes were defined viz., excellent, good, poor, very poor and unsuitable. None of the samples collected were found of good quality and were categorised as poor (57.14 %), very poor (14.28%) and unsuitable (28.57%). The results were in good agreement with the users' perception surveyed along the river using river water in place of groundwater for domestic purpose where the measured WQI based on chemical properties stand 'unsuitable'. The high score of WQI was due to contamination of iron, manganese, magnesium, nitrate, hardness, calcium, alkalinity and bicarbonate in the groundwater. This suggest that the groundwater requires physical as well as chemical treatment for its potable use.

Similarly the WQI of groundwater along Rushikuliya command area was estimated for irrigation and potential use based on the water quality data obtained for CGWB, Bhubaneswar and also validated through ground trothing. It has been observed that in some areas due to sea water intrusion there is high salinity as well as potassium concentration for which the water (30.3 %) has severe restriction for irrigation. Thus groundwater recharge, pumping schedules for abstraction are some of the measures to be taken to prevent sea water intrusion as well as to dilute the existing concentration of bases.

It may be concluded from the study that WQI defined based on chemical characteristics have been acceptable and can predict the suitability for domestic purpose based on Indian standards .The methodology is quite simple and adaptable and programmable to develop a software leading towards decision support system .Water quality is of immense importance to maintain soil, crop and human health and any causality may lead to show poisoning of natural resources and human being.

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CALCIUM CONCENTRATION (Ca_x) EXPECTED TO REMAIN IN NEAR-SURFACE SOIL-WATER FOLLOWING IRRIGATION WITH WATER OF GIVEN HCO_3/Ca RATIO AND EC_w [1,2,3]													
		Salinity of applied water (EC_w) (dS/m)											
		0.1	**0.2**	**0.3**	**0.5**	**0.7**	**1.0**	**1.5**	**2.0**	**3.0**	**4.0**	**6.0**	**8.0**
Ratio of HCO_3/Ca	.05	13.20	13.61	13.92	14.40	14.79	15.26	15.91	16.43	17.28	17.97	19.07	19.94
	.10	8.31	8.57	8.77	9.07	9.31	9.62	10.02	10.35	10.89	11.32	12.01	12.56
	.15	6.34	6.54	6.69	6.92	7.11	7.34	7.65	7.90	8.31	8.64	9.17	9.58
	.20	5.24	5.40	5.52	5.71	5.87	6.06	6.31	6.52	6.86	7.13	7.57	7.91
	.25	4.51	4.65	4.76	4.92	5.06	5.22	5.44	5.62	5.91	6.15	6.52	6.82
	.30	4.00	4.12	4.21	4.36	4.48	4.62	4.82	4.98	5.24	5.44	5.77	6.04
	.35	3.61	3.72	3.80	3.94	4.04	4.17	4.35	4.49	4.72	4.91	5.21	5.45
	.40	3.30	3.40	3.48	3.60	3.70	3.82	3.98	4.11	4.32	4.49	4.77	4.98
	.45	3.05	3.14	3.22	3.33	3.42	3.53	3.68	3.80	4.00	4.15	4.41	4.61
	.50	2.84	2.93	3.00	3.10	3.19	3.29	3.43	3.54	3.72	3.87	4.11	4.30
	.75	2.17	2.24	2.29	2.37	2.43	2.51	2.62	2.70	2.84	2.95	3.14	3.28
	1.00	1.79	1.85	1.89	1.96	2.01	2.09	2.16	2.23	2.35	2.44	2.59	2.71
	1.25	1.54	1.59	1.63	1.68	1.73	1.78	1.86	1.92	2.02	2.10	2.23	2.33
	1.50	1.37	1.41	1.44	1.49	1.53	1.58	1.65	1.70	1.79	1.86	1.97	2.07
	1.75	1.23	1.27	1.30	1.35	1.38	1.43	1.49	1.54	1.62	1.68	1.78	1.86
	2.00	1.13	1.16	1.19	1.23	1.26	1.31	1.36	1.40	1.48	1.54	1.63	1.70
	2.25	1.04	1.08	1.10	1.14	1.17	1.21	1.26	1.30	1.37	1.42	1.51	1.58
	2.50	0.97	1.00	1.02	1.06	1.09	1.12	1.17	1.21	1.27	1.32	1.40	1.47
	3.00	0.85	0.89	0.91	0.94	0.96	1.00	1.04	1.07	1.13	1.17	1.24	1.30
	3.50	0.78	0.80	0.82	0.85	0.87	0.90	0.94	0.97	1.02	1.06	1.12	1.17
	4.00	0.71	0.73	0.75	0.78	0.80	0.82	0.86	0.88	0.93	0.97	1.03	1.07
	4.50	0.66	0.68	0.69	0.72	0.74	0.76	0.79	0.82	0.86	0.90	0.95	0.99
	5.00	0.61	0.63	0.65	0.67	0.69	0.71	0.74	0.76	0.80	0.83	0.88	0.93
	7.00	0.49	0.50	0.52	0.53	0.55	0.57	0.59	0.61	0.64	0.67	0.71	0.74
	10.00	0.39	0.40	0.41	0.42	0.43	0.45	0.47	0.48	0.51	0.53	0.56	0.58
	20.00	0.24	0.25	0.26	0.26	0.27	0.28	0.29	0.30	0.32	0.33	0.35	0.37
	30.00	0.18	0.19	0.20	0.20	0.21	0.21	0.22	0.23	0.24	0.25	0.27	0.28

[1] Adapted from Suarez (1981).

[2] Assumes a soil source of calcium from lime ($CaCO_3$) or silicates; no precipitation of magnesium, and partial pressure of CO_2 near the soil surface (P_{CO2}) is .0007 atmospheres.

[3] Ca_x, HCO_3, Ca are reported in me/l; EC_w is in dS/m.

TOLERANCE LIMITS OF SELECTED WATER QUALITY PARAMETERS FOR INLAND SURFACE WATER PRESCRIBED FOR DIFFERENT USES BY BUREAU OF INDIAN STANDARDS IN INDIA
(March 2002)

Constituent	Unit	Designated use Classes of Inland Surface water				
		A	B	C	D	E
PH		6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5
Electric Conductivity at 25^{0}C	micromho/cm (Max)	-	-	-	10000	2250
Calcium (Ca)	mg/l(Max.)	80.00	-	-	-	-
Magnesium (Mg)	mg/l(Max.)	24.00	-	-	-	-
Iron (Fe)	mg/l(Max.)	0.30	-	50.00	-	-
Free Ammonia (NH_4)	mg/l(Max.)	-	-	-	1.20	-
Chloride (Cl)	mg/l(Max.)	250.00	-	600.00	-	600.00
Fluoride (F)	mg/l(Max.)	1.50	1.50	1.50	-	-
Sulphate (SO_4)	mg/l(Max.)	400.00	-	400.00	-	1000.00
Nitrate (NO_3)	mg/l(Max.)	20.00	-	50.00	-	-
Dissolved Oxygen (DO)	mg/l(Max.)	6.00	5.00	4.00	4.00	-
Biochemical Oxygen Demand (BOD)	mg/l(Max.)	2.00	3.00	3.00	-	-
Total Coliform	**Most Probable**	**50.00***	**500.00**	**50000.00 ***	**-**	**-**
	Number/100ml	**-**	**-**	**-**	**-**	**-**
Arsenic (As)	mg/l(Max.)	0.05	0.20	0.20	-	-
Boron (B)	mg/l(Max.)	-	-	-	-	2.00
Cadmium (Cd)	mg/l(Max.)	0.01	-	-	-	-
Chromium (Cr)	mg/l(Max.)	0.05	0.05	0.05	-	-
Coper (Cu)	mg/l(Max.)	1.50	-	1.50	-	-
Cyanide (Cn)	mg/l(Max.)	0.05	0.05	0.05	-	-s
Lead (Pb)	mg/l(Max.)	0.40	-	0.10	-	-
Maganese (Mn)	mg/l(Max.)	0.05	-	-	-	-
Mercury (Hg)	mg/l(Max.)	0.001	-	-	-	-
Zinc (Zn)	mg/l(Max.)	15.00	-	15.00	-	-
Phenolic Compounds (C_6H_5OH)	mg/l(Max.)	0.0002	0.005	0.005	-	-
Total Hardness ($CaCO_3$)	**mg/l(Max.)**	**300.00**	**-**	**-**	**-**	**-**
Sodium Percentage	(Max.)	-	-	-	-	60.00
Sodium Absorption Ratio (SAR)	(Max.)	-	-	-	-	26.00

Note :

A: Drinking Water Source without Conventional Treatement but after Disinfection.

B: Out Door Bathing Organised.

C: Drinking Wate Source with Conventional Treatment Followed by Disinfection.

D: Propagation of Wildlife, Fisheries Etc.

E: Irrigation, Industrial Cooling, Controlled Waste Disposal.

F: If Coliform Count is More Than the Prescribed Tolerance Limit, the Criteria for Colifrom shall be Satisfied if not More Than 20% of Samples show more than the Tolerance Limit Specified and Not More Than 5% Samples show More Than 4 Times the Tolerance Limit. Further, the Faecal Coliform should Not be More Than 40% the Total Coliform.

DRINKING WATER QUALITY AS PRESCRIBED BY BUREAU OF INDIAN STANDARDS IN INDIA BIS 105000 (2004 - 05)		
Constituent	**Unit**	**Drinking water quality standards**
PH		6.5-8.5
Total Dissolved solid	mg/l (Max)	500
Electric Conductivity at 25^0C	micromho/cm (Max)	-
Alkalinity as $CaCO_3$	mg/l (Max.)	200
Total hardness as $CaCO_3$	mg/l (Max.)	300
Calcium (Ca)	mg/l (Max.)	75.00
Magnesium (Mg)	mg/l (Max.)	30.00
Iron (Fe)	mg/l (Max.)	0.30
Free Ammonia (NH_4)	mg/l (Max.)	-
Chloride (Cl)	mg/l (Max.)	250.00
Fluoride (F)	mg/l (Max.)	1.00
Sulphate (SO_4)	mg/l (Max.)	200.00
Nitrate (NO_3)	mg/l (Max.)	45.00
Dissolved Oxygen (DO)	mg/l(Max.)	6.00
Biochemical Oxygen Demand (BOD)	mg/l (Max.)	2.00
Arsenic (As)	mg/1(Max.)	0.01
Boron (B)	mg/1(Max.)	0.3
Cadmium (Cd)	mg/1(Max.)	0.003
Chromium (Cr)	mg/1(Max.)	0.05
Coper (Cu)	mg/1(Max.)	0.05
Cyanide (Cn)	mg/1(Max.)	0.05
Lead (Pb)	mg/1(Max.)	0.01
Maganese (Mn)	mg/1(Max.)	0.05
Mercury (Hg)	mg/1(Max.)	0.001
Zinc (Zn)	mg/1(Max.)	5.00
Phenolic Compounds (C_6H_5OH)	mg/1(Max.)	0.001
Total Hardness ($CaCO_3$)	**mg/1(Max.)**	**300.00**
Sodium Percentage	(Max.)	-
Sodium Absorption Ratio (SAR)	(Max.)	-

- **Revised as per BIS 105000 (2004-05)**

LABORATORY DETERMINATIONS NEEDED TO EVALUATE COMMON IRRIGATION WATER QUALITY PROBLEMS (FAO 1985)				
Water parameter	**Symbol**	**Unit**[1]	**Usual range in irrigation water**	
SALINITY				
Electrical Conductivity	EC_w	dS/m	0 - 3	dS/m
Total Dissolved Solids	TDS	mg/l	0 - 2000	mg/l
Cations and Anions				
Calcium	Ca^{++}	me/l	0 - 20	me/l
Magnesium	Mg^{++}	me/l	0 - 5	me/l
Sodium	Na^{+}	me/l	0 - 40	me/l
Carbonate	CO_3^{--}	me/l	0 - 1	me/l
Bicarbonate	HCO_3^{-}	me/l	0 - 10	me/l
Chloride	Cl^{-}	me/l	0 - 30	me/l
Sulphate	So_4^{-}	me/l	0 - 20	me/l
NUTRIENTS[2]				
Nitrate-Nitrogen	NO_3^{-}-N	mg/l	0 -10	mg/l
Ammonium-Nitrogen	NH_4^{+}-N	mg/l	0 - 5	mg/l
Phosphate-Phosphorus	PO_4^{---}-P	mg/l	0 - 2	mg/l
Potassium	K^{+}	mg/l	0 - 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 - 2	mg/l
Acid/Basicity	pH	1–14	6.0 - 8.5	
Sodium Adsorption Ratio[3]	SAR	$(me/l)^{1/2}$	0 - 15	

[1] dS/m = deciSiemen/metre in S.I. units (equivalent to 1 mmho/cm = 1 millimmho/centi-metre)

mg/l = milligram per litre ≃ parts per million (ppm).

me/l = milliequivalent per litre (mg/l ÷ equivalent weight = me/l); in SI units, 1 me/l= 1 millimol/litre adjusted for electron charge.

[2] NO_3 -N means the laboratory will analyse for NO_3 but will report the NO_3 in terms of chemically equivalent nitrogen. Similarly, for NH_4-N, the laboratory will analyse for NH_4 but report in terms of chemically equivalent elemental nitrogen. The total nitrogen available to the plant will be the sum of the equivalent elemental nitrogen.The same reporting method is used for phosphorus.

[3] SAR is calculated from the Na, Ca and Mg reported in me/l

RECOMMENDED MAXIMUM CONCENTRATIONS OF TRACE ELEMENTS IN IRRIGATION WATER[1]		
Element	**Recommended Maximum Concentration[2] (mg/l)**	**Remarks**
Al(aluminium)	5.0	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
As (arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Be (beryllium)	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cd (cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co (cobalt)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr (chromium)	0.10	Not generally recognized as an essential growth element. Con-servative limits recommended due to lack of knowledge on its toxicity to plants.
Cu (copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
F (fluoride)	1.0	Inactivated by neutral and alkaline soils.
Fe (iron)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Li (lithium)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
Mn (manganese)	0.20	Toxic to a number of crops at a few -tenths to a few mg/l, but usually only in acid soils.
Mo (molybdenum)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.

Ni (nickel)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pd (lead)	5.0	Can inhibit plant cell growth at very high concentrations.
Se (selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
Ti (titanium)	----	Effectively excluded by plants; specific tolerance unknown.
V (vanadium)	0.10	Toxic to many plants at relatively low concentrations.
Zn (zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

[1] Adapted from National Academy of Sciences (1972) and Pratt (1972).

[2] The maximum concentration is based on a water application rate which is consistent with goodirrigation practices (10 000 m^3 per hectare per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 m^3 per hectare per year. The values given are for water used on a continuous basis at one site.


OR-02AA