Original Research Article

Assessment of Surface and Groundwater Quality and their Suitability for Irrigation Purposes in Odisha, Eastern India

ABSTRACT

The study was conducted during the pre-monsoon period in April- May 2019 to monitor the quality of different water sources for assessing their suitability for irrigation purposes in Odisha state of eastern India. Twenty-seven surface water and twenty-one groundwater samples were collected and analyzed for chemical parameters. The suitability of the surface and groundwater for irrigation were evaluated based on pH, residual sodium bicarbonate (RSBC), electrical conductivity (EC), sodium adsorption ratio (SAR), Adjusted SAR (Adj. SAR), residual sodium carbonate (RSC), soluble sodium percentage (SSP), permeability index (PI), Kelly's ratio (KR), Chloride (Cl^-), boron (B), nitrate (NO_3^-), iron (Fe), Manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr) and cadmium (Cd). Results showed that three rivers, Mahanadi, Brahmani and Bansadhara, were found medium salinity (EC 0.25-0.75 dSm^{-1}), and all the rivers have no sodicity problem with RSC within the permissible limit of 2.5 $meqL^{-1}$ and free of chloride and boron toxicity. All the surface water samples were safe with respect to Zn (2 mgL^{-1}), Cu (0.2 mgL^{-1}), Fe (5 mgL^{-1}), Mn (0.2 mgL^{-1}) and Cr (0.1 mgL^{-1}). Four rivers were exceeded the maximum permissible limit of Cd. All the groundwater samples were found below the toxicity level and safe concerning Cl^-, NO_3^-, B, Zn (2 mgL^{-1}), Cu (0.2 mgL^{-1}), Fe (5 mgL^{-1}), Mn (0.2 mgL^{-1}) and Cr (0.1 mgL^{-1}) where Cd content of three sources exceeded the MPL (OUAT Agronomy Farm 0.011 mgL^{-1}, Putibandh of Sambalpur 0.011 mgL^{-1} and Rourkela 0.010 mgL^{-1}). Results depicted that all the surface water samples collected from nine different rivers are of good quality and suitable for irrigation purpose except for some specific limitations. Among all the groundwater sources, groundwaters of the Putibandh area in Sambalpur district are found very poor in quality and unsuitable for irrigation.

Keywords: Surface water; Groundwater; Quality; Irrigation.

1. INTRODUCTION

Water is a most important natural resource; it is an essential human need and a valuable national asset. In addition to drinking, it is required for other human activities like agriculture, industry, bathing, cooking, washing, recreation, navigation, fisheries etc. [1, 2]. Groundwater plays an important role worldwide in the survival of both flora and fauna. India is one of the largest groundwater users, particularly for drinking and agriculture purposes [3]. Groundwater has become the major source of water use in the agricultural sector in many countries where river and drainage systems are not sufficient. Therefore, poor groundwater quality for irrigation purposes has been a matter of worry in recent years [4]. The groundwater quality assessment based on different agriculture indices has been

studied in different parts of the world [5, 6]. There are several reports on the assessment of groundwater quality from Cameroon [7], Ghana [8], Bangladesh [9], Tamil Nadu [10, 11, 12, 2], Bhatina, Southwest Punjab. [13], Madhya Pradesh [14, 15]) and Sant Ravidas Nagar, Bhadohi, Uttar Pradesh [16]. In Uttarakhand, irrigation water quality assessment has been done in Doon Valley [17], Nainital [18], Almora [19, 20], Haridwar [21], Udham Singh Nagar [22]. In Odisha, physico-chemical analysis of surface and groundwater of Bargarh district [23], Keonjhar city [24]. Surface water quality is a sensitive global environmental issue that is important for long-term economic development and environmental sustainability [25, 26, 27]. Awareness and attention to water irrigation quality have increased worldwide in recent years, and new approaches have been developed to achieve sustainable water resources management [28, 29]. In the same context, the shortage of water resources has become a big problem in many countries, particularly under continued population growth, accelerated industrialization, rapid urbanization, and global climate change [30, 31]). Therefore, water scarcity and sustainable irrigation water management have become global challenges for sustainable agriculture development in order to produce sufficient food to satisfy the population's food requirements [32, 33, 34]. In Odisha, there are mostly three sources of water rivers, surface storage and groundwater. Odisha is neither abundant nor certain about its water resources, and it is not a good sign for the future. According to the water source, the quality and characteristics vary mainly due to varying geology and climate. On a local level also, there may be differences due to weather and the source from surface water or groundwater with varying geology. The plant growth is affected due to the chemical parameters of irrigation water through toxicity and deficiency directly and by altering the availability of nutrients indirectly. Anthropogenic activities within river basins, erosion and atmospheric depositions are also the major negative impacts on the water quality of most reservoirs [35]. Anthropogenic influence as well as natural processes degrade surface waters and impair their use for drinking, industrial, agricultural and recreational purposes [36]. Urban runoffs and sewage disposal in the catchment area of rivers also contribute to poor water quality [37]. Industrial wastewater, runoff from the agricultural lands, and municipal sewage disposal are the most vulnerable to water pollution [38]. The soil salinity is also an important factor in determining water quality. Therefore, a study on the quality of major surface water and groundwater sources is very important for managing irrigation in the present situation. To the best of our knowledge, no comprehensive study has been made on the water quality of major rivers and groundwater used for irrigation in Odisha. Therefore, in the present investigation, an attempt has been made to assess the quality of different water resources and classify water based on their suitability for irrigation purposes collected from different places of Odisha.

2. MATERIALS AND METHODS

2.1 Study area

Odisha is located on the eastern coast of India, between $17^{o}31"$ and 22^{o} 31" N latitude and 81^{o} 31" and 87^{o} 31" E longitude. It covers 155,707 km^2, which is about 4.74% of the area of India. The climate is tropical with 1450mm average rainfall. The state is spread over 155,707 km^2 and 1030 km from north to south and 500 kilometers from East to West. Its coastline is 480 km long. The state has 30

districts. Locations of water sample collection from different river basins are decided based on the physiographic data and maps of rivers and according to its place of tributaries where it flows and covers the maximum area (Fig. 1). Physiographically, Odisha consists of coastal plains, central plateaus, central hilly regions, flood plains, and uplands.

2.2 Sampling and analysis

Surface water samples were collected during April-May 2019 from the middle reach of nine major rivers *viz.* Mahanadi, Rushikulya, Brahmani, Subarnarekha, Kolab, Bansadhara, Salandi, Bahuda, and Ib of Odisha. Thus, twenty seven samples were collected from nine surface water sources. Similarly, groundwater samples were collected at two hours intervals from seven borewells and three borewells of Odisha University of Agriculture and Technology Research Farm. Agronomy Farm, Central Farm and Orchard, one each at Sambalpur, Rourkela, Gajapati and Ganjam districts of Odisha. Twenty-one groundwater samples (bore well) were collected in the pre-monsoon season in 2019 from different sites. The surface and groundwater samples were collected in pre-washed polyethylene narrow mouth bottles of 500 ml capacity and stored (three times rinsed with the same water before collecting the samples). The sampling sites of surface water and groundwater were measured using a global positioning system (GPS) for most samples (Fig. 1). The method involved in the analysis of water samples is depicted in Tables 1 and 2.

(Insert Fig. 1 and Table 1 and 2)

2.3 Statistical interpretation

The entire data obtained in the present study were analyzed using a completely randomized design (CRD). To evaluate significant differences among the sites for all water quality variables, data of nine treatments of different rivers and three replication of each river and seven treatments of different groundwater samples and three replication of each were analyzed using one- way analysis of variance (ANOVA) at 0.05% and 0.01% level of significance [39]. Data for different parameters of water samples were presented as mean values.

3. RESULTS AND DISCUSSION

The results obtained from laboratory analysis of various chemical parameters and calculated indices values collected from all the sources and locations are given in Table 3 to 11 and Supplementary data Table 1 to 2. To ascertain the suitability of collected surface and groundwater samples for irrigation purposes was discussed compared to recommended standard values given by different authors.

3.1 pH

In the present study area, the pH showed that all the surface water collected from canals and rivers at different points varied from 6.23 to 8.05 with a mean of 7.29 and 5.68-8.10 for groundwater with a mean of 7.04 (Table 3 and 4). The highest pH of 8.02 was measured in the water of Ib river

and the lowest 6.51 for the river near Janiguda farm, Kolab. Among the groundwater samples, the highest pH of 8.02 was found in the bore well water of Sambalpur, Putibandh area and lowest of 5.97 measured in the borewell, water of Agronomy farm, OUAT, Bhubaneswar. The pH of water is an important index of hydrogen ion activity, and it is the resulting value of the acid-base interaction of several minerals and organic components in water. pH is an important ecological factor and universally express the intensity of the acid and alkaline condition of the water samples. According to the Food and Agriculture Organization (FAO) recommendation, the permissible limit of irrigation water pH is 6.5-8.5 [40, 41]. All the surface water samples collected in our study had pH between 6.23 and 8.05, and groundwater, 5.68 to 8.1 (Fig. 2). The present investigation showed that all the surface water sources tested had pH value within the safe limit except the water of Kolab, which had a pH of 6.47, which was less than the permissible limit of 6.5 and groundwater used for irrigation in Central Farm and Agronomy Farm of OUAT have pH less than the allowable limit of 6.5. But all other samples collected from industrial and urban areas had alkaline and significantly higher pH (7.48-8.02).

(Insert Fig. 2)

3.2 Electrical Conductivity (EC)

The EC values of water samples during monitoring periods ranged between 0.068-0.705 dSm^{-1}, and the mean is 0.25 dSm^{-1} of surface water and 0.045-0.723 dSm^{-1} with a mean of 0.31 dSm^{-1} of groundwater (Table 3 and 4). The highest EC of 0.57 dSm^{-1} was measured in the water of Bramhani river at Rourkela-3 (sector-7) of Sundergarh district, and lowest of 0.07 dSm^{-1} in the water of Salandi river collected at Keonjhar and among all groundwater sources, highest EC of 0.70 dSm^{-1} was found in Putibandh area of Sambalpur and lowest of 0.06 dSm^{-1} in the Orchard of OUAT at Bhubaneswar (Fig. 3). The permissible range of EC is 0.25-0.75 dSm^{-1}[42]. So, all the samples fall into C1 (low salinity) and C2 (medium salinity water some leaching sensitive crops) classes of salinity hazard classification by USDA [43] (Table 7).

(Insert Fig. 3)

3.3 Carbonate (CO_3^{2-}) and Bicarbonate (HCO_3^-)

The presence of CO_3^{2-} and HCO_3^- ions in irrigation water significantly influences the concentration of calcium and magnesium content of water and soil permeability after its application. Results showed that CO_3^{2-} was absent in almost all the water samples except a few groundwater samples where it ranged from 0.99 to 5.40 meq L^{-1} with a mean of 1.12 meq L^{-1} (Table 3 and 4). The highest carbonate content of 4.59 meq L^{-1} was found in groundwater samples of the Putibandh area of Sambalpur district. The HCO_3^- ranged from 0.99 to 2.97 meq L^{-1} with a mean of 2.09 meq L^{-1} for surface samples (Table 4). In the case of groundwater samples, HCO_3^- varied from 0.99 to 2.97 meq L^{-1} with a mean value of 1.46 meq L^{-1} (Table 6). Alkalinity in water is mainly due to CO_3^{2-}, HCO_3^- and OH^- content. Carbonate content should be between 0-1 meqL^{-1}[6]. There was no carbonate in all the

surface water and groundwater except Samabalpur (Putibandh), Rourkela -3 (sector-7), and Gajapati (Paralakhemundi) had higher mean CO_3^{2-} concentration with highest of 4.59 $meqL^{-1}$ measured at Sambalpur, which is more than the safe limit 1.0 $meqL^{-1}$. These samples also had higher pH values.

3.4 Basic Cations (Na^+, K^+, Ca^{2+} and Mg^{2+})

In this study, four cations that directly and indirectly influence the quality of irrigation water have been measured, and the analysis results of all surface water and groundwater have been presented in Tables 3 and 4. The concentration of four cations *viz.* Na^+, K^+, Ca^{2+} and Mg^{2+} ranged from 0.09 to 2.54, 0.018 to 0.65, 0.23 to 1.2, 0.09 to 1.2 $meqL^{-1}$ with respective mean values of 0.59, 0.078, 0.66, 0.35 $meqL^{-1}$ for surface water and ranges of 0.112 to 3.04, 0.005 to 0.078, 0.24 to 1.72, 0.13 to 0.54 $meqL^{-1}$ with respective mean values 0.98, 0.037, 0.861, 0.28 $meqL^{-1}$ in groundwater. In irrigation water, the permissible limit for Na^+, K^+, Ca^{2+} and Mg^{2+} are 200, 30, 80 and 35 mg L^{-1} [44, 45].

3.5 Specific Elements/Ions Chloride (Cl^-)

The chloride content ranges from 21.27-67.36 mgL^{-1} with a mean of 36.37 mgL^{-1} for surface water and 3.54 to 60.26 mgL^{-1} with a mean of 39.98 mgL^{-1} for groundwater samples with the highest concentration found in Kolab river near Janiguda of Koraput, lowest in Subernarekha river of Mayurbhanj. Among the groundwater samples collected highest was found in Rourkela-3 (sector-7) and lowest in the groundwater of OUAT Horticulture orchard, Bhubaneswar (Table 3 and 4). The chloride concentration serves as an indicator of pollution by sewage and industrial effluents. In this study, all the samples are within the safe limit based upon suitability classification based on chloride concentration (< 10 $meqL^{-1}$ or 350 $meqL^{-1}$). The chloride content in well water of Behampur (11.52 $meqL^{-1}$), Jaipatna (21.20 $meqL^{-1}$), Odagaon (10.37 $meqL^{-1}$), Puri (18.44 $meqL^{-1}$) canal water from Soro (10.37 $meqL^{-1}$) pond water of (21.2 $meqL^{-1}$) are found unsuitable for irrigation purposes [13].

3.6 Boron (B)

B content ranges from 0.0225-0.934 mgL^{-1} with a mean of 0.28 mgL^{-1} for surface water (Table 3) and 0.043-0.912 mgL^{-1} with a mean of 0.26 mgL^{-1} for groundwater samples (Table 4). The highest concentration was found in the Salandi river (Keonjhar) and lowest in the Rushikulya river among surface water samples. The highest was groundwater samples found in the water of OUAT Agronomy farm at Bhubaneswar and lowest in Putibandh of Sambalpur district. B is also present in irrigation water as unionized boric acid expressed as boron element in mgL^{-1}. Sensitivity to boron encompasses many fields and tree crops, although fruit, nut and berry crops are particularly sensitive. There is no B toxicity in the present investigation as all the samples had boron less than 2 mgL^{-1} [46].

3.7 Nitrate (NO_3^{-1})

Nitrate content ranges from 0.98-3.23 mgL^{-1} with a mean of 2.10 mgL^{-1} for surface water (Table 3) and 2.96-8.2 mgL^{-1} with a mean of 4.75 mgL^{-1} (Table 4) for groundwater samples with the highest concentration found in Ib river, lowest in Salandi river, Keonjhar. Among groundwater samples highest was measured in the water of the bore well in the Horticulture Orchard of Bhubaneswar and lowest in the groundwater of Rourkela -3 (sector-7). In the present study, all the samples are safe with respect to NO_3^{-1} (< 30 mgL^{-1}) [46].

3.8 Micronutrients and Heavy metals

The content of trace and heavy metals (Zn, Cu, Fe, Mn, Cr and Cd) in water sources is presented in Table 3 and 4. The results revealed that Cr concentration was non-detectable in AAS in surface and groundwater samples. The ranges of Zn, Cu, Fe, Mn and Cd were 0.002- 0.043, 0.032-0.052, 0.036-0.184, 0.01-0.056 and 0.001-0.035 mgL^{-1} respectively in surface water and 0.007-0.044, 0.026-0.045, 0.033-1.09, 0.01-0.11 and 0.007- 0.012 mgL^{-1} in groundwater samples respectively. All the water samples, both surface and groundwater, were below the toxicity level and safe with respect to Zn, Cu, Fe, Mn, Cr except Cd, which is more than the permissible limit for the Kolab, Bahuda, Rushikulya and Mahanadi river and from groundwater samples Agronomy field, OUAT, Rourkela-3 sector-7 and Putibandh of Sambalpur samples (Fig. 4).

(Insert Table 3 and 4) (Insert Fig. 4)

3.9 Sodium Adsorption Ratio (SAR)

Results showed (Table 5 and 6) that SAR values varied from 0.16 to 2.73 with a mean of 0.79 for surface water and 0.18 to 3.26 with a mean of 1.33 for groundwater. The suitability of the well water samples was evaluated by determining the Sodium Adsorption Ratio value, which is an expression of concentration of Na^+ relative to Ca^{2+} and $Mg^{2+,}$ and they were categorized under different classes based on salinity and alkalinity hazards. U.S Salinity laboratory proposed that SAR is a more reliable criterion for evaluating Na hazard in irrigation water. According to Richards [47], water samples having SAR 10-18 are of medium sodium hazard, and these waters cannot be used for fine-textured soils. Water with SAR less than 10 has no sodium hazard. According to Richards, SAR values measured in the sampled waters in surface water and groundwater was found no sodicity. All the samples are within the permissible range of FAO, and all the samples are found to be in the S1 class of sodicity hazard classification of USSL (1954) as all the values are within 0-10. The groundwater of Sambalpur having EC 0.70 dSm^{-1} and SAR 3.20 is classified under the moderate sodicity category as per the guidelines [48, 46].

3.10 Adjusted SAR ($SAR_{adj.}$)/ $Adj.R_{Na}$

Results showed that $SAR_{adj.}$ (Table 5 and 6) ranged from 0.12 to 2.65, with a mean of 0.73 for surface water and 0.13 to 3.18 with a mean of 1.01 for groundwater. According to the guidelines, the present study found all the surface and groundwater in the S1 category [49]. Adjusted SAR (SARadj.) is a better criterion for assessing the sodicity effect of irrigation water than SAR. Irrigation of Ca-rich or Mg-rich soil with water containing carbonate and bicarbonate ions will form insoluble calcium and magnesium carbonates resulting in a decrease in the concentration of Ca and Mg used in the SAR calculation. This leads to an increase in the value of measured SAR, which does not show the real picture of sodicity under such a situation. Irrigation water contains sufficient quantities of sulphate and bicarbonate ions to produce precipitation of calcium sulphate and calcium carbonate that remove calcium from solution and hence markedly increase sodium hazards. SAR under this situation may not give the correct sodium hazard since it is the SARsw value rather than the SARiw value that affects the soil's ESP and, eventually, the soil permeability. Hence, a new index called adjusted SAR [50] and is calculated from procedure [51] is recommended, but both the older SAR procedure and the new $adjR_{Na}$ are acceptable, with a preference expressed towards the $adjR_{Na}$ because it and the Ca_x of Supplementary Table 3 offer a better insight into the change in calcium in the soil-water due to addition by the dissolution of calcium from soil carbonates and silicates or loss of calcium from soil-water by precipitation as carbonates [46].

3.11 Permeability Index (PI)

The PI values ranged from 65.71 to 305.38%, with a mean of 143.28% for surface water and 77.79 to 160.27% with a mean, 112.19% for groundwater (Table 5 and 6). The highest and lowest PI were found in the Subernarekha and Bahuda rivers. Among surface water samples and groundwater samples, the highest and lowest PI were measured in the groundwater collected from the Central farm, OUAT Bhubaneswar and Rourkela-3 (sector-7), respectively. The Permeability Index (PI) value is used to evaluate the sodium hazards of irrigation water. High sodium in the irrigation water can cause severe soil permeability problems. Permeability is affected not only by high sodium but also by CO_3^{2-} and HCO_3^- content in water. Long term irrigation affects the permeability of the soil due to the presence of Na^+, Ca^{2+}, Mg^{2+} and HCO_3^- ions in water. Therefore, the PI values can be effectively used to determine the suitability of surface water and groundwater to be used for irrigation purposes. Water can be classified as class I, class II and class III. Class I is excellent when PI is more than 75%, class II is good with PI 25-75%, and Class III is unsuitable when PI is less than 25% [52, 53]. All the samples are fall in the class I (more than 75%) category of classification.

3.12 Residual sodium carbonate (RSC)

Results showed that the range of RSC was found to be 0.75 to 2.53 $meqL^{-1}$ with a mean of 1.075 $meqL^{-1}$ for surface water and -0.25 to 4.49 $meqL^{-1}$with a mean of 1.44 $meqL^{-1}$ for groundwater (Table 5 and 6). It is used to predict the additional sodium hazard associated with $CaCO_3$ precipitation by calculating the residual sodium carbonate. RSC is another alternative measure of sodium content concerning calcium and magnesium. The proportion of bicarbonate ions higher than calcium

ions is considered undesirable because bicarbonate ions tend to precipitate calcium ions after evaporation of irrigation water. Therefore, the effect of bicarbonate and carbonates evaluated through RSC is a better indicator of the sodium hazard of irrigation water. Two samples collected from this river from sites at Mayurbhanj are above the permissible limit out of all surface water samples**.** For groundwater samples, the highest RSC of 4.49 $meqL^{-1}$ was found in the Putibandh area, Sambalpuri district. Samples from Putibandh were found above the permissible limit of 2.5 $meqL^{-1}$ [54]. Samples from river Mahanadi, Brahmani, Subarnarekha, Ib and groundwater of Rourkela and Gamjam were found to be above the safe limit (1.25 - 2.5 $meqL^{-1}$) but within the maximum permissible limit, as shown in Table 7 and Fig. 5.

(Insert Table 5, 6 and 7) (Insert Fig. 5)

3.13 Residual Sodium Bicarbonate (RSBC)

RSBC ranges from 0.21-2.74 $meqL^{-1}$ with a mean of 1.43 $meqL^{-1}$ for surface water and -0.73–1.95 $meqL^{-1}$ with a mean of 0.68 $meqL^{-1}$ for groundwater samples presented in Table 5 and 6. Among surface water samples highest RSBC was measured in Subernarekha river, lowest in Bahuda river, and among groundwater samples, highest found in Gajapati and lowest at Putibandh, Sambalpur. Since carbonate ions do not occur very frequently in appreciable concentrations, and as bicarbonate ions do not precipitate magnesium ions, the residual sodium bicarbonate was calculated [55, 56] suggested that alkalinity hazard should be determined through the index called Residual Sodium Bicarbonate (RSBC). Water with RSBC <5, 5–10 and >10 $meqL^{-1}$ is considered safe, marginal, and unsatisfactory. In the present study area, all the samples are within the safe limit and are classified as low alkaline water (< 2.5 $meqL^{-1}$).

3.14 Soluble Sodium Percentage (SSP)

Results presented in Table 5 and 6 reveal that SSP ranges from 13.33% to 65.98%, with a mean of 36.73 % for surface water and 13.49% to 654 % with a mean of 44.16% for groundwater. Highest SSP from surface water samples found in Bramhani river of Banei and lowest in Bahuda river of Gajapati and from all the groundwater samples, highest SSP found in Putibandh area, Sambalpur and lowest in Horticulture orchard of OUAT at Bhubaneswar. Excess of sodium ions characterizes the water as saline or alkaline depending upon its occurrence in association with chloride/ sulphate or carbonate/ bicarbonate ions. The quality of irrigation water used to be evaluated with respect to sodium based on soluble sodium percentage (SSP) since a high value indicates soft water and low-value hard water. Classification of irrigation water based on SSP (Table 7) [57]. In the present study, the highest SSP from surface water samples was found in the Bramhani river of Banei and the lowest in the Bahuda river of Gajapati. From all the groundwater samples, the highest SSP was found in the Putibandh area, Sambalpur and lowest in the Horticulture orchard of the Odisha University of Agriculture Technology at Bhubaneswar. All the surface water and groundwater samples fall in excellent, good and permissible range of SSP except Putibandh of Sambalpur (Table 7; Fig. 6).

High SSP reduces the permeability of the soil and eventually results in soil with poor drainage conditions [58].

(Insert Fig. 6)

3.15 Kelley's Ratio (KR)

Results showed that KR content ranges from 0.11 to 1.46 with a mean of 0.55 for surface water and 0.13 to 1.78 (Table 5 and 6) with a mean of 0.78 for groundwater samples. The highest value of KR was found in Rushikulya river, lowest found in Bahuda river among all surface water samples, highest found in Putibandh, Sambalpur and lowest in Rourkela-3 (sector-7). The level of Na^+ measured against Ca^{2+} and Mg^{2+} is known as Kelley's ratio, based on which irrigation water can be rated; Kelley's groundwater having less than one is considered good for irrigation (Kelley) [59]. KR >1 indicates an excess level of Na^+ in waters. Therefore, water with a KI≤1 has been recommended for irrigation, while water with KI≥1 is not recommended for irrigation due to alkali hazards [60, 61]. KR content ranged from 0.11 to 1.46 with a mean of 0.54 for surface water and 0.13 to 1.78 with a mean of 0.78 for groundwater samples. In the present study, all surface water sources have KR less than 1 and are recommended for irrigation. Similarly, among the groundwater sources, water collected from Sambalpur (1.66) and Gajapati (1.12) had KR more than 1 (Table 7; Fig. 7).

(Insert Fig. 7)

In the present study area, all the surface water samples are of good quality and suitable for irrigation purposes as based upon all the parameters, the samples are within a safe limit. Based upon SSP, only the Bahuda river is of excellent quality, Mahanadi, Subarnarekha, Salandi is of good quality, and others are within the permissible range according to the classification [57] while studying the water quality of Puri district. Based upon EC, all the samples fall in low salinity class except Mahanadi, Bramhani, Bansadhara river, which falls in medium salinity class, according to class [47]. The SAR, Adj. SAR and PI fall in the excellent category of suitability classification and are based upon all other parameters, and the samples are safe for irrigation purposes (Table 8). The groundwater samples are suitable for irrigation purposes based upon all parameters except Putibandh of Sambalpur based upon the RSC falls in unsuitable category [54], based upon SSP under doubtful class, based on KR bad category and sample of Gajapati based upon KR which falls in bad category [62]. Based upon EC, all the samples fall under low salinity class except Sambalpur, Rourkela-3 (sector-7), Ganjam, Gajapati, which fall under medium salinity class [47]. Based upon SSP, only samples of Orchard fall under the excellent category, the sample of Sambalpur under the doubtful category and all other samples are under the permissible category of suitability classification [57]. Based upon SAR, Adj.SAR, PI all the samples fall under the excellent category of suitability classification (Table 8, 9 and 10 and Supplementary data Table 1 to 2).

(Insert Table 8, 9 and 10 and, if required Supplementary data Table 1 to 2 may be inserted)

4. CONCLUSION

The present study concluded that all the surface water samples collected from 27 points of nine different rivers are of good quality and suitable for irrigation purposes based on quality assessment parameters except some specific limitations associated with certain sources, which can be overcome with management. Based upon salinity measured in EC, all rivers except three rivers, Mahanadi, Brahmani and Bansadhara, have no salinity hazard. These three rivers are of medium salinity (0.25-0.75 dSm^{-1}), but the water can be safely used for irrigation with management. In other cases, the salinity level is safe (<0.25 $meqL^{-1}$). Water samples of all rivers except Subarnrekha, Brahmani, Ib and Mahanadi have no sodicity hazard. The water of these three rivers was above the safe limit but within the permissible limit of RSC, 2.5 $meqL^{-1,}$ but can be used with management. When measured individually, two samples collected from the Subarnarekha river from two sites at Mayurbhanj are above the permissible limit of 2.5 $meqL^{-1}$ and thus not suitable for irrigation. The water of all the nine rivers collected from different places of their mid-reach have no chloride and boron toxicity. Nitrate was much below the maximum permissible level. All the surface water samples were below the toxicity level and safe for Zn (2 mgL^{-1}), Cu (0.2 mgL^{-1}), Fe (5 mgL^{-1}), Mn (0.2 mgL^{-1}) and Cr (0.1 mgL^{-1}). But the water of four major rivers exceeded the maximum permissible limit of Cd. These are in the order: Rushikulya, 0.034 mgL^{-1} > Kolab, 0.023 mgL^{-1} > Mahanadi, 0.014 mgL^{-1} > Bahuda, 0.011 mgL^{-1}. On the other hand, groundwater samples collected from the three Farms of OUAT at Bhubaneswar are acidic in reaction and are below the permissible limit of 6.5-8.5 with respect to other characteristics; they are safe to use.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Suresh R, Prabakaran R, Babu K, Selvaraj B. Spatial analysis of groundwater quality for Chinnar river sub basin, Tamilnadu, India using GIS. Int J Mod Res Rev, 2015; 3:1034-1037.
2. Ramamoorthy P, Backiaraj S, Ajithkumar R. Evaluation of ground water quality for drinking and irrigation suitability: A case study in Marakkanam Block, Villupuram district, Tamilnadu, India. J Ind Pollut Control, 2018;34(2): 2159-2163.
3. Sarkar AA, Hasan A. Water quality assessment of a ground water basin in Bangladesh for irrigation use. Pak J Biol Sci. 2006; 9 (9): 1677-1684.
4. Rawat KS, Singh SK, Gautam SK. Assessment of groundwater quality for irrigation use: a peninsular case study. Appl Water Sci. 2018; 8: 233.
5. Raihan F, Alam JB. Assessment of groundwater quality in Sunamganj of Bangladesh. Iran J Environ Health Sci Eng, 2008; 5(3): 155–166.
6. Sarkar AA, Hasan A. Water quality assessment of a ground water basin in Bangladeshfor

irrigation use. Pak J Biol Sci, 2006; 9(9): 1677-1684.

7. Andrew AA, Shimada J, Hosono T. Evaluation of ground water quality and its suitability drinking and agriculture uses in banana plain (Mbanga Njmabe,) of the Cameroon volcanic line. Environ Geochem Health, 2013; 33 (6): 559–575.
8. Ackah M, Agymang O, Anim AK. Assessment of ground water quality for drinking and irrigation the case study of Tweimann Oyrifa community Ga east municipality Ghana. Int J. Ecol Environ Sci, 2011; 1 (3-4): 185–194.
9. Baher MM, Reja MS. Hydrochemical characteristics and quality assessment of shallow ground water in a coastal area of south west Bangladesh. Environ Earth Sci, 2010; 61(5):
10. Ahamad J, Longnathan K, Anathakrishnan S. A comparative evaluation of ground water suitability for drinking and irrigation purpose in Pugular area Karur district Tamilnadu, India. Appl Sci Res, 2013; 5 (1): 213–223.
11. Nepolian M, Chidambram S, Thivya et al. C. Assessment of hydrochemical and qualities studies in ground water of Villupuram district Tamilnadu, India. *International Research Journal of Earth Sciences*, 2016; *4*(3): 1-10
12. Samaahayira S, Florrence AC. Evaluation of ground water quality for irrigation purpose Rediyarchatram block of Dindigul district Tamilnadu, India. Int Res J Earth, 2017.
13. Sharma AD, Rishi SM, Kessari T. Evaluation of ground water quality and suitability for irrigation and drinking purpose in south west Punjab, India using hydrochemical approach. Appl Water Sci, 2017; 7: 3137-3150.
14. Tripathi AK, Mishra, UK, Mishra A, Dubey P. Assessment of groundwater quality of Gurh Tehseel, Rewa district Madhya Pradesh, India. Int J. Sci. Eng Res, 2012; 3(9): 1-12.
15. Mishra SK, Mishra UK, Tripathy AK, Singh AK, Mishra AK. Hydrogeochemical studies in Ground water quality in and sajjanpur area Satna district Madhya Pradesh. Int J. Sci. 2013.
16. Mahadev S, Ahamad A, Kushwaha J, Singh P, Mishra PK. Geochemical assessment of ground water quality for its suitability drinking and irrigation purpose in rural areas of Sant Ravidas Nagar (Bhadohi),Uttar Pradesh. Geol Ecol Landsc, 2018; 2(2):127-136.
17. Dudeja D, Bartarya SK, Biyani, AK. Hydrochemical and water quality assessment of groundwater in Doon valley of outer Himalaya, Uttarakhand, India. Environ Monit Assess, 2011; 181(1-4): 183.
18. Jain CK, Bandopadhyay A, Bhadra A. Assessment of ground water quality for irrigation purpose district in Nainital Uttarakhand, India. J Indian Water Resources Soc. 2012; 32: (3-4): 8-14.
19. Bhandari, NS, Nayal, K. Correlation study on physicochemical parameters and quality assessment of Kosi river water, Uttarakhand. J Chem, 2008; 5 (2): 342-346.
20. Seth R, Sharma MM, Gupta VK, Singh P, Singh R, Gupta S. Application of technique in the assessment of ground water quality of Udham Singh Nagar Uttarakhand. Water Qual Expos Hea, 2014; 6(4): 199-216.
21. Bahukhandi, KD, Bartarya, SK, Siddqui, NA. Assessment of ground and surface water quality Haridwar district, Uttarakhand. Int J Chemtech Res. 2017; 10 (10): 95–118.
22. Singh KK, Tewari G, Kumar S. Evaluation of Groundwater Quality for Suitability of Irrigation

Purposes: A Case Study in the Udham Singh Nagar, Uttarakhand. J Chem Article ID 6924026, 2020;15 https://doi.org/10.1155/2020/6924026

23. Mahananda MR, Mohanty BP, Behera NR. Physico-chemical analysis of surface and ground water of Bargarh district, Orissa, India. Int J Recent Res Appl Stud, 2010; 2(3): 285-295.
24. Madhav S, Kumar A, Kushawaha J, Ahamad A, Singh P, Dwivedi· SB. Geochemical assessment of groundwater quality in Keonjhar City, Odisha, India. Sustain Water Resour Manag, 2020;6(46): 1-11. https://doi.org/10.1007/s40899-020-00395-7
25. Nagy-Kovács Z, Davidesz J, Czihat-Mártonné K, Grischek T. Water quality changes during riverbank filtrationin Budapest, Hungary. Water, 2019; 11(2): 302. https://doi.org/10.3390/w11020302
26. Sandhu C, Grischek T, Börnick H, Feller J, Sharma SK. A water quality appraisal of some existing and potential riverbank filtration sites in India. Water, 2019; 11(2): 215. https://doi.org/10.3390/w11020215
27. El-Zeiny AM, Abd El-Hamid HT, El-Alfy, MA. Anthropogenic impacts on water quality of river nile and marine environment, Rosetta branch using geospatial analyses. Res J Environ Sci, 2018;47(3-4): 89-101. DOI: 10.21608/joese.2018.158202
28. Shirmohammadi B, Malekian A, Salajegheh A, Taheri B, Azarnivand H, Malek Z, Verburg PH. Scenario analysis for integrated water resources management under future land use change in the Urmia Lake region, Iran. *Land Use Policy*, 2020; 90, 104299. https://doi.org/10.1016/j.landusepol.2019.
29. El-Alfy MA, Hasballah AF, Abd El-Hamid HT, El-Zeiny AM. Toxicity assessment of heavy metals and organochlorine pesticides in freshwater and marine environments, Rosetta area, Egypt using multiple approaches. Sustain Environ Res, 2019; 29: 19. https://doi.org/10.1186/s42834-019-0020-9
30. Osman R, Ferrari E, McDonald S. Water scarcity and irrigation efficiency in Egypt. *Water Economics and Policy,* 2016; 2(4) 1650009. https://doi.org/10.1142/S2382624X16500090
31. Wang F, Wang X, Zhao Y, Yang ZF. Long-term water quality variations and chlorophyll a simulation with an emphasis on different hydrological periods in Lake Baiyangdian, northern China. J Environ Inform , 2012; 20(2): 90–102 doi:10.3808/jei.201200223
32. Wallace JS. Increasing agricultural water use efficiency to meet future food production. Agric Ecosyst Environ, 2000; 82(1-3): 105–119. https://doi.org/10.1016/S0167 8809(00)00220-6
33. Molden D. Water for Food Water for Life: A Comprehensive Assessment of Water Management in Agriculture; Routledge: Abingdon, UK. 2013.
34. Movilla-Pateiro L, Mahou-Lago XM, Doval MI, Simal-Gandara J. Toward a sustainable metric and indicators for the goal of sustainability in agricultural and food production. Critical Reviews in Food Science and Nutrition, 2020; 61(7): 1108-1129. DOI: 10.1080/10408398.2020.1754161
35. Haydar S, Arshad M, Aziz JA. Evaluation of drinking water quality in urban areas of Pakistan: A Case Study of Southern Lahore. Pakistan J Eng Appl Sc. 2009; 5:16-23.
36. Kumar A, Dua A. Water quality index for assessment of water quality of river Ravi at Madhopur (India). Glob J Environ Sci., 2010; 8(1): 49-57. DOI: 10.4314/gjes.v8i1.50824

37. Central Pollution Control Board of India Status of groundwater quality in India part-II, groundwater quality series: gwqs/10/2007-2008. New Delhi, 2008.

38. Singh KK, Tewari G, Kumar S. Evaluation of Groundwater Quality for Suitability of Irrigation Purposes: A Case Study in the Udham Singh Nagar, Uttarakhand. J. Chem. 2012; Article ID 6924026, 2020:15 https://doi.org/10.1155/2020/6924026

39. Zar JH. Biostatistical analysis (5th ed.). Upper Saddle River, New Jersey: Prentice Hall.

40. Ayres RS, Westcott DW. Water quality for agriculture. F.A.O. Irrigation and Drainage Paper No. 29, Rev., 1985; 1. F.A.O., Rome, 2009:174.

41. Kundu S. Assessment of surface water quality for drinking and irrigation purposes: A case study of Ghaggar river system surface water. Bull Env Pharmacol Life Sci. 2012; 1 (2): 1-1.

42. Ayers RS, Westcot DW. Water quality for agriculture. FAO Irrigation and Drainage Paper 29, Rev. 1. Rome, Italy: Food and Agricultural Organization of the United Nations, 1994.

43. USSL Staff. Diagnosis and improvement of saline and alkali soils. USDA Handbook No 60.Washington DC, USA, 1954: 160 pp.

44. Duncan, RR, Carrow, RN, Huckle M. Understanding water quality and guideline to management (An overview of challenges of water uses on golf course 21st Century), USGA, Far Hills, NJ, USA, 2000.

45. Sharifi Z, Sinegani AAS. Arsenic and other water quality indicators of groundwater in an agriculture area of Qorveh Plain, Kurdistan, Iran. Am Eurasian J Agric Environ Sci. 2012; 12(4): 548–555.

46. Ayres RS, Westcott DW. Water quality for agriculture. F.A.O. Irrigation and Drainage Paper No. 29, Rev., 1985; 1. F.A.O., Rome, 174 p.

47. Richards LA. Diagnosis on improvement of saline and alkali soils, USDA., Handbook No.60, Agri. Handbook .U.S. Dep. Agric., 1954; 160.

48. Miller RW, Gardiner DT. Soils in our environment. 9th edition. Prentice Hall-Inc., Upper Saddle River, New Jersey 07458. ISBN 0-13-020036-0, 2007; p-452.

49. Gupta IC. Use of saline water in agriculture in arid and semi-arid zones of India. 1979; ref 16, 210.

50. Rhoades JD. Reclamation and management of salt-affected soils after drainage. Proc. First Annual Western Provincial Conference on Rationalization of Water and Soil Research and Management, Alberta, Canada. 1982; 123–197.

51. Suarez DL. Relation between pHc and sodium adsorption ratio (SAR) and an alternative method of estimating SAR of soil or drainage waters. Soil Sci Soc. Am. J., 1981; 45(3): 469-475.

52. Doneen LD. Notes on water quality in agriculture. Water Science and Engineering. Paper, 4001. University of California., 1964:10.

53. Al-Amry AS. Hydro geochemistry and groundwater quality assessment in an arid region: A case study from Al Salameh area, Shabwah, Yemen. The 3rd International Conference on Water Research and Arid Environment and the 1st Arab Water Forum. 2008.

54. Eaton FM. Significance of carbonates in irrigation waters. Soil Sci. 1950;69:123-134. https://doi.org/10.1097/00010694-195002000-00004

55. Gupta SK., Gupta IC. Management of saline soils and water. Oxford and IBH publication Company. New Delhi, India, 1987:399.

56. Gupta SK. Variations of water table in Yamuna drainage basin of Haryana-implications and management strategies. Paper presented at the Seminar on Strategies for Irrigation Water Management, Patna, 1983.

57. Behera B, Das M, Rana, GS. Groundwater quality for drinking and irrigation purpose in Damonjodi area, Koraput District, Odisha, India. World Appl Sci. J. 2016; 34 (6): 695-703.

58. Laze P, Rizani S, Ibraliu A. Assessment of irrigation water quality of Dukagjin basin in Kosovo. J Int Sci Publ, 2016; 4: 544-551.

59. Kelly WP. Permissible composition and concentration of irrigated waters. In: Proceedings of the A.S.C.F, 1940;607.

60. Ramesh K, Elango L. Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India. Environ Monit Assess, 2012; 184: 3887-3899.

61. Karanth KR. Groundwater assessment development and management. Tata McGrawHill Publishing Company Ltd., New Delhi, 1987; p 725.

62. Shah S., Mistry N. Groundwater quality assessment for irrigation use in Vadodara district, Gujarat, India. Int J Agril Biosys Eng., 2013; 7(7): 719 – 724.

Table 1 Methodology for analysis of chemical parameters

Sl. No.	Parameters	Method used	Reference
1	pH	Glass Electrode pH meter	Jackson, 1973
2	EC	Conductivity meter	Jackson, 1973
3	Carbonate and Bicarbonate	Volumetric Rapid titration Method	Jackson, 1973
4	Chloride	Silver Nitrate Titration Method	Jackson, 1973
5	Nitrate	Colorimetric method using phenol disulphonic acid	Page et al.,1982
6	Calcium and Magnesium	Versenate titration method	Jackson, 1973
7	Potassium	Flame photometer method	Page et al.,1982
8	Boron	Colorimetrically using Azomethine-H	Bingham, 1982
9	Fe, Mn. Zn, Cu, Cd, Cr	Atomic absorption spectrophotometer	Lindsay and Norvell,1978

Table 2 Methodology for analysis of different indices

Indices	Formula	Parameters used in the calculation and their units	Reference
Sodium Adsorption Ratio (SAR)	$\mathbf{SAR} = \frac{\mathbf{Na^+}}{\frac{\sqrt{\mathbf{Ca^{2+} + Mg^{2+}}}}{\mathbf{2}}}$	Na^+, Ca^{2+}, Mg^{2+} are in meq L^{-1}	Richards (1954); Todd (1980)
Adjusted Sodium Adsorption Ratio ($Adj^R Na$/ Adj. SAR)	$\mathbf{Adj^R Na} = \frac{[\mathbf{Na^+}]}{\frac{\sqrt{\mathbf{Ca_x^{2+} + Mg^{2+}}}}{\mathbf{2}}}$	Na^+, Ca_x^{2+}, Mg^{2+} are in meq L^{-1}	Suarez (1981), Ayers and Westcot (1994)
Soluble Sodium Percentage (SSP)	$\mathbf{SSP} = \frac{\mathbf{Na^+ + K^+}}{\mathbf{Ca^{2+} + Mg^{2+} + Na^+ + K^+}} \mathbf{x\ 100}$	Na^+, Ca^{2+}, Mg^{2+} are in meq L^{-1}	Doneen (1964); Todd (1980)
Permeability Index (PI)	$\mathbf{PI} = \frac{\mathbf{Na^+ + \sqrt{HCO_3^-}}}{\mathbf{Ca^{2+} + Mg^{2+} + Na^+}} \mathbf{x\ 100}$	HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+ are in meq L^{-1}	Doneen (1964)
Residual Sodium Carbonate (RSC)	$\mathbf{RSC} = (\mathbf{CO_3^{2-} + HCO_3^-}) - (\mathbf{Ca^{2+} + Mg^{2+}})$	CO_3^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+}, are in meq L^{-1}	Eaton (1950); Richards (1954)
Residual Sodium Bicarbonate (RSBC)	$\mathbf{RSBC} = (\mathbf{HCO_3^-} - \mathbf{Ca^{2+}})$	HCO_3^-, Ca^{2+} are in meq L^{-1}	Gupta and Gupta (1987)
Kelly's Ratio (KR)	$\mathbf{KR} = \frac{\mathbf{Na^+}}{\mathbf{Ca^{2+} + Mg^{2+}}}$	Na^+, Ca^{2+}, Mg^{2+} are in meq L^{-1}	Kelly (1963)

Table 3 Chemical parameters of the collected surface water samples from different water sources measured during Pre Monsoon period, 2019

Sl. No.	Rivers		pH	EC (dSm^{-1})	CO_3^{2-}	HCO_3^-	Na	K	Ca	Mg	Cl^{-1}	B	NO_3^-	Zn	Cu	Fe	Mn	Cd	Cr
					meq L^{-1}						mg L^{-1}			mg L^{-1}					
1	Mahanadi	Mean values	7.38	0.27	0	2.64	0.58	0.115	0.71	0.37	38.40	0.23	2.31	0.013	0.035	0.173	0.011	0.014	ND*
2	Rushikulya		7.54	0.22	0	2.31	1.52	0.075	0.55	0.91	29.54	0.05	1.25	0.017	0.048	0.043	0.034	0.034	ND
3	Bramhani		7.09	0.57	0	2.64	0.93	0.079	1.10	0.13	34.38	0.16	2.96	0.011	0.044	0.038	0.054	0.005	ND
4	Subernarekha		7.30	0.21	0	2.64	0.16	0.069	0.29	0.29	23.63	0.12	2.19	0.008	0.042	0.170	0.014	0.008	ND
5	Bahuda		7.69	0.09	0	1.32	0.30	0.071	1.03	0.49	36.63	0.15	2.07	0.009	0.043	0.045	0.015	0.011	ND
6	Kolab		6.51	0.15	0	1.65	0.42	0.052	0.28	0.39	46.08	0.09	2.18	0.040	0.046	0.169	0.017	0.023	ND
7	Bansadhara		7.37	0.45	0	1.98	0.81	0.101	1.08	0.22	37.81	0.73	1.79	0.013	0.050	0.047	0.016	0.007	ND
8	Salandi		6.75	0.07	0	0.99	0.10	0.100	0.33	0.22	29.54	0.89	1.10	0.020	0.037	0.181	0.017	0.002	ND
9	Ib		8.02	0.21	0	2.64	0.53	0.044	0.61	0.13	50.81	0.10	3.07	0.003	0.036	0.108	0.014	0.006	ND
Grand mean			7.29	0.25	0	2.09	0.59	0.078	0.66	0.35	36.31	0.28	2.10	0.015	0.042	0.108	0.021	0.012	
SEm (±)			0.081	0.05	0	0.40	0.24	0.008	0.08	0.08	4.76	0.04	0.13	0.001	0.002	0.002	0.001	0.001	
CD (0.05)			0.242	0.14	0	1.19	0.72	0.023	0.240	0.25	1585	0.12	0.38	0.002	0.005	0.006	0.003	0.002	
Standard value			6.5-8.5	0.25-0.75	0-1	0-10	0 – 40	0-0.051	0-20	0-5	350	0-2	5-30	2.00	0.20	5.00	0.20	0.01	
Observed Range			6.23 - 8.05	0.068-0.705	0	0.99 - 2.97	0.09-2.54	0.018-0.65	0.23-1.2	0.09-1.2	21.27-67.36	0.0225-0.934	0.98-3.23	0.002-0.043	0.032-0.052	0.036-0.184	0.01-0.056	0.001-0.035	

**ND: Non-detectable*

Table 4 Chemical parameters of the collected groundwater samples measured during Pre Monsoon period, 2019

Sl. No.	Groundwater source		pH	EC (dS/m)	CO_3^-	HCO_3^{2-}	Na	K	Ca	Mg	Cl^-	B	NO_3^-	Zn	Cu	Fe	Mn	Cd	Cr
					meq L^{-1}						mg L^{-1}			mg kg^{-1}					
1	Agronomy field, OUAT, Bhubaneswar	Mean values	5.97	0.21	0.00	1.65	0.73	0.055	1.01	0.22	37.81	0.86	4.74	0.018	0.032	0.959	0.018	0.011	ND
2	Sambalpur, Putibandh		8.02	0.70	4.59	1.32	3.01	0.018	1.61	0.22	55.53	0.05	5.33	0.042	0.038	0.035	0.109	0.011	ND
3	Rourkela -3 (sector-7)		7.89	0.30	1.65	1.32	0.50	0.06	0.98	0.33	56.60	0.13	3.06	0.008	0.036	0.036	0.018	0.010	ND
4	Orchard, OUAT, Bhubaneswar		6.46	0.06	0.00	1.32	0.13	0.016	0.41	0.43	22.42	0.13	7.92	0.033	0.043	0.130	0.037	0.008	ND
5	Central Farm, OUAT, Bhubaneswar		5.97	0.11	0.00	0.99	0.40	0.018	0.33	0.18	24.34	0.21	3.99	0.023	0.035	1.033	0.016	0.009	ND
6	Ganjam, Krishna Nagar		7.48	0.48	0.00	1.98	1.17	0.074	1.18	0.29	47.26	0.39	4.84	0.028	0.033	0.036	0.012	0.008	ND
7	Gajapati ,Paralakhemundi		7.50	0.31	1.65	1.65	0.89	0.016	0.48	0.31	35.92	0.09	3.41	0.035	0.028	0.046	0.011	0.009	ND
Grand mean			7.04	0.31	1.12	1.46	0.98	0.037	0.86	0.28	39.98	0.26	4.75	0.026	0.035	0.325	0.032	0.009	
SEm (±)			0.076	0.01	0.37	0.36	0.02	0.003	0.05	0.03	4.10	0.01	0.12	0.001	0.001	0.012	0.001	0.000	
CD (0.05)			0.228	0.03	1.12	1.06	0.08	0.010	0.15	0.10	12.30	0.05	0.38	0.003	0.004	0.036	0.002	0.001	
Standard value			6.5-8.5	0.25-0.75	0-1	0-10	0-40	0-0.051	0-20	0-5	140-700	0-2	5-30	2.00	0.20	5.00	0.20	0.01	
Observed Range			5.68-8.1	0.045-0.723	0.99-5.4	0.99 - 2.97	0.112-3.04	0.005-0.078	0.24-1.72	0.13-0.54	3.54-60.26	0.043-0.912	2.96-8.2	0.007 - 0.044	0.026 - 0.045	0.033-1.09	0.01-0.11	0.007-0.012	

**ND: Non-detectable*

Table 5 Calculated indices of the collected surface water samples from different sources during the pre-monsoon period 2019

Sl. No.	Rivers		SAR	Adj. SAR	RSC (meq L^{-1})	PI (%)	KR	RSBC (meq L^{-1})	SSP (%)
1	Mahanadi	Mean values	0.80	0.76	1.56	133.63	0.55	1.93	39.49
2	Rushikulya		1.68	1.60	0.84	106.52	0.93	1.76	43.60
3	Bramhani		1.18	1.19	1.41	118.26	0.75	1.54	45.06
4	Subernarekha		0.32	0.28	2.05	254.97	0.32	2.35	29.90
5	Bahuda		0.35	0.28	-0.20	79.39	0.19	0.29	19.27
6	Kolab		0.74	0.57	0.98	153.36	0.65	1.37	41.47
7	Bansadhara		1.01	0.90	0.68	104.77	0.63	0.90	41.28
8	Salandi		0.19	0.13	0.44	169.25	0.18	0.66	26.80
9	Ib		0.87	0.82	1.90	169.38	0.72	2.03	43.74
Grand mean			0.79	0.73	1.07	143.28	0.55	1.43	36.73
SEm (±)			0.25	0.25	0.42	19.15	0.13	0.42	4.82
CD (0.05)			0.76	0.75	1.28	57.40	0.41	1.27	14.47
Standard value			10 -18	10-20	<1.25	>25	<1	<3	20-40
Observed range			0.16-2.73	0.12-2.65	-0.75 - 2.53	65.71-305.38	0.11-1.46	0.21-2.74	13.33-60.36

Table 6 Calculated indices of the collected groundwater samples of different sources during the pre-monsoon period 2019

Sl. No.	Groundwater source		SAR	Adj.SAR	RSC (meq L^{-1})	PI (%)	KR	RSBC (meq L^{-1})	SSP (%)
1	Agronomy field, OUAT, Bhubaneswar	Mean values	0.93	0.81	0.41	99.87	0.59	0.64	56.92
2	Sambalpur, Putibandh		3.16	2.61	4.08	85.82	1.66	0.29	62.43
3	Rourkela -3(sector-7)		0.62	0.49	1.65	90.47	0.38	0.33	29.92
4	Orchard, OUAT, Bhubaneswar		0.20	0.16	0.47	130.63	0.16	0.90	15.02
5	Central Farm, OUAT, Bhubaneswar		0.78	0.54	0.47	152.78	0.76	0.66	45.90
6	Ganjam, Krishna Nagar		1.78	1.27	2.15	97.37	0.79	0.80	45.64
7	Gajapati, Paralakhemundi		1.87	1.16	0.85	128.38	1.12	1.16	53.32
Grand mean			1.33	1.01	1.44	112.19	0.78	0.68	44.16
SEm (±)			0.13	0.12	0.44	8.97	0.03	0.38	1.97
CD (0.05)			0.40	0.37	1.33	26.90	0.09	1.16	5.90
Standard value			10 -18	10-20	<1.25	>25	<1	<3	20-40
Observed range			0.18-3.26	0.13-3.18	-0.25 - 4.49	77.79-160.27	0.1375 - 1.78	-0.73-1.95	13.49-654

Table 7 Classification of surface and groundwater samples based on EC, SAR, Adj. SAR, RSC, SSP and KR

Parameter/Index	Quality	Surface water sources	% of total surface water samples	Groundwater sources	% of total groundwater samples
EC range (dSm^{-1}) (Richards, 1954)					
< 0.25	Low salinity (C1)	6 samples (Rushikulya, Bahuda, Subarnarekha, Kolab, Salandi and Ib)	66.67	3 samples (OUAT Agronomy Field, OUAT Orchard and OUAT-Central farm)	42.86
0.25-0.75	Medium salinity water some leaching for sensitive crops (C2)	3 samples (Mahanadi, Bansadhara and Bramhani)	33.33	4 samples (Sambalpur, Rourkela, Ganjam and Gajapati)	57.14
0.75-2.25	High salinity (C3)	Nil	-	Nil	-
> 2.25	Very high salinity (C4)	Nil	-	Nil	-
SAR (Richards, 1954; Todd, 1980)					
< 10	Excellent (S1)	9 samples (Mahanadi, Rushikulya, Bramhani, Subarnarekha, Bahuda, Kolab, Bansadhara Salandi and Ib)	100	7 samples (OUAT Agronomy Field, Sambalpur, Rourkela, OUAT Orchard, OUAT Central farm, Ganjam and Gajapati)	100
10-18	Good (S2)	Nil		Nil	
19-26	Doubtful (S3)	Nil		Nil	
> 26	Unsuitable (S4)	Nil		Nil	
Adj. RNa/ Adj. SAR (Gupta, 1979)					
< 10	Normal (S1)	9 samples (Mahanadi, Rushikulya, Bramhani, Subarnarekha, Bahuda, Kolab, Bansadhara Salandi and Ib)	100	7 samples (OUAT Agronomy Field, Sambalpur, Rourkela, OUAT Orchard, OUAT Central farm, Ganjam and Gajapati)	100
10-20	Medium (S2)	Nil		Nil	
20-30	High (S3)	Nil		Nil	
30-40	Very High (S4)	Nil		Nil	
> 40	Unsuitable (S5)	Nil		Nil	
RSC ($meq\ L^{-1}$) (Eaton, 1950; Richards, 1954)					

< 1.25	Safe	5 samples (Rushikulya, Bahuda, Kolab, Bansadhara and Salandi)	55.56	4 samples (OUAT-Agronomy Field, OUAT Orchard, OUAT-Central farm and Gajapati)	57.14
1.25-2.5	Can be used with management	4 samples (Mahanadi, Brahmani, Subarnarekha, Ib)	44.44	2 samples (Rourkela, Ganjam)	28.57
> 2.5	Unsuitable	Nil		1 sample (Sambalpur)	14.29
SSP range (%) (Wilcox, 1954; Behera *et al.*, 2016)					
< 20	Excellent	1 sample (Bahuda)	11.11	1 sample (OUAT Orchard)	14.29
20-40	Good	3 samples (Subarnarekha, Salandi and Mahanadi)	33.33	1 sample (Rourkela)	14.29
40-60	Permissible	2 samples (Rushikulya and Bramhani) 3 samples (Kolab, Bansadhara and Ib)	55.56	4 samples (OUAT-Agronomy Field, OUAT-Central farm, Ganjam and Gajapati)	57.14
60-80	Doubtful	Nil	-	1 sample (Sambalpur)	14.29
KR range (Kelly, 1963)					
≤1	Good	9 samples (Mahanadi, Rushikulya, Bramhani, Subernareka, Bahuda, Kolab, Bansadhara, Salandi and Ib)	100	5 samples (OUAT Agronomy field Bhubaneswar, Rourkela - 3(sector-7), Orchard OUAT Bhubaneswar, Central Farm OUAT Bhubaneswar, and Ganjam)	71.43
> 1	Bad	Nil	-	2 samples (Sambalpur and Gajapati)	28.57

EC electrical conductivity, *SAR* sodium adsorption ratio, *Adj. SAR* adjusted sodium adsorption ratio, *RSC* residual sodium carbonate, *SSP* soluble sodium percentage, *KR* kelly's ratio

Table 8 Suitability classification of surface water and groundwater samples based upon different parameters

Rivers	**SAR**	**Adj.SAR**	**RSC**	**PI**	**KR**	**RSBC**	**SSP**	**pH**	**EC**	**HCO_3^-**	**Cl^-**	**B**	**NO_3^-**
Mahanadi	Ext	Ext	S	Ext	G	S	G	S	MS	S	S	S	S
Rushikulya	Ext	Ext	S	Ext	G	S	PI	S	LS	S	S	S	S
Bramhani	Ext	Ext	S	Ext	G	S	PI	S	MS	S	S	S	S
Subernarekha	Ext	Ext	S	Ext	G	S	G	S	LS	S	S	S	S
Bahuda	Ext	Ext	S	Ext	G	S	Ext	S	LS	S	S	S	S
Kolab, Nagavali	Ext	Ext	S	Ext	G	S	PI	S	LS	S	S	S	S
Bansadhara	Ext	Ext	S	Ext	G	S	PI	S	MS	S	S	S	S
Salandi	Ext	Ext	S	Ext	G	S	G	S	LS	S	S	S	S
Ib	Ext	Ext	S	Ext	G	S	PI	S	LS	S	S	S	S
Groundwater source													
Agronomy field, OUAT	Ext	Ext	S	Ext	G	S	PI	A	LS	S	S	S	S
Sambalpur, Putibandh	Ext	Ext	US	Ext	B	S	Db	S	MS	S	S	S	S
Rourkela-3, sector-7	Ext	Ext	S	Ext	G	S	PI	S	MS	S	S	S	S
Orchard, OUAT, Bhubaneswar	Ext	Ext	S	Ext	G	S	Ext	A	LS	S	S	S	S
Central Farm, OUAT, Bhubaneswar	Ext	Ext	S	Ext	G	S	PI	A	LS	S	S	S	S
Ganjam, Krishna nagar, Berhampur	Ext	Ext	S	Ext	G	S	PI	S	MS	S	S	S	S
Gajapati Paralakhemundi	Ext	Ext	S	Ext	B	S	PI	S	MS	S	S	S	S

A Acidic, *Db* Doubtful, *Ext* Excellent, *PI* Permissible, *LS* low Salinity, *MS* Medium Salinity, *G* good, *B* Bad, *S* safe, *US* Unsuitable, *EC* electrical conductivity, *SAR* sodium adsorption ratio, *Adj. SAR* adjusted sodium adsorption ratio, *RSC* residual sodium carbonate, *RSBC* residual sodium bicarbonate, *PI* permeability index, *SSP* soluble sodium percentage, *KR* Kelly's ratio,

Table 9 Suitability of water of nine major rivers of the state for irrigation

Rivers	Acidity/ alkalinity (pH, RSBC)	Salinity (EC)	Sodicity (RSC, SAR, adj. SAR PI, KR, SSP)	Specific ion Toxicity (Cl, B, NO_3)	Trace element and Heavy Metal Toxicity (Fe, Mn, Zn, Cu, Cd, Cr)	Water Quality
Mahanadi	Safe	Medium	RSC > SL but < MPL	safe	Cd > MPL	Can be used with Management
Rushikulya	Safe	Safe	safe	safe	Cd > MPL	Can be used with Management
Bramhani	Safe	Medium	RSC > SL but < MPL	safe	Safe	Can be used with Management
Subernarekha	Safe	Safe	RSC > SL but < MPL	safe	Safe	Can be used with Management
Bahuda	Safe	Safe	safe	safe	Cd > MPL	Can be used with Management
Kolab	Safe	Safe	safe	safe	Cd > MPL	Can be used with Management
Bansadhara	Safe	Medium	safe	safe	Safe	Suitable
Salandi	Safe	Safe	safe	safe	Safe	Suitable
Ib	Safe	Safe	RSC > SL but < MPL	safe	Safe	Can be used with Management

EC electrical conductivity, *SAR* sodium adsorption ratio, *Adj. SAR* adjusted sodium adsorption ratio, *RSC* residual sodium carbonate, *RSBC* residual sodium bicarbonate, *PI* permeability index, *SSP* soluble sodium percentage, *KR* Kelly's ratio

Table 10 Suitability of water of seven groundwater sources of the state for irrigation

Groundwater source	Acidity/ alkalinity (pH, RSBC)	Salinity (EC)	Sodicity (RSC, SAR, SARadj, PI, KR, SSP)	Specific ion Toxicity (Cl, B, NO_3)	Trace element and Heavy Metal Toxicity (Fe, Mn, Zn, Cu, Cd, Cr)	Water Quality
Agronomy field, OUAT, Bhubaneswar	Acidic	Safe	safe	safe	Cd > MPL	Can be used with Management
Putibandh, Sambalpur	safe	Medium	RSC> MPL KR - Bad SSP-Doubtful	Safe	Cd > MPL	Unsuitable
Rourkela-3, sector-7	safe	Medium	RSC > SL but < MPL	safe	Cd > MPL	Can be used with Management
Orchard, OUAT, Bhubaneswar	Acidic	Safe	safe	safe	Safe	Can be used with Management
Central Farm, OUAT, Bhubaneswar	Acidic	Safe	safe	safe	Safe	Can be used with Management
Ganjam, Krishna nagar, Berhampur	safe	Medium	RSC > SL but < MPL	safe	Safe	Can be used with Management
Gajapati Paralakhemundi	safe	Medium	KR- Bad	safe	Safe	Can be used with Management

EC electrical conductivity, *SAR* sodium adsorption ratio, *Adj. SAR* adjusted sodium adsorption ratio, *RSC* residual sodium carbonate, *RSBC* residual sodium bicarbonate, *PI* permeability index, *SSP* soluble sodium percentage, *KR* Kelly's ratio

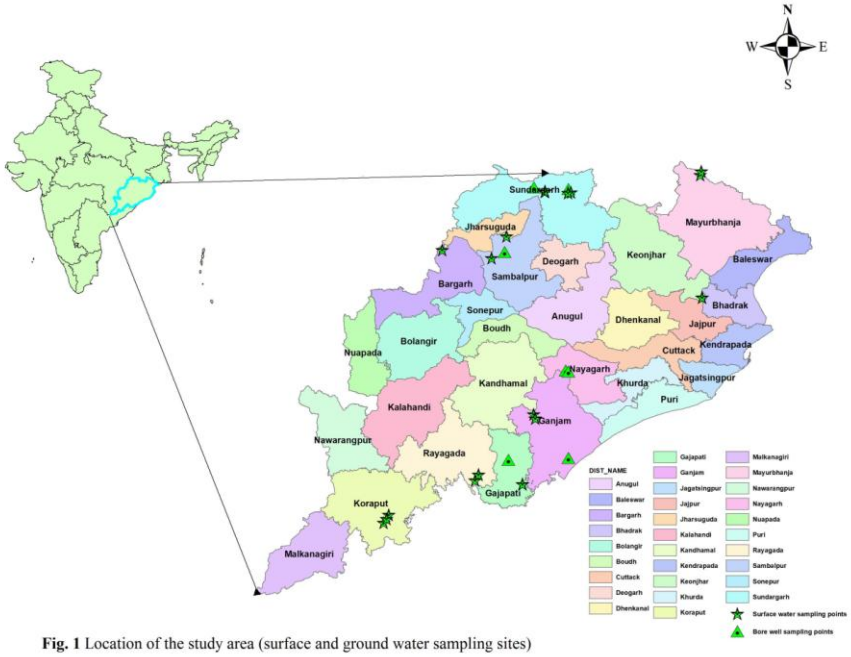

Fig. 1 Location of the study area (surface and ground water sampling sites)

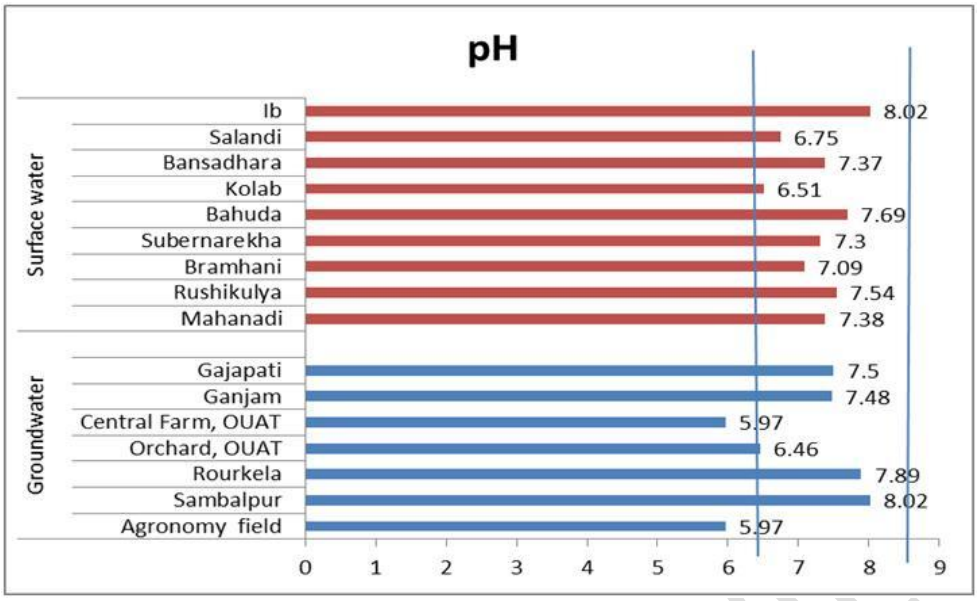

Fig. 2 pH of different surface and ground water samples used for irrigation

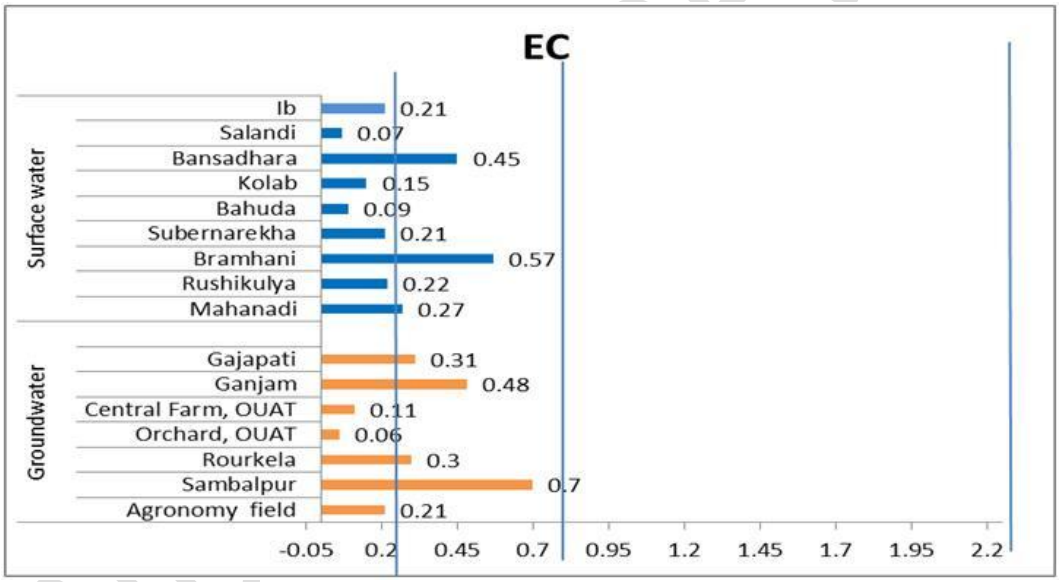

Fig. 3 Electrical conductivity (EC) of different surface and ground water samples used for irrigation

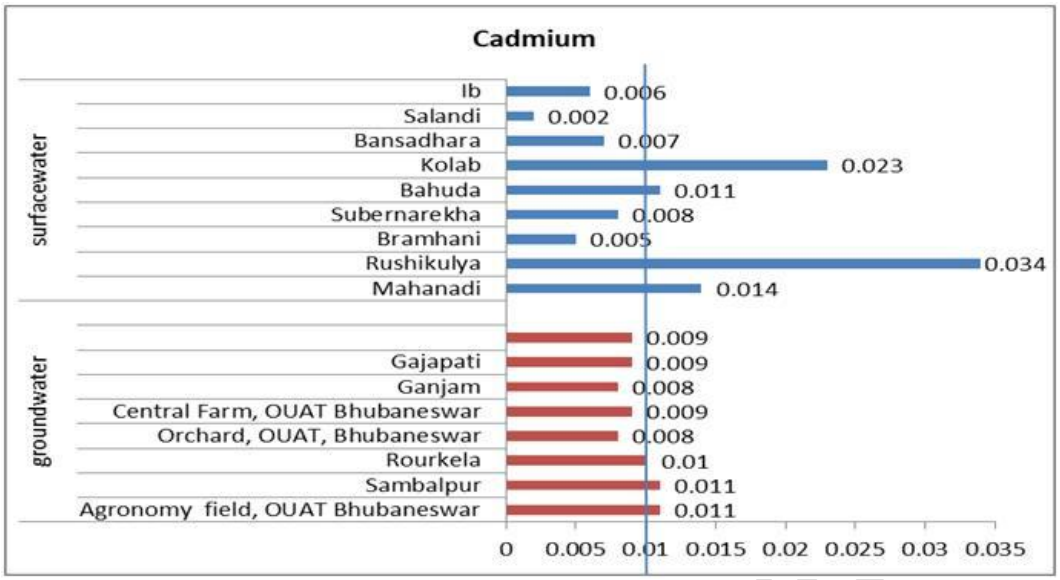

Fig. 4 Cadmium (Cd) content of different surface and ground water samples used for irrigation

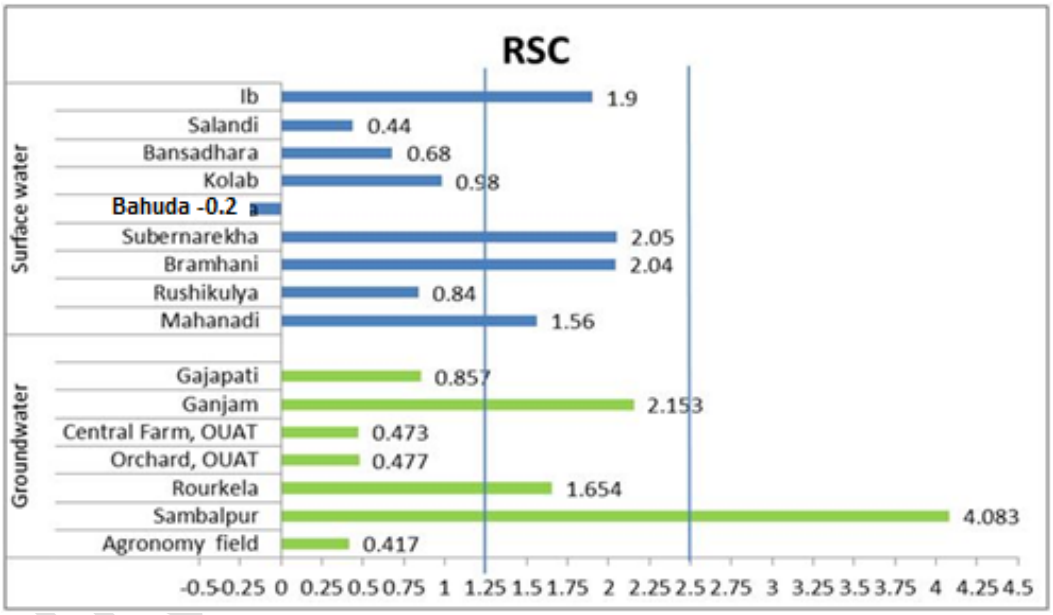

Fig. 5 Residual sodium carbonate (RSC) of different surface and ground water samples used for irrigation

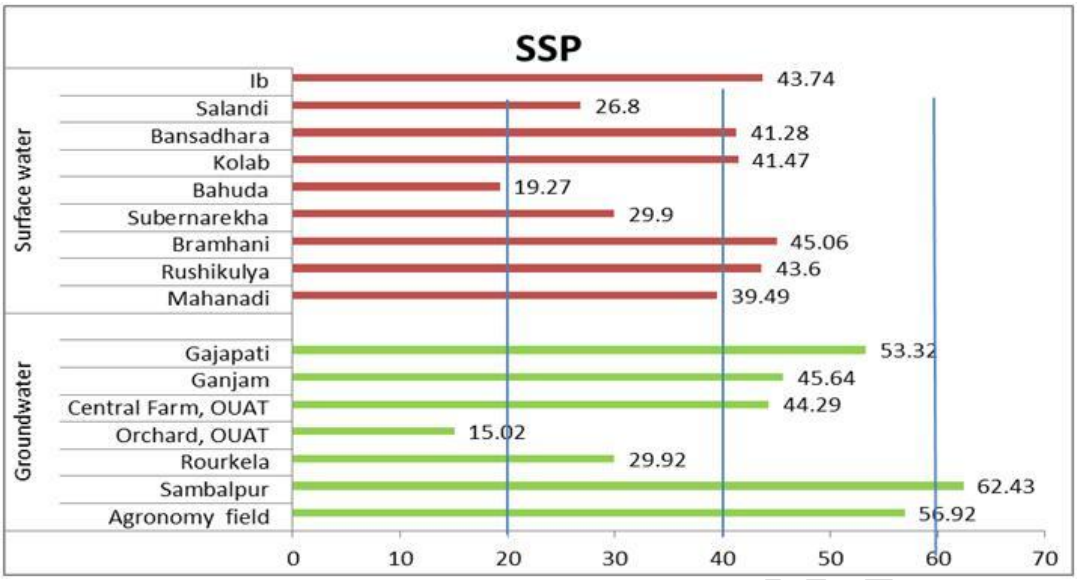

Fig. 6 Soluble sodium percentage (SSP) of different surface and ground water samples used for irrigation

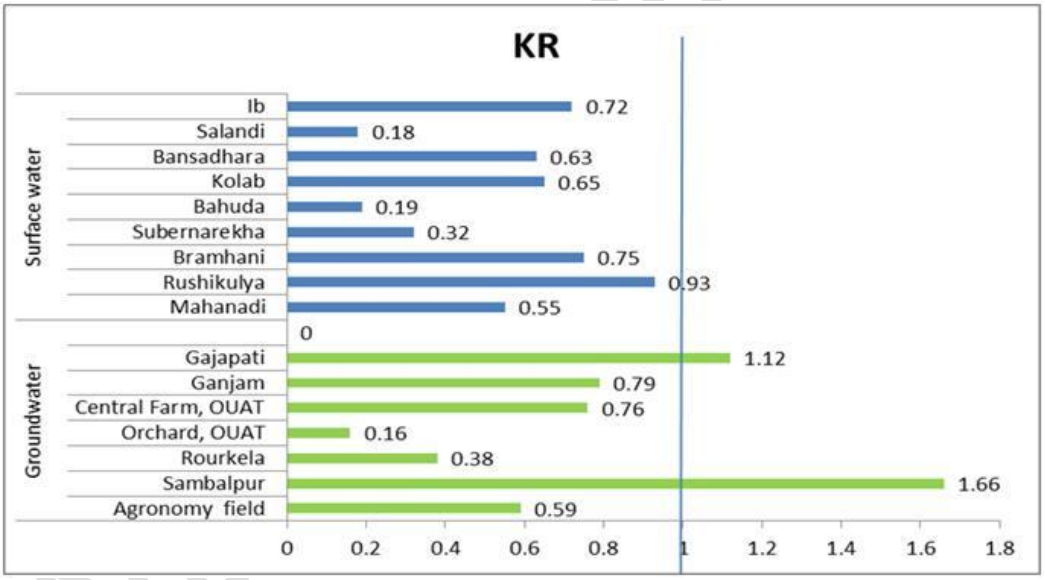

Fig. 7 Kelly's ratio (KR) of different surface and ground water samples used for irrigation