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Soil Characteristics and Agro-well Water Quality in Newly Developed Farmlands in *Mahaweli* System L-*Ethawetunuwewa* Block, Sri Lanka

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Abstract: Agro-wells are the most reliable water resource in newly developed farmlands in Mahaweli System L. However, water quality of agro-wells and its relationship with soil parameters in surrounding farmlands have not yet been investigated. This study was conducted to investigate agro-well water quality, to explore its relationship with soil elements and to find out short-scale soil spatial variability of surrounding areas of agro-wells. Water samples were collected from 10 agro-wells located in the study area at three time points. Soil samples from surrounding farmlands of each agro-well were also collected. In addition, intensive soil sampling was done surrounding a selected agro-well to prepare short-scale spatial variability soil maps using Inverse Distance Weighting interpolation technique. Soil and water samples were analyzed for relevant chemical parameters. Correlation analysis was performed to investigate relationship between soil and water quality parameters. All water quality parameters except NO_3 -N, K and Cd were within acceptable range. Potassium, Cd in all tested agro-wells and NO_3 -N levels in 6 agro-wells have exceeded the maximum permissible level. Correlation analysis revealed a strong positive linear correlation between soil and water concentrations of NO_3 -N (r = 0.83) Available Sulfur (r = 0.81) and Ca (r = 0.82). Natural short-scale spatial variability pattern of soil N, P, K in the studied area have been altered due to anthropogenic activities such as fertilizer applications.
Keywords: Agro-well, Soil spatial variability, Water quality

Introduction

The concept of groundwater utilization for agriculture in Sri Lanka has been confined traditionally to the northern and eastern provinces since early 1960s. (Padmarajah 2002). It includes systematic exploitation of both shallow and deep aquifers. In 1970s, north central dry zone farmers also have started use of groundwater of hard rock aquifers through large diameter dug wells, which are popularly called as agro-wells. Those are usually 5-10m depth and 5-8m wide in diameter. In 1989, the national agro-well program was launched by Agricultural Development Authority (ADA) to promote the use of agro-wells through a subsidy scheme (Padmarajah 2002). According to the Panabokke et al. (2005) there are four major types of aquifers in dry zone, Sri Lanka. Shallow karstic aquifer in Jaffna peninsula, shallow unconfined aquifers on the sandy regosols of Kalpitiya peninsula and eastern coastal belt, deep confined sedimentary limestone formation of Vanathawillu and Mulankavil and also hard metamorphic rock in Rajarata and Wanni complex.

Water from agro-wells are being utilized during much drier *yala* cropping season and water stress time of the *maha* cropping season (Jayakody 2006). Also annual rainfall of the dry zone is less than 1500 mm and in this approximately two third is falling during *maha* and rest is during *yala* (Padmarajah 2002). This irregular rainfall distribution and acute water storage in some period of the year are the major constraints for agriculture development in this region. Under this condition groundwater can be used as a good supplementary source (Pathmarajah 2002). The concept behind the quality of agro-well water is also equally important as its quantity owing to the suitability of water for irrigation. According to the FAO readings, irrigated agriculture is dependent on an adequate water supply of usable quality. Water quality used for irrigation can vary greatly depending upon type and quantity of dissolved salts.

Several factors are affected to deteriorate water quality in agro-wells. The chemistry of ground water fluctuates due to atmospheric inputs, soil and weathering material, pollutant from mining, land clearing, saline intrusion in coastal area and agricultural industrial and domestic wastes (Abeysinghe et al. 2018). Unlike rivers, aquifers do not have any self-cleansing ability. Hence once get polluted will remains unchanged. Therefore, proper attention must be given to minimize the pollution of ground water (Amarasingha et al. 2006). However, in the systematic monitoring of agro-well water and analysis on the relationship between soil nutrient and their presence in agro-well water has not been carried out in Mahaweli system L. Therefore, this study was conducted to evaluate the suitability of agro-well water for irrigation, evaluate the relationship between soil elements and their presence in agro-well water and explore short scale spatial variability of soil elements in surrounding areas of a selected agro-well in *Ethawetunuwewa*, Mahaweli system L.

Materials and Methods

Study area

The study was conducted in Mahaweli system L, Ethawatunuwewa block. The study area belongs to Welioya secretarial division in Anuradhapura district of the North Central Province and DL1b agro-ecological zone. Annual rainfall and annual average temperature are 1480 mm and 30 ^{0}C, respectively. Soils in the study area belongs to a Reddish Brown Earth great soil group *Aluthwewa* soil series (USDE taxonomy: Typic Haplustalf) (Mapa et al. 2010). The textural class of soil in the studied area is sandy loam. Ten agro-wells were selected randomly by considering the spatial distribution and construction procedure of agro-wells to represent whole block.

Sampling and preparation of soil and water samples

Ground water from selected agro-wells were sampled once a month from December 2018 to March 2019. Two samples from each well were collected into 250ml pre-cleaned polypropylene bottles after rinsing the bottles with same water and covered with a lid. Water samples were filtered using Whatman No. 1 filter paper and filtrates were used for analysis. The prepared samples were stored under cool temperature (4 C^0) during the period of analyses.

Three soil samples were collected separately from surrounding area of each agro well at two depths (0-15 cm and 15-30 cm) by using Edelman augur. Composite samples of top and subsoil samples were prepared by mixing three samples at 1: 1: 1 ratio in polythene bags. The prepared composite samples were brought to the laboratory for analyses. Soil samples (32 samples) were intensively collected for investigating the spatial variability of soil chemical properties of surrounding area of the selected agro-well. Google Earth pro software was used to find the gradient of the field and spatially representing sampling locations. Soils were collected from 0-15cm depth.

All the soil samples were air-dried without allowing to be contaminated with external material. After air drying, samples were ground by using mortar and pestle. The ground soil samples were passed through a 2 mm sieve and sieved soil samples were stored in clean polythene bags after proper labeling.

Analysis of Samples

pH, EC and TDS of water sample and pH and EC of soil samples were measured by Multi-parameter analyzer. Soil and water Nitrate nitrogen (NO_3 - N) was measured using Salicylic acid colorimetric method (Cataldo et al. 1975) by UV- VIS spectrophotometer. Sodium Salicylate colorimetric method (Markus et al. 1985) was used to analyze Ammonium nitrogen (NH_4-N) in soil and water samples. Ascorbic acid colorimetric method (Olsen et al. 1954) by UV- VIS Spectrophotometer was used to measure Phosphate phosphorus (PO_4 - P) concentrations in both type of samples. Carbonate($CO_3^{2-)}$ and bicarbonate (HCO_3^-) was analyzed using Acid base titration. Calcium, Mg, K, Na cations and As, Cd and Pb trace elements were measured by using Inductivity Couple Plasma Optical Emission Spectrophotometer (ICP-OES, method by Martin, 1994). Total nitrogen of soil samples was measured using Kjeldhal titrimetric procedure (Bremner et al. 1982) Turbidimetric method (Chapmen et al. 1961) was used to measure available Sulphur in soil samples. In addition to above-mentioned parameters, Sodium Adsorption Ratio (SAR), Sodium Percentage (SP) and Residual Sodium Carbonate (RSC) of agro-well water was calculated.

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Data Analysis

Investigated water quality parameters of agro-wells were graphically represented using Microsoft Excel. Further, these values were compared with FAO irrigation water quality standards. Correlation analysis was performed to find the relationship between nutrients concentrations in soil and agro- well water.

Short Scale Spatial Mapping

Short-scale spatial variabilities of soil chemical properties were investigated using Inverse Distance Weighting (IDW) interpolation technique This method was used due to the low number of sampling points in the study area. Arc GIS 10.0 software package were used to carry out spatial interpolation followed by final map preparation for the pH, EC, Total N, Nitrate nitrogen, Ammonium nitrogen, Available phosphorous, Exchangeable Na, K, Ca and Mg.

Results and Discussion

Water Quality Assessment

Suitable pH range of groundwater for irrigation generally varies from 6.5 to 8.4 according to the FAO (Food and Agricultural Organization) standards. The mean value of pH in all studied wells varied between 7.4 (well no L7) and 7.9 (well no L6) (Figure: 1a). Therefore, all wells were within the pH range suitable for irrigation of the agricultural field. Salinity of water is the measurement of all salts dissolved in a considered water resource.it is estimated by using Electrical Conductivity (EC) and Total Dissolved Solids (TDS). According to the Ayers and Westcot (1985), irrigation with saline water repeatedly tends to develop high salinity in soil, leading to sudden crop yield losses. Mean value of EC in studied wells were below the 0.7 dS/m which is FAO limit. Therefore, EC of water has not become any barrier for irrigation of any cropping field. Highest (0.57 dS/m) and lowest (0.08 dS/m) EC values were recorded in well L2 and well L9, respectively (Figure: 1b). Mean TDS value in all studied wells were under the

450mg/l which were in the none degree of restriction on use as irrigation water. (Figure: 1c) (Ayers et al. 1976,1985)

Six wells (L2, L3, L4, L5, L6 and L7) expressed severe nitrate nitrogen pollution. Mean value of ammonium nitrogen in all studied agro-wells were within the permissible level. Highest (433 mg/l) and lowest (5 mg/l) nitrate nitrogen concentrations were observed in well no L7 and L8, respectively (Figure: 1d). According to the FAO guidelines, nitrate concentration more than 30 mg/l is considered as severe NO_3 - N pollution. Indiscriminate application of N fertilizer may be a major reason for increasing nitrate N in shallow ground water. Well no. L7, L5 and L2 were surrounded with intensively cultivating paddy and vegetable lands. L3, L4 and L6 wells were also surrounded by paddy and upland cultivations.

Acceptable range of Ammonium nitrogen in irrigation water is 0-5 mg/l. Therefore, ammonium nitrate concentration of L5 has exceeded the permissible range. The lowest ammonium nitrogen (2.24 mg/l) was observed in well no. L8 (Figure: 1e).

Average PO_4 - P concentration of water in agro-wells varied from 0.02mg/l (L6) to 0.16 mg/l (L5). The highest (0.16 mg/l) and the lowest (0.02 mg/l) PO_4-P concentration were observed in well no. L6 and well no. L5, respectively (Figure: 1f). According to FAO guidelines, acceptable Phosphate-P range for irrigation water is between 0 and 2mg/l. Sperling (1996) have shown that some critical levels of water P concentrations emphasizing different trends of eutrophication. (ie: <0.01mg/l – non-eutrophic, 0.01-0.02mg/l – intermediate stage and > 0.05 mg/l – eutrophic. According to FAO classification, water in studies agro wells showed a high suitability for irrigation. However, water in seven agro wells (L5, L3, L4, L10, L2, L7 and L9) showed a high trend for eutrophication and other are in intermediate stage for irrigation according to Sperling's classification.

Phosphate is immobile in most soils due to precipitation and adsorption to mineral surfaces. Hence, leaching of P in many soils except in certain very organic soils is negligible (Wild 1988). This may be the reason low phosphate concentration in water even under high TSP (Triple super

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phosphate) application. However, dissolved organic phosphorus forms in comparisons to inorganic phosphate are more mobile in soil (Havlin et al. 1990). Moreover, phosphorus attached to soil particles is removed from soil surfaces and deposit in surface water bodies due to erosion.

Mean value of potassium concentration in agro-wells ranged from 46.8 mg/l to 53.4 mg/l (Figure: 1g). The highest (53.4 mg/l) and the lowest (46.8 mg/l) K concentrations in water were observed in well no L5 and L8, respectively. According to the FAO guidelines, acceptable range of potassium for irrigation is between 0 and 2 mg/l. Water K concentration of all studied agro-well water has exceeded the acceptable range. Moreover, soils in this area belong to *Aluthwewa* series which is having higher inherent K concentration in comparison to other series in Dry zone of Sri Lanka as its inherent character (Mapa et al. 2010).

Calcium concentration in agro-well water varied from 0.17 me/l to 3.46 me/l in selected agro-wells. Out of selected ten agro-wells, high Ca concentrations were observed in three wells (L2, L5 and L10) in comparison to others. The lowest average Ca concentration was observed in well no. L9(Figure: 1h) However, all wells were within the acceptable range of Ca (0-20 me/l) for irrigation according to FAO standards. The level of Mg concentration in agro-well water ranged from 0.18 me/l to 1.85 me/l. The highest and the lowest water Mg concentrations were observed in L2 and L9, respectively (Figure: 1i). According to the FAO guideline, acceptable range of Mg for irrigation water is between 0 and 20 me/l. Dissolved Mg level in any of the tested agro-wells did not exceed the maximum permissible level (20 me/l) set by FAO.

The Sodium hazard of irrigation water is expressed by Na% and SAR. Mean value of Na% was varied from 61.8% to 21.1% in tested agro-wells (Figure: 1j). FAO guideline have revealed that >80% of Na in irrigation water is unsuitable. Na% of all agro-wells were within the acceptable range. However, it is doubtful that Na% of L8 has an increasing trend to be problematic in future. Mean value of SAR values of agro-well water varied from 1.18 to 3.14. The lowest and highest SARs were reported in L2 and L8, respectively (Figure: 1k). Excessive sodium in irrigation water creates undesirable impacts on soil structures followed by reducing soil

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permeability. When sodium salts dissolved in water, they form highly soluble positively charged sodium ions. Higher sodium concentration in soil solution is adversely affected to many salinity intolerant plants.

According to FAO classification says that SAR value between 0-10 is Suitable for all types of soils except for those crops which are highly sensitive to sodium. Value between 10-18 Suitable for coarse textured or organic soil with good permeability while relatively unsuitable in fine textured soil. 18-26 SAR value is harmful for almost all types of soils. Average RSC values varied from -2.67 to 0.75.

The highest and the lowest residual RSC were recorded in well no. L9 and L2, respectively (Figure: 1l). The maximum It requires good drainage, high leaching and gypsum addition and SAR value more than 26 is Unsuitable for irrigation. So water in all agro-wells was within suitable range for irrigation. Bicarbonate hazard is usually expressed in term of Residual Sodium Carbonate (RSC). Permissible level of RSC for irrigation water is 2.5. Hence, all tested agro-wells were within the permissible range.

Mean Cd values in all the studied agro-wells were above permissible level in both short term and long term use (Table 1). The highest (0.26 mg/l) Cd concentrations were observed in agro-well no. L6 and L7 while and the lowest (0.22 mg/l) Cd concentrations were observed in agro-well no. L1 and L4 (Figure: 1m). This was supported by a finding that phosphate fertilizers contain Cd as an impurity and repeated application of phosphate fertilizer results in Cd accumulation in soil (Lambert et al., 2007). The As and Pb contents were not at detectable levels in the studied agro-wells.

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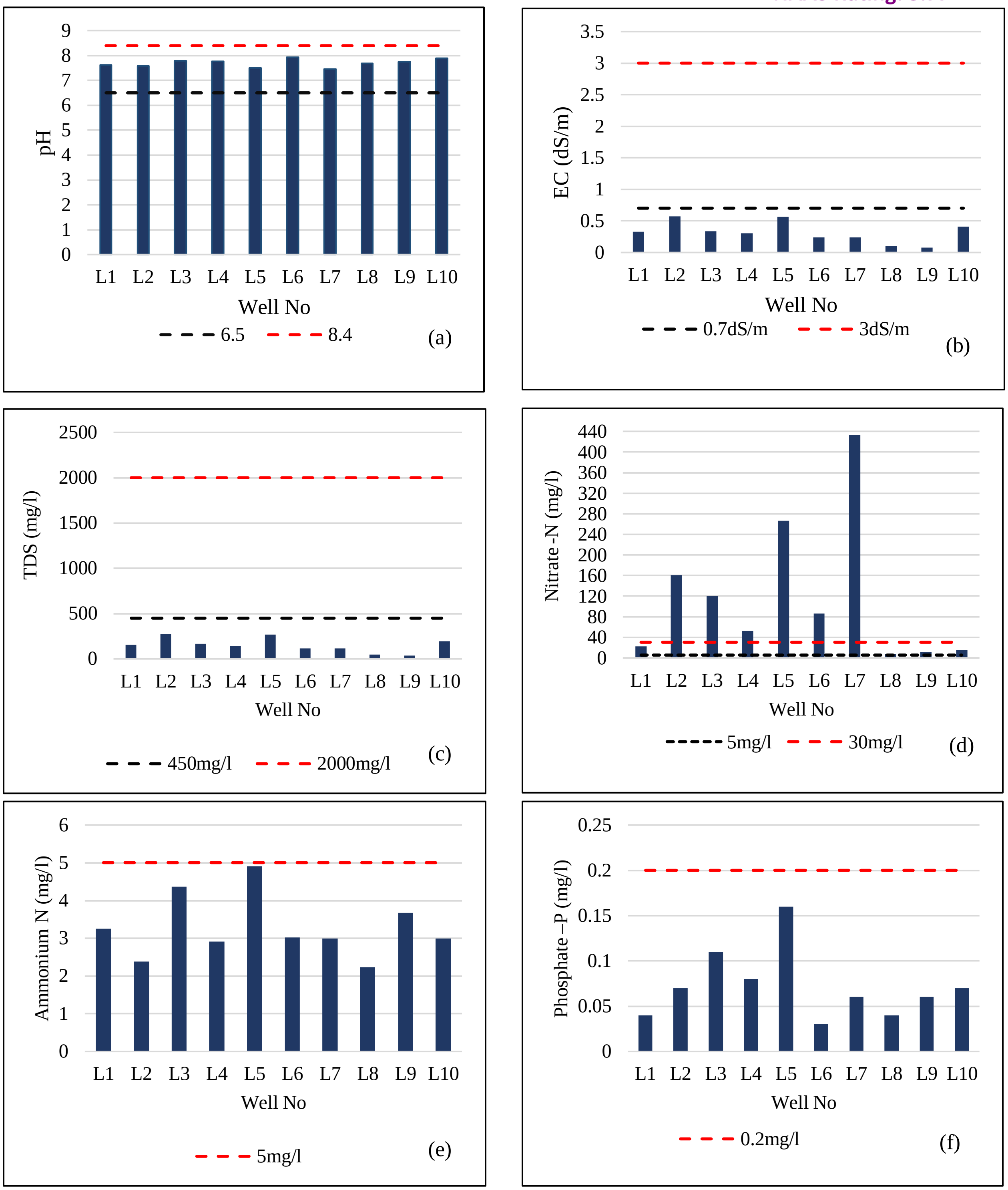
Table 1: Maximum permissible level of As, Cd & Pb in irrigation water according to FAO guidelines.

Constituent	Short term use (mg/l)	Long term use (mg/l)	Remarks
As	0.10	2.0	Toxicity to plants varies widely, ranging from 12mg/l for sudan grasss to less than 0.05mg/l for rice
Cd	0.01	0.05	Toxic to beans, beets and turnips at concentrations as low as 0.1mg/l in nutrient solution. Conservation limits recommended
Pb	5.0	10.0	Can inhibit plant cell growth at very high concentration

(Source: Ayers et al. 1985)

Mean chloride concentration in water varied from 0.39 me/l to 2.25 me/l (Figure: 1n)). The highest and the lowest water chloride contents were observed in agro-well no. L5 and L8, respectively. Concentration of chloride in agro-wells did not exceed the maximum permissible level (0-30 me/l) set by FAO (Ayers et al. 1985).

Mean fluoride concentration in water varied from 0.21mg/l to 0.55mg/l. The highest and the lowest fluoride concentration in water were observed in agro-well no. L9 and L5, respectively. (Figure: 1o). According to Rowe and Abdel- Magid (1995), permissible level of fluoride in irrigation water is 1.0 mg/l for long term use and 15 mg/l for short term use, respectively. However, mean value of fluoride in water of all studied agro- wells was below the permissible level defined for both short term and long term. Sulfate-S in water varied from 0.08 me/l to 0.49 me/l (Figure: 1p). The lowest and the highest Sulfate-S concentration of water were observed in well no. L7 and L2, respectively. Acceptable sulfate –S range for irrigation water is between 0 and 20 me/l according to the FAO guidelines. Therefore, Sulfate-S concentration of water in all agro-wells within the permissible level according to the FAO guidelines.


pH
Well No
L1 L2 L3 L4 L5 L6 L7 L8 L9 L10
6.5
8.4
(a)
EC (dS/m)
Well No
0.7dS/m
3dS/m
(b)
TDS (mg/l)
Well No
450mg/l
2000mg/l
(c)
Nitrate -N (mg/l)
Well No
5mg/l
30mg/l
(d)
Ammonium N (mg/l)
Well No
5mg/l
(e)
Phosphate –P (mg/l)
Well No
0.2mg/l
(f)

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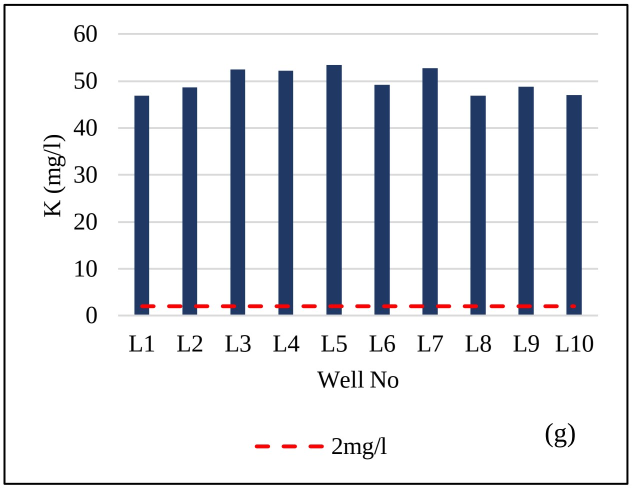

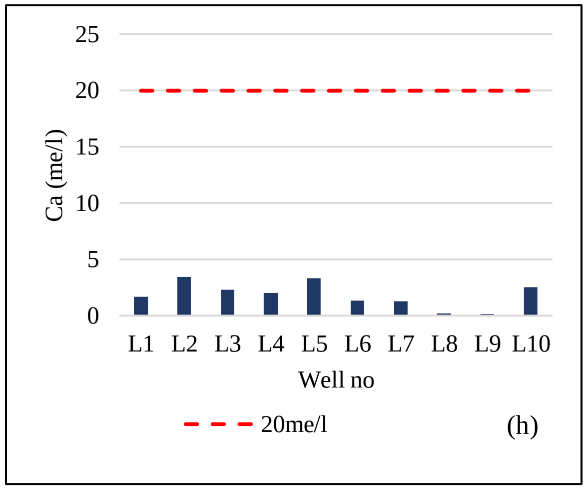

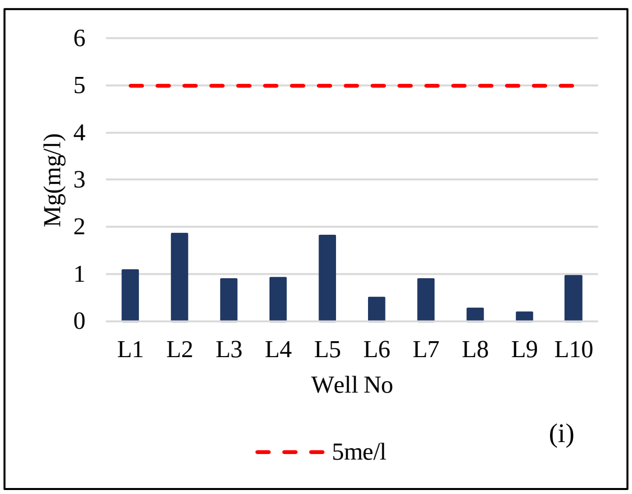

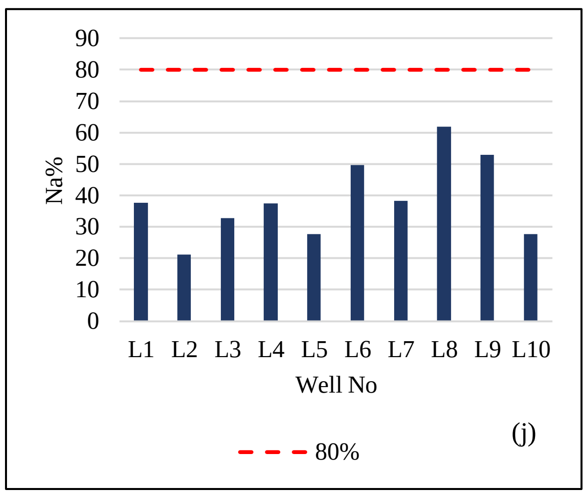

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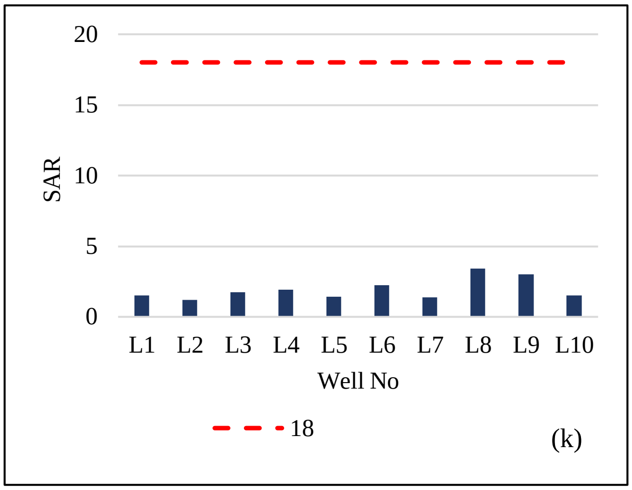

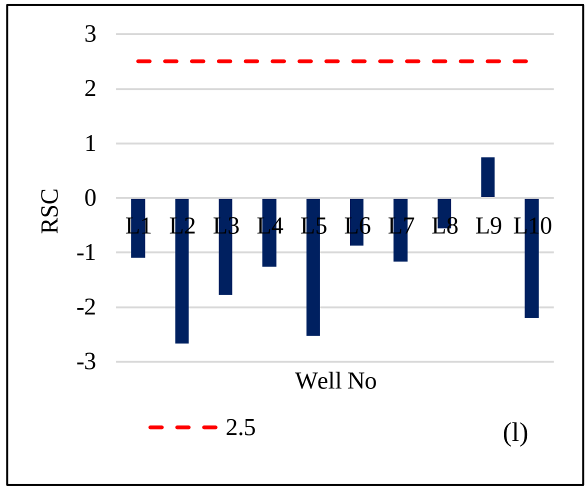

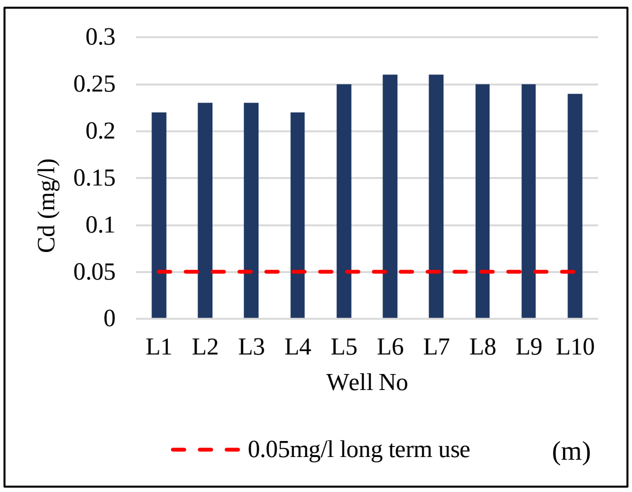

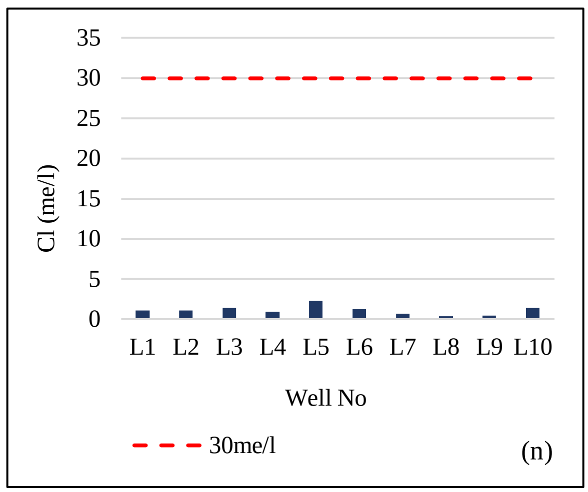

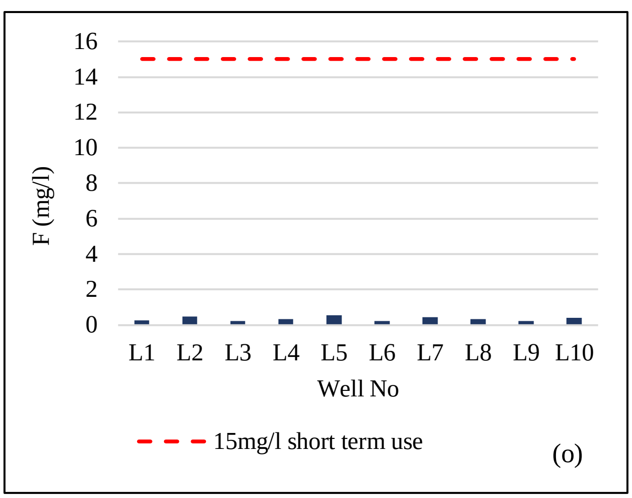

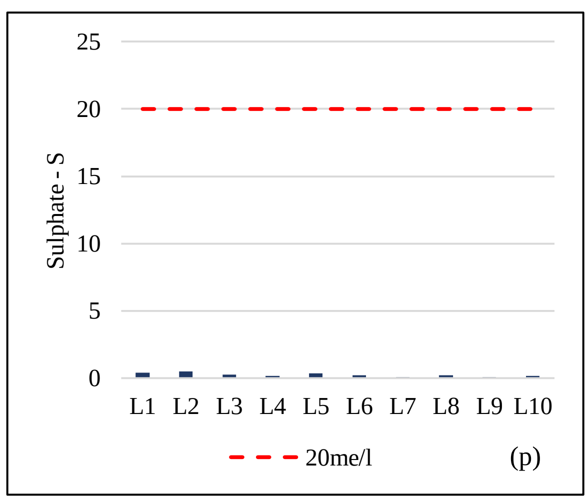

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Figure 1: Mean value of a). pH. b). EC c). TDS d). Nitrate – N e). Ammonium – N f). Phosphate – P g). K h). Ca i). Mg j). Na% k). SAR l). RSC m). Cadmium n). Chloride o). Fluoride and p). Sulfate – S

--------- lowest permissible level ---------- Maximum permissible level

Relationship between soil chemical parameters and their presence in Water

Soil fertility in a site can be altered due to the anthropogenic activities such as fertilization. Therefore, study of residual soil concentration of different plant nutrients indirectly gives an idea of level of fertilizers applied to agricultural soils. After plants uptake, the excessive nutrients are leached to the shallow ground water (agro-well water) through soil profile. Thus, nutrients which are more mobile in soil tends to accumulate in shallow ground water showing higher correlation between soil and water concentration of that particular nutrient. Correlation analysis revealed that higher correlations between water and soil concentrations of NO_3-N, Ca and SO_4 -S and moderate correlations between water and soil concentrations of Mg and K were observed. The scatter plots between soil and water concentrations of NO_3-N, Ca, SO_4 -S, Mg and K were shown in figure 2. These results revealed high impact of agro-chemicals added to soil on pollution of water in shallow water table. The higher mobility of these nutrients within the soil system might lead to greater accumulation in ground water.

Table 2: Pearson correlations between soil and water concentration of different plant nutrients

Soil Element	Water Element	Correlation Coefficient	Level of significant
NO_3 -N	NO_3 -N	0.83	0.005
Ca	Ca	0.82	0.0039
SO_4 -S	SO_4 -S	0.81	0.0048
Mg	Mg	0.65	0.042
K	K	0.61	0.058

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However, poor correlation was observed between soil and water concentrations of PO_4 -P, Na, NH_4-N. It might be due to high P fixation in tropical soils and high soil retention capacities of cations such as NH_4^+ and Na^+.

Short scale spatial variability maps

Short scale spatial variability maps were prepared surrounding area of the agro-well no. L2. The land uses of surrounding area of the agro-well no. L2 were shown Figure 3a. The area consists of three major land uses i.e. lowland, upland and bare land. Lowland is composed of paddy cultivation whereas upland is composed of coconut, vegetables and other field crops. Study area has a gentle slope towards the agro-well from each direction. Agro-well was located in the lowest positions of the catena. No any natural variability pattern was observed in available nitrogen, total nitrogen and available phosphorous in developed maps (Figure 3b, 3c, 3d and 3e). This may probably due to fertilizer application over a long period of time in different quantities for crop grown in selected area.

There was higher K concentration in the upland in comparison to the lowland (Figure 3f). At the time of soil sampling, paddy cultivation was its optimum maturity stage. Therefore, rice plants have taken up lager fraction of available K in paddy soil leading to lower K soil content. Agro-well water rich in potassium, well was frequently irrigated upland crops rather than lowland paddy. This may be reasons for developing high potassium concentrations in uplands.

Sodium and Magnesium have been concentrated towards the lowland (Figure: 3h,3i). Those cations were accumulated in lowland due to lower slope (Catenary distribution). Calcium and pH values of soil weren't showed any of specific special variability (Figure: 3j). However, there was high EC value in lowland compared to upland due to water logging condition (Figure: 3k). In irrigated agricultural land, water logging is often accomplished by soil salinity as waterlogged soils prevent leaching of the salts imported by the irrigated water (Tyagi, 2014).

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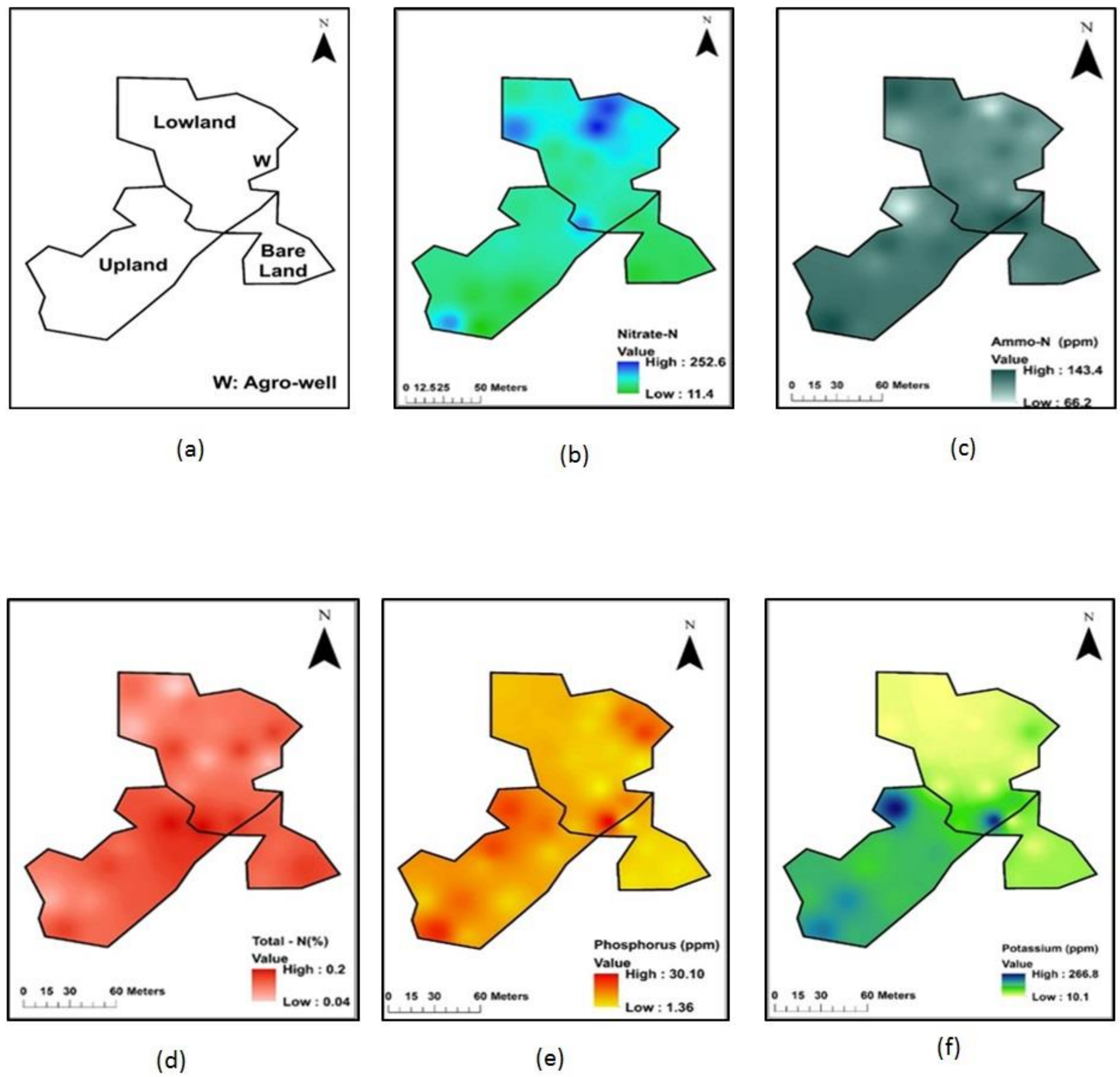

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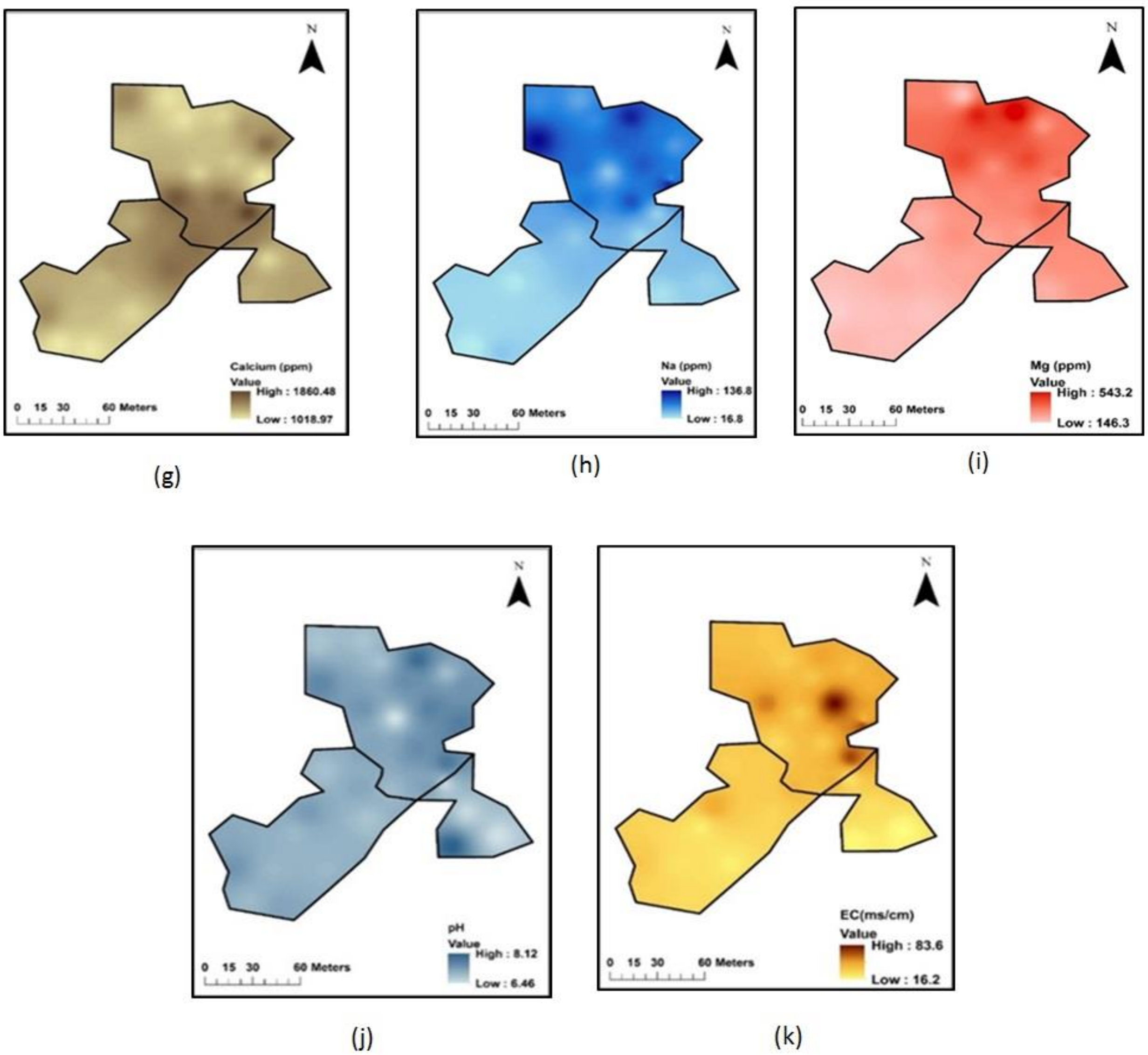

Figure 3: a) Land use map of the study area and Short spatial variability maps of b). Nitrate- N c). Ammonium-N d). Total N e). Phosphate- P f). Potassium g). Calcium h). Sodium i). Magnesium j). pH k). EC

Conclusion

When considering water quality of tested agro wells, most of the chemical parameters i.e. pH, EC, TDS, NO_3-N, NH_4-N, PO_4- P, exchangeable K, Ca, Mg, S, Cl, F, Na and HCO_3 were within the acceptable range showing higher suitability for crop irrigation, according to FAO guidelines. Natural spatial variability of soil N, P and K was varied probably due to anthropogenic activities such as inorganic fertilizer applications. A strong positive correlations was observed in NO_3-N, Ca and S between soil in the surrounding area and the agro well water. However, poor correlations between soil and water PO_4- P, Na, NH_4-N and CO_3^{2-} were observed in the same location. It clearly indicates a higher mobility of NO_3-N and lower mobility of NH_4-N and PO_4-P in the soil. As a result, a considerable nitrogen pollution was observed in agro-well No. L7, L5, L2, L3, L6 and L4. In addition, to that, increasing trend of K and Cd levels were also observed in all studied agro-wells.

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