Temporal Variations in Groundwater Quality with Special Reference to Irrigation in Faridkot and Muktsar Areas of Southwest Punjab, India

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Abstract: Punjab, known as the “bread basket of India”, is a modest-sized state tucked away on the north-western border of India with huge grain surplus produced by its farmers since the green revolution, thus helping the country in its journey towards self-sufficiency in food. Yet, the agriculture in its intensive form involved high consumption of fertilizers and irrigation. Recent studies from different organizations confirmed massive concentration of chemical fertilizers and heavy metals insouth-western parts of Punjab. Faridkot and Muktsar, located in southwest of the state, are two agriculture dominated districts of Southwest Punjab. This paper highlights temporal variations of groundwater quality and comparison on its suitability for irrigation purposes in these two districts. In both the districts, total hardness and sodium adsorption ratio was indicative of the unsuitability of groundwater for irrigation purposes. The water samples in the study area showed appreciable rise in electrical conductivity indicating high salinity, especially in Muktsar district. In order to use the water resources judiciously and maintain the agricultural productivity, there is a need for groundwater management, which will lead to sustainable development in Faridkot and Muktsar.

Keywords: Groundwater, Irrigation, Salinity, Sodium adsorption ratio, Sustainable Development.

1. Introduction

On planet Earth, water is basic and most important resource for the sustenance of life. Groundwater, a significant natural resource, has become increasingly popular because of the relative ease and flexibility with which it can be tapped. It is the most extracted natural resource in the world providing for both drinking and agricultural activities like irrigation. Globally, irrigation accounts for more than 70% of total water withdrawals and for more than 90% of total consumptive water use [1][2][3]. The use of groundwater of marginal and poor quality without proper mixing with canal water may degrade the soils, especially at the tail end of the canal system [4].

The south-western part of Punjab in India is a region with predominantly agrarian culture, and irrigation has been the mainstay of their economy, prosperity and development. Therefore, the main occupation of majority of the population is agriculture and the main sources of irrigation are tubewells, wells, pumping sets and canals. The large scale extraction of groundwater can be attributed to the ‘Green Revolution’. Irrigation accounts for 69 percent of all global fresh water use, while industry and domestic uses consume 23 percent and 8 percent respectively [5].

During the last decade, implementation of agricultural practices in the state has become increasingly environmentally unsustainable, which has taken its toll on the groundwater of the region. The groundwater is facing problems of depletion of water table, saltwater encroachment, drying of aquifers, groundwater pollution, water logging and salinity and these are major consequences of overexploitation and intensive irrigation [6]. Two districts of southwest Punjab namely Faridkot and Muktsar, which are very distinct in their sub-surface lithology and soil type as well as the groundwater scenario (Table 1) were thereby chosen to assess the temporal variations of groundwater quality and diagnose the hazards of groundwater in relation to its suitability for irrigation purpose due to their varying lithological units and aquifer disposition. Thus, the proposed study will not only help in devising suitable strategies to protect water regime of southwest tracts of Punjab but can also give directions for the protection of those areas that have not yet been invaded for groundwater mining.

2. Location of Study Area

Figure 1: Map showing sampling locations of the study area
Table1: Comparative Status of Two Districts at a Glance

| Particulars                  | Faridkot | Muktsar |
|-----------------------------|----------|---------|
| i)Geographical Area(km²)    | 1468.75  | 2630    |
| ii)Administrative Division  | 171      | 235     |
| No. of Panchayats/villages  |          |         |
| iii)Population(as per 2001 census) | 550892    | 7,7493  |
| (as per 2011 census)        | 618008   | 9,02702 |
| (% Increase)                | 10.86    | 13.87   |
| iv)Avg. annual rainfall(mm) | 449      | 430.7   |

GEOMORPHOLOGY

Major physiographic units   Alluvium  Alluvium
Major Drainage              Sutlej     Sutlej
LAND USE(km²)
 a.Forest area              20.04     20
 b.Net area sown            1258.51   2260
 c.Cultivable area          860       2210
MAJOR SOIL TYPES
 Sandy loam       Sierozem soil and desert soil
AREA UNDER PRINCIPAL CROPS (Ha)
 92300(kharif)    Rice-770
 86650(rabi)      Wheat-2000 Cotton-1170

PREDOMINANT GEOLOGICAL FORMATIONS
 Alluvium       Alluvium
HYDROGEOLOGY
 Major Water bearing formations
 Sand, gravel  Sand
Pre-monsoon depth to Water Level
 2.8-14.10mbgl 1.65-6.43mbgl
Post-monsoon depth to Water Level
 1.85-15.20mbgl 1.49-6.63mbgl
Long term water level trend in 10 years in m/yr.
 0.10-0.70mbgl -1.16-3.87mbgl
 Average-0.40m/year

DYNAMIC GROUNDWATER RESOURCES (mcm)
 Annual Replenishable groundwater resources
 610.61       779.14
 Net Annual groundwater Draft
 975.46       540.85
 Projected demand for domestic and industrial uses upto 2025
 26.60        1.60
 Stage of groundwater development (%)
 106          74
 Groundwater Problems and Issues
 Salinity and decline in water table. Salinity and water logging.

3. Material and Method

A systematic and periodical sampling was conducted to collect the water samples from tubewells and handpumps during pre and post monsoon in the area for evaluation. Water samples were collected and analyzed, hydrogeological and statistical data was collected from state Govt. agencies to supplement the field investigations. During sampling, record of location, temperature, depth and special characteristics was maintained. Thirty groundwatersamples each were collected from both the districts in April (pre-monsoon) and same locations were again sampled in September (post-monsoon) to evaluate seasonal variations (Fig. 1). Water samples were collected in clean polyethylene bottles. At the time of sampling, bottles were thoroughly rinsed two to three times with groundwater to be sampled. To remove groundwater stored in the well, in the case of borewells and handpumps, the water samples were collected after pumping for 10 min.

A scientific, well tested and technically sound methodology was followed for performing the water analysis. pH, EC and TDS were measured Electrometrically using pH meter and conductivity meter. Carbonates, Bicarbonates and Total Hardness were measured using EDTA (Ethylene diaminetetraacetic acid) Titrimetric method, using ammoniabuffer solution. Measurement of Chloride was done using Argetonometric method, Sodium and Potassium using Flame photometric method and Phosphate and Nitrate by UV Spectrophotometric method.

Sulphate and Fluoride were determined using UV Spectrophotometric and SPADNS method respectively.

Suitability of Groundwater for Irrigation Based on SAR and RSC

The suitability of water for irrigation depends upon the effect of chemical constituents in water on plant growth and soil. The important parameters are salinity, relative proportion of sodium to calcium and magnesium (SAR), relative proportion of bicarbonate to calcium and magnesium (RSC) which was calculated using table 2 and 3 for Faridkot and Muktsar respectively. The majority of groundwater in the area has high salt contents and high RSC, which poses following type of hazards and rendered many areas unproductive.
### Table 2: Summary statistics of chemical constituents of groundwater in Faridkot district

| Parameter | Unit | Minimum | Maximum | Average | Median | Std deviation |
|-----------|------|---------|---------|---------|--------|---------------|
| pH        | -    | 7.2     | 6.9     | 8.3     | 7.1    | 7.6           |
| TDS       | mg/l | 610.0   | 650.0   | 7.5     | 6.7    | 7.6           |
| EC        | μS/cm| 880.0   | 82.4    | 1.1     | 1.0    | 1.3           |
| Na+       | mg/l | 1.0     | 2.4     | 1.3     | 1.0    | 1.3           |
| K+        | mg/l | 3.0     | 2.1     | 2.1     | 2.0    | 2.0           |
| Ca²⁺      | mg/l | 25.2    | 16.8    | 21.0    | 19.0   | 20.0          |
| Mg²⁺      | mg/l | 32.6    | 33.2    | 33.0    | 32.0   | 32.0          |
| HCO₃⁻     | mg/l | 105.0   | 150.0   | 127.0   | 123.0  | 125.0         |
| Cl⁻       | mg/l | 117.7   | 142.7   | 130.0   | 126.0  | 128.0         |
| SO₄²⁻     | mg/l | 40.2    | 46.7    | 43.0    | 42.0   | 43.0          |
| PO₄³⁻     | mg/l | 0.1     | 0.0     | 0.0     | 0.0    | 0.0           |
| NO₃⁻      | mg/l | 0.1     | 0.2     | 0.1     | 0.1    | 0.1           |
| F         | mg/l | 0.1     | 0.0     | 0.0     | 0.0    | 0.0           |
| TH        |       | 224.0   | 200.0   | 212.0   | 206.0  | 210.0         |
| TH as CaCO₃ | mg/l | 60.0    | 40.0    | 53.0    | 47.0   | 49.0          |

*PRM- Pre monsoon POM- Post monsoon

### Table 3: Summary statistics of chemical constituents of groundwater in Muktsar district

| Parameter | Units | Minimum | Maximum | Average | Median | Std deviation |
|-----------|-------|---------|---------|---------|--------|---------------|
| pH        | -     | 7.4     | 7.0     | 7.5     | 7.1    | 7.6           |
| TDS       | mg/l | 150.0   | 186.0   | 176.0   | 171.0  | 175.0         |
| EC        | μS/cm| 400.0   | 689.0   | 530.0   | 506.0  | 524.0         |
| Na+       | mg/l | 3.8     | 8.0     | 5.7     | 5.4    | 5.5           |
| K+        | mg/l | 2.4     | 1.9     | 2.1     | 2.0    | 2.0           |
| Ca²⁺      | mg/l | 17.6    | 17.6    | 17.6    | 17.6   | 17.6          |
| Mg²⁺      | mg/l | 0.9     | 1.0     | 0.9     | 0.9    | 0.9           |
| HCO₃⁻     | mg/l | 105.0   | 150.0   | 127.0   | 123.0  | 125.0         |
| Cl⁻       | mg/l | 58.2    | 69.5    | 63.5    | 62.0   | 63.0          |
| SO₄²⁻     | mg/l | 11.3    | 11.4    | 11.3    | 11.3   | 11.3          |
| PO₄³⁻     | mg/l | 0.0     | 0.0     | 0.0     | 0.0    | 0.0           |
| NO₃⁻      | mg/l | 1.6     | 1.7     | 1.7     | 1.7    | 1.7           |
| F         | mg/l | 0.1     | 0.1     | 0.1     | 0.1    | 0.1           |
| TH        |       | 120.0   | 108.0   | 115.0   | 112.0  | 114.0         |
| TH as CaCO₃ | mg/l | 42.0    | 42.0    | 42.0    | 42.0   | 42.0          |

*PRM- Pre monsoon POM- Post monsoon

### Table 4: Statistical analysis of groundwater samples with respect to agricultural practices in Faridkot district

| Sample No. | Location          | % Na (PRM) | %Na (POM) | SAR (PRM) | SAR (POM) | RSC (PRM) | RSC (POM) |
|------------|------------------|------------|-----------|-----------|-----------|-----------|-----------|
| F1         | Mehmuan          | 20.09      | 17.00     | 0.01      | 0.10      | -3.83     | -2.62     |
| F2         | MachakiKalan     | 21.26      | 23.76     | 0.70      | 0.93      | -4.76     | -2.32     |
| F3         | KaumPind         | 10.82      | 12.54     | 0.42      | 0.52      | -4.34     | -3.65     |
| F4         | Sadiq            | 5.84       | 12.79     | 0.13      | 0.43      | 0.47      | 2.00      |
| F5         | Ghugiana         | 16.64      | 23.59     | 0.51      | 0.84      | -2.74     | 2.78      |
| F6         | DhillwanKhurd    | 21.61      | 11.33     | 0.80      | 0.32      | -3.34     | -2.09     |
| F7         | BhagsinghWala    | 38.84      | 43.07     | 2.06      | 2.30      | -0.01     | 2.31      |
| F8         | Chandbaja        | 59.45      | 72.81     | 4.12      | 8.32      | 1.42      | 3.14      |
| F9         | Moranwali        | 28.01      | 5.04      | 1.25      | 0.05      | 0.15      | 2.28      |
| F10        | Kater            | 45.59      | 47.58     | 3.81      | 3.95      | 4.46      | 7.62      |
| F11        | Tehna            | 42.97      | 45.01     | 3.46      | 3.67      | -5.06     | -4.27     |
| F12        | Chahal           | 79.05      | 79.84     | 18.68     | 19.61     | -6.30     | -4.93     |
| F13        | Dhudhi           | 28.43      | 32.45     | 1.57      | 1.82      | -1.93     | -0.71     |
| F14        | Faridkot         | 44.18      | 47.25     | 3.57      | 3.97      | -4.38     | -1.93     |
| F15        | Kotapura         | 23.89      | 10.20     | 1.17      | 0.39      | -2.07     | -1.07     |
| F16        | DhillwanKalan    | 77.60      | 79.33     | 10.32     | 11.25     | 0.68      | 1.22      |
| F17        | Matta            | 57.72      | 58.89     | 5.68      | 5.92      | -6.80     | -5.67     |
| F18        | Bargari          | 67.05      | 69.62     | 6.62      | 7.12      | -0.16     | 0.86      |
| F19        | RamuwaLa         | 24.55      | 26.14     | 1.53      | 1.66      | -8.30     | -7.31     |
| F20        | Thara            | 34.74      | 37.98     | 2.34      | 2.67      | -5.35     | -4.48     |
| F21        | Maur             | 39.61      | 41.21     | 2.79      | 2.97      | -5.52     | -4.22     |
| F22        | Karirwali        | 90.52      | 91.7      | 28.19     | 31.11     | 4.70      | 6.25      |

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Table 5: Statistical analysis of groundwater samples with respect to agricultural practices in Muktsar district

| Sample | Location | % Na (PRM) | %Na (POM) | SAR (PRM) | SAR (POM) | RSC (PRM) | RSC (POM) |
|--------|----------|------------|-----------|-----------|-----------|-----------|-----------|
| M1     | Dohak    | 14.61      | 16.91     | 0.52      | 0.65      | -4.08     | -2.87     |
| M2     | Galabewala | 12.70      | 14.40     | 0.54      | 0.67      | -11.49    | -10.25    |
| M3     | Akalgarh | 8.15       | 9.12      | 0.46      | 0.53      | -13.64    | -12.94    |
| M4     | Bariwala | 8.22       | 11.99     | 0.12      | 0.26      | -1.67     | -1.13     |
| M5     | Udekaran | 33.52      | 38.05     | 1.29      | 1.51      | -1.29     | -0.71     |
| M6     | Haraj    | 41.85      | 45.98     | 1.77      | 2.05      | 0.46      | 0.99      |
| M7     | Bhuttiwala | 15.39      | 17.17     | 0.88      | 1.01      | -6.69     | -6.61     |
| M8     | Bhullar | 7.71       | 10.32     | 0.30      | 0.41      | -10.64    | -7.8      |
| M9     | Rupana   | 61.30      | 66.23     | 3.98      | 4.62      | 2.27      | 2.77      |
| M10    | Bham     | 29.86      | 37.28     | 1.15      | 1.45      | 2.26      | 4.02      |
| M11    | Chakduwala | 14.69      | 15.22     | 0.82      | 0.85      | -8.88     | -8.18     |
| M12    | Sotha   | 64.78      | 68.98     | 4.04      | 4.62      | 15.15     | 18.13     |
| M13    | Doda     | 17.51      | 18.94     | 0.91      | 0.98      | -7.64     | -6.24     |
| M14    | Mehrajwala | 10.39      | 11.55     | 0.66      | 0.74      | -11.09    | -10.06    |
| M15    | Giljewala | 52.50      | 54.97     | 2.37      | 2.51      | 2.71      | 3.29      |
| M16    | Samagh  | 37.71      | 40.07     | 1.67      | 1.79      | 3.14      | 4.03      |
| M17    | Muktsar | 24.88      | 32.68     | 0.88      | 1.23      | -0.51     | 0.34      |
| M18    | Aulakh  | 87.90      | 89.10     | 23.65     | 25.75     | 1.56      | 2.3       |
| M19    | Midda   | 9.11       | 14.31     | 0.40      | 0.74      | -3.24     | -2.33     |
| M20    | Ghagga  | 22.58      | 25.46     | 0.75      | 0.92      | -1.32     | -0.19     |
| M21    | Their   | 26.85      | 30.64     | 0.89      | 1.04      | 4.67      | 5.57      |
| M22    | Husner  | 16.61      | 24.08     | 0.69      | 1.10      | 0.37      | 1.48      |
| M23    | Malout  | 71.28      | 82.76     | 7.73      | 13.77     | 1.68      | 2.97      |
| M24    | Qabarwala | 72.69      | 82.69     | 8.90      | 14.94     | 0.35      | 1.06      |
| M25    | Lambi   | 90.77      | 92.09     | 25.95     | 30.42     | -0.95     | -0.57     |
| M26    | Kuttiwali | 79.23      | 82.08     | 13.81     | 16.29     | 4.08      | 7.82      |
| M27    | Punjawa | 86.78      | 89.59     | 20.73     | 24.16     | -1.25     | 1.73      |
| M28    | Bhittiwala | 61.43      | 62.77     | 8.20      | 8.62      | -7.26     | -6.53     |
| M29    | Middikheri | 26.76      | 33.05     | 1.16      | 1.51      | -0.50     | 0.37      |
| M30    | Gaggar  | 25.96      | 29.91     | 0.87      | 1.05      | -0.25     | 0.39      |

*PRM- Pre monsoon POM- Post monsoon

Salinity Hazard
The analytical data plotted on US salinity diagram [7] shows that in Faridkot district, the groundwater for irrigation purposes is of both C3S1 and C4S1 type indicating that water in shallow aquifer is of high salinity and low sodium and very high salinity and low sodium hazard characteristic (Fig.2) similarly in district Muktsar, water samples fall almost in equal proportion in C3S1 and C4S1 fields which is suitable for plants which have good salt tolerance but restricts its suitability for irrigation, especially in soils with restricted drainage [8][9] (Fig.4). Some of the samples in both the districts fall in C4S4 field indicating very high salinity and high sodium water thus enhancing the danger of exchangeable sodium. Both the areas need special attention as far as irrigation is concerned.

Sodicity Hazard
Around 6.6% samples of Faridkot fall in unsuitable category (Fig.2) comparatively 40% samples of Muktsar fall in unsafe category of water class in both the seasons using the Wilcox diagram in (Fig.3)[10]. The high concentration of sodium reduces the permeability for Ca²⁺ and Mg²⁺ resulting in poor drainage (Kumar et al. 2007). This may also attribute to water logging condition.
Suitability of Groundwater for Irrigation Based on TH (as CaCO₃) and EC
Total Hardness results from the presence of divalent metallic cations of which calcium and magnesium are the most abundant. Table 6(a) and 6(b) shows how various natural and anthropogenic factors affect the individual ion concentrations in the two districts affecting the agriculture and irrigation.

Alkalinity Hazard
Faridkot, groundwater occurring in the shallow aquifer is saline except in some places where groundwater is fresh which is due to occurrence of fresh water lenses created by return seepage and canal seepage, 10% samples fall in Hard water category during both pre-monsoon and post monsoon season (Table 6(a)) whereas in Muktsar 46.6% samples in pre monsoon and 33.3% samples in post monsoon fall in Hard water category. In district Muktsar 10% samples in pre-monsoon and 13.3% in post monsoon season fall in very hard water category. The natural cause is the presence of soil minerals producing sodium carbonate (Na₂CO₃) and sodium bicarbonate (NaHCO₃) upon weathering. The water thus has objectionable taste and also very high conductivity values. The values are increasing in post-monsoon which indicates leaching of agricultural fertilizers and chemicals with rainwater to the groundwater. The basic difference between rainwater and irrigation water is that the former is Practically free from salts, while irrigation water contains...
varying amounts of salts in varying degrees depending on its source. This means with every irrigation a certain amount of salts are added to the soil. Table 6(b) shows that the shallow groundwater was brackish in about 23.3% samples in pre monsoon and 20% samples in post monsoon and saline in 3.3% samples in pre monsoon and 6.6% samples in post monsoon in district Faridkot. In Muktsar, 13.3% samples in pre monsoon and 10% samples in post monsoon fall in brackish category and 33.3% in pre monsoon and 36.6% samples in post monsoon are saline. All the villages with high salinity falls under water logged areas in Muktsar block. Sodic soils present particular challenges because they tend to have very poor structure which limits or prevents water infiltration and drainage [13]. In addition to mineral weathering, salts are also deposited via dust and precipitation. In dry regions salts may accumulate, leading to naturally saline soils [8][9]. Figure 4 and 5 shows the distribution of total hardness as CaCO3 in the groundwater of district Faridkot and Muktsar respectively.

**Table 6(a): Based on Total Hardness as CaCO3**

| TH as CaCO3 (mg/l) | Water Class | % of Faridkot Samples | % of Muktsar Samples |
|-------------------|-------------|------------------------|----------------------|
| >75               | Soft        | 23.3(7)                | 13.3(4)              |
| 75-150            | Moderately Hard | 70(20)            | 30(9)                |
| 150-300           | Hard        | 10(3)                  | 46.6(14)             |
| >300              | Very Hard   | 0                      | 0                    |

*PRE- Pre monsoon, POM- Post monsoon (Source: Sawyer and McCartly, 1967)
(Figures in parenthesis are number of samples in the particular categories of degree of problem)

**Table 6(b): Based on EC**

| EC (µS/cm) | Water Class | % of Faridkot Samples | % of Muktsar Samples |
|-----------|-------------|------------------------|----------------------|
| 0-2000    | Fresh       | 73.3(22)               | 53.3(16)             |
| 2000-4000 | Brackish    | 23.3(7)                | 10(3)                |
| >4000     | Saline      | 3.3(1)                 | 33.3(10)             |

*PRE- Pre monsoon, POM- Post monsoon (Figures in parenthesis are number of samples in the particular categories of degree of problem)

Figure 4: Distribution of TH as CaCO3 in the groundwater of Faridkot district
suitability of water for irrigation mainly in clays soils which has high cation exchange capacity. When dissolved sodium in comparison to dissolved calcium and magnesium is high in water, clay soil swells or undergoes dispersion which drastically reduces its infiltration capacity.

Water with low Ca$^{2+}$ (<2 meq/l) and high amounts of carbonates result in specific toxicity symptoms. These include scorching and leaf burning at the early seedling development stage of crops. High bicarbonate also result in increase in pH of the soil rendering it to a condition known as Black Alkali Bicarbonate Hazard, which is caused by RSC or Residual alkalinity in water, has been computed by method devised by Richards (1954). The residual sodium carbonate (RSC) can be expressed as (where all ions are expressed in meq/l):

$$RSC (\text{meq/l}) = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+})$$

$< 1.25 =$ Good; $1.25-2.5 =$ Doubtful; $> 2.5 =$ Unsuitable for irrigation

In Faridkot during pre monsoon season, RSC ranged from -8.30 meq/l to 4.79 meq/l with average value of -2.27 meq/l whereas in post monsoon, the concentration of RSC ion varied from -7.31 meq/l to 7.62 meq/l with an average value of -0.73 meq/l (Table 4). 3% samples in pre and post monsoon seasons fall in doubtful category and 10% samples in pre monsoon and 13% samples in post monsoon fall in unsuitable category (Fig. 6).

In Muktsar during pre monsoon season, RSC ranged from -13.64 meq/l to 15.15 meq/l with average value of -1.59 meq/l whereas in post monsoon, the concentration of RSC ion varied from -12.94 meq/l to 18.13 meq/l with an average value of 0.44 meq/l (Table 5). 13% samples in pre monsoon and 6% samples in post monsoon seasons fall in doubtful category and 19% samples in pre monsoon and 29% samples in post monsoon fall in unsuitable category (Fig. 7).
5. Conclusions and Recommendations

The hydrochemical analysis reveals that the availability of good water in both the districts is limited and farmers have to resort to the use of saline groundwater and available canal water. Faridkot district which decade back used to be water logged now shows declining water table while Muktsar faces serious water logging conditions. In Faridkot district salinity is increasing making water unsuitable for irrigation whereas in case of Muktsar district water is unsuitable for irrigation in almost entire district and most of the area is water logged, as the groundwater is not used at all. From the above analysis, it is concluded that the groundwater in Faridkot and Muktsar districts is in general unsuitable for agricultural and irrigation purposes except for few locations. In Faridkot district the crops consuming less quantity of water may be grown in place of crop requiring more water in the over exploited block. Encouraging tolerant crops like Barley, Wheat, cotton, sunflower, so that groundwater of marginal quality can be used for irrigation. Conjunctive use of groundwater with canal water for irrigation is necessary to avoid further degradation and overexploitation of groundwater.

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