# Estimation of groundwater contribution to crop water use in Kulavat irrigation command area in Khorezm, Uzbekistan

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## *Abstract*

Due to arid climate of Uzbekistan, water scarcity threatens the sustainable development of irrigated agriculture. In future, accounting all non-conventional water resources to mitigate water scarcity and to increase in-situ crop water use become main topic for most researches. In this context, groundwater evaporation ($E_{gw}$) can be considered one of the sources to meet crop-water use where the water table is shallow and groundwater salinity is low. In this study, soil texture, groundwater table depth and salinity maps were developed analyzing long-term archive data in geographical information system (GIS). These data then employed to estimate and map $E_{gw}$ through a semi-empirical approach. The results suggest that surface irrigation may be reduced considering $\mathrm{E}_{\mathrm{gw}}$ contribution ranging from 205-240 mm (e.g. light soils) to 305-360 mm (e.g. medium to heavy soils). The approach can be recommended to adjust the soil water balance in the root zone and optimize irrigation schedule.

***Key words:*** *soil texture, groundwater table, groundwater evaporation, Khorezm*

## 1. Introduction

Irrigation water, consuming 90% of total available water resources, is a key driver of agricultural production in Uzbekistan. However, water scarcity, due to climate change and improper water management, has become an increasingly acute problem that threatens the sustainable development of irrigated agriculture in the country. Moreover, recent drought events in 2001, 2008 and 2011 caused tremendous damage to agriculture, economy, human wellbeing and health in the lowlands of the Amudarya River. Agricultural damage from drought in 2001 cost about 45 and 22.5 billion UzSum, where 36 and 13% of irrigated lands were not cultivated and 22 and 8% of croplands were dried up in Karakalpakstan and Khorezm, respectively (Gaipnazarov & Deivy, 2006). Considering the amount of water in the Amudarya River is predicted to reduce further due to the impacts of climate change (Dukhovny & de Schutter, 2010), modifying the irrigation scheduling is needed to incorporate in-situ crop water use from shallow groundwater and correspondingly reduce irrigation water application and drainage water volumes to be disposed.

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Therefore, investigating the potential of groundwater evaporation contribution to crop-water use may be helpful in reducing water demand from the river.

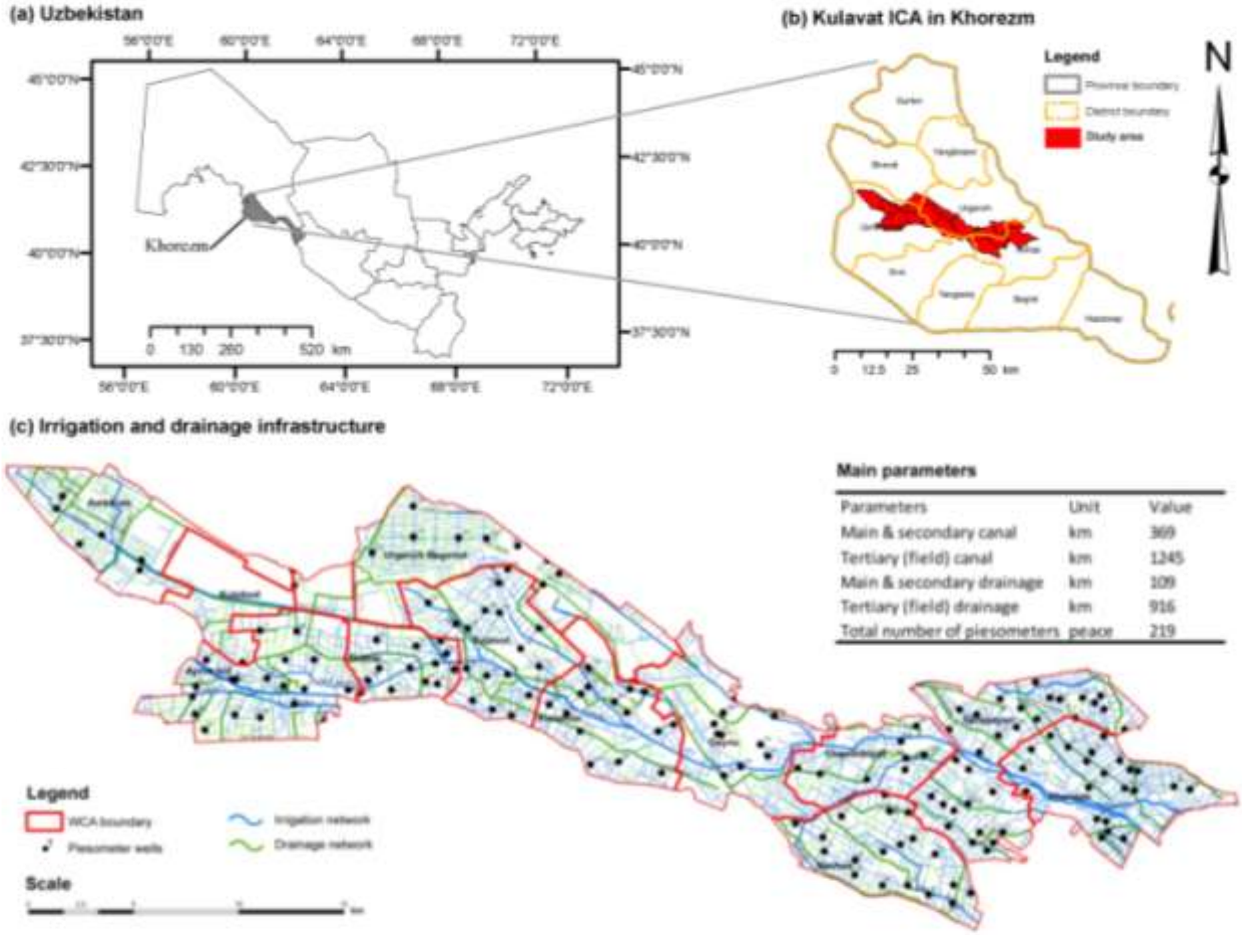
Upward water flux from groundwater depend on several factors such as groundwater table (GWT) depth, soil hydraulic properties, crop growth stage, weather and irrigation, among others. Although, direct measurement of groundwater evaporation is possible through lysimetric studies (Engulatov et al., 1964; Kats, 1976 etc.), modeling approaches (e.g., UPFLOW, Raes & Deproost, 2003; HYDRUS, Simunek et al., 1998 etc.), empirical approaches (e.g., empirical/semi-empirical equations with power or exponential functions, Laktaev, 1983; Dukhovny, 1984 etc.) and simple approach (e.g., graphical procedure, Doorenbos & Pruitt, 1977) are also available. However, these approaches are expensive and time consuming (lysimeters), require specific environmental conditions valid during the time period considered (models), usually undertaken within limited time to quantify the whole spectrum of groundwater contribution to crop-water use under the influences of inter-seasonal GWT (empirical and graphical procedures) and basically based on point data. Keeping aforementioned, main goal of the research is to spatially explicit groundwater evaporation map using geographical information system (GIS).

## 2. Methodology

### *2.1. Study area*

The study site is located in left bank plain of the Amudarya River within “Kulavat” irrigation command area (ICA) of Khorezm, Uzbekistan (Fig.1a&b). The site covering an area of approximately 42,000 hectares lies within the northern climatic zone (FAO, 2003). According to Köppen-Geiger climate classification map, the site is classified as arid and cold desert climate (BWk, Kottek et al, 2006). With scars and uneven distribution of mean annual precipitation of 94 mm year$^{-1}$ (Ibrakhimov et al., 2011) and high evaporation rate of 1400-1600 mm year$^{-1}$ (Kienzler et al., 2011), water from the Amudarya River is main source in practicing irrigated agriculture. Soils in the study site are formed under the influence of water from the meandering Amudarya River (Kats, 1976).

Total length of irrigation and collector-drainage network in the study area are 1614 and 1025 km, respectively (Fig.1c) where specific length of in-farm irrigation (63 m/ha) and drainage (32 m/ha) network are denser compared to average values (51 and 25 m/ha, respectively) in the Khorezm province (CAWATERinfo, 2016; Djanibekov, 2008).



**Main parameters**

| Parameters | Unit | Value |
|---|---|---|
| Main & secondary canal | km | 369 |
| Tertiary (field) canal | km | 1245 |
| Main & secondary drainage | km | 109 |
| Tertiary (field) drainage | km | 916 |
| Total number of piesometers | peace | 219 |

Figure 1: Location of Khorezm region, Uzbekistan (a), study area (b) and main land reclamation infrastructures in study area (c)

### *2.2.Soil texture and mapping*

The soils of the study site consist of rock debris (alluvial deposits), which are fine layered and very deep (FAO, 2003). Soil texture map of the study area at 1:25,000-scale was acquired from Scientific Research Institute of Soil Science and Agrochemistry (SRISSA). The map containing texture information up to 2-3 m was scanned, digitized and geo-referenced in Khorezm Rural Advisory Support Service (KRASS) using georeferencing extension in ArcMap$^{TM}$ 9.2. In this study soil texture at 0-2 m was average weighted in order to create one layer soil texture map.

### *2.3. Groundwater monitoring wells and GWT depth and salinity mapping*

Long-term observations (1990-2004) at a 10-daily basis on GWT and seasonal (April, July, October) basis on GW salinity were obtained from the Khorezm Melioration Expedition (ME) of the Ministry of Agriculture and Water Resources Management (MAWR). The depth to GW is measured by field-staff from the ME using a tapeline with a man-made cylinder (*xlopushka*) that flaps when it reaches the water surface in the well. The GW salinity samples were analyzed using the hand-held conductivity meter "IKS – Express T" device (Chernishev, 2007). In total

219 monitoring wells are exist within the Kulavat command area. Although, one observation well has to serve about 100 ha land area according to acting norm (VNIIGiM, 1978), in fact one well serves about 130 ha that may influence on proper assessment of land reclamation condition. Nevertheless, due to availability of data for long-term period, archive data from the ME were used in this study. Spatial distribution of average long-term vegetation period (April-September) GWT and GW salinity were mapped through inverse distance weighting (IDW) method in ArcMap$^{TM}$ environment. Being a deterministic method, in IDW, surfaces are created from measured well data that based on the extent of similarity and value for any unmeasured location (in-between wells) are predicted using the measured values surrounding the prediction location.

### 2.4. Groundwater evaporation

Capillary rise in this study is defined as the volume of water leaving a static water table due to soil evaporation and plant transpiration (ETo) within corresponding soil texture boundary. Hence soils in the study site are correspond to semi-hydromorphic reclamation regime (Dukhovny et al., 1979); following equation proposed by Averyanov (1978) was used in order to estimate evaporation from GWT:

$$E_{gw} = ETo\left(1 - \frac{h}{H_{cr}}\right)^{n} \qquad [1]$$

Where, $E_{gw}$: seasonal groundwater contribution to aeration zone due to soil evaporation and crop transpiration (mm); *ETo*: potential evapotranspiration during the season considered (mm); h: average GWT for the vegetation period (m); Hcr: critical GWT from which aeration zone GW contribution starts (m); n: index that depend on soil capillarity condition (-).

Daily average climate parameters from 1970-2007 are collected from “Urgench” weather station (Tab.1). Air temperatures (mean, minimum and maximum), mean relative humidity and wind speed at 2 m height above soil surface were used to estimate ETo (e.g., “ETo Calculator”, Raes, 2009) that based on FAO Penman-Monteith method (Allen et al., 1998).

Table 1: Climate parameters of “Urgench” weather station, Khorezm (Uzhydromet, 2008)

| Parameters | Annual | | | Growing period | | | Non-growing period | | |
|---|---|---|---|---|---|---|---|---|---|
| | mean | sd[1] | cv[2] | mean | sd | cv | mean | sd | cv |
| Air temperature ($^{o}$C) | 13.1 | 0.7 | 5 | 23.0 | 0.7 | 5 | 3.1 | 1.4 | 10 |
| Relative humidity (%) | 58.3 | 3.3 | 6 | 46.4 | 4.1 | 7 | 70.3 | 3.5 | 6 |
| Wind speed (m/s) | 3.6 | 0.2 | 7 | 3.6 | 0.3 | 8 | 3.6 | 0.3 | 7 |
| Precipitation (mm) | 94.7 | 34.5 | 4 | 33.3 | 23.3 | 7 | 61.3 | 24.9 | 4 |

[1]standard deviation from mean; [2]coefficient of variation (%)

Parameters such as "$H_{cr}$" and "$n$" for Eq. [1] were obtained from Laktaev (1978) that is given for light textured soil classes (Tab.2).

Table 2: Parameters "$n$" and "$H_{cr}$" for various soil textures used in Eq. [1] (Laktaev, 1978)

| Parameters | Soil textures | | | | |
|---|---|---|---|---|---|
| | sandy loam | light loam | medium loam | heavy loam | clay |
| $H_{cr}$ | 2 | 2.5 | 3 | 3.5 | 4 |
| $n$ | 1.5 | 1.6 | 1.75 | 1.9 | 2 |

## 3. Results and Discussions

### 3.1. Soil texture

Soils in the site according to USDA soil texture classification are dominated by medium loams (41%) which together with light loams and sands constitute 89% of all soils in the study area (Fig.2). These soils are also dominated in irrigated lands of Khorezm province (86%, Akramkhanov et al., 2012).

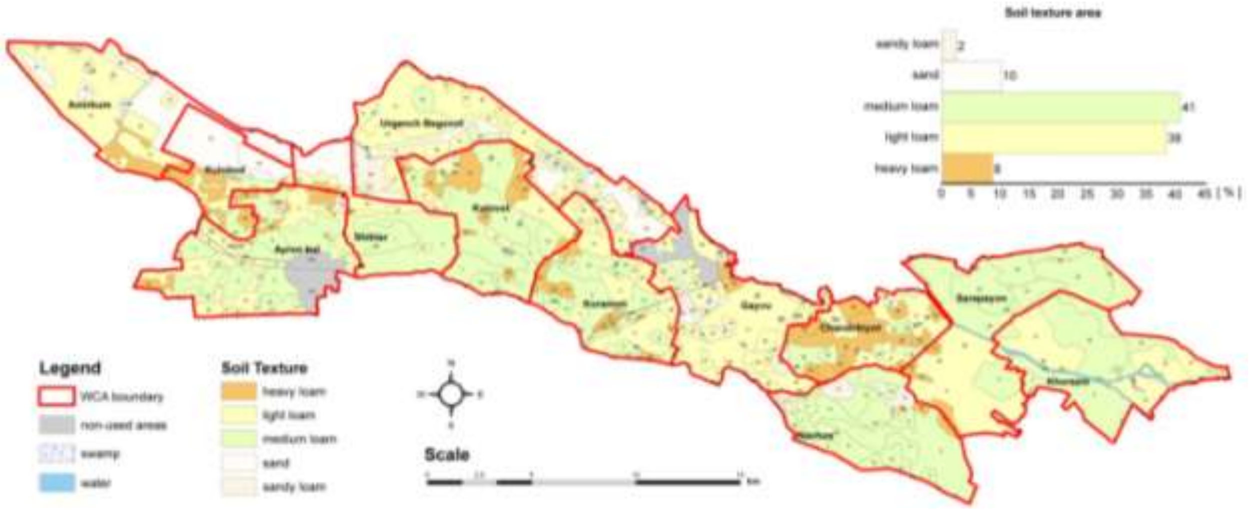


Figure 2: Soil texture map and area by classes (in %)

### 3.2. Groundwater table depth and salinity

About 50% of lands in the study area were covered by shallow GWT depth (0-1.5 m) during the vegetation period (Fig.3a) which is higher than the critical threshold of 1.5 m defined for the Khorezm Region (Khamzina et al., 2008). Such shallow GWT depth may pose a risk for secondary soil salinization in one hand and increase considerably groundwater contribution to ET on other hand (Forkutsa, 2006). The latter, however, in long-term perspective may result soil salinization in the irrigated areas, if significant salt exists in the groundwater. Fortunately, 98.7% of total land area in study site has GW salinity ≤ 3 g/l during the vegetation period (Fig.3b).

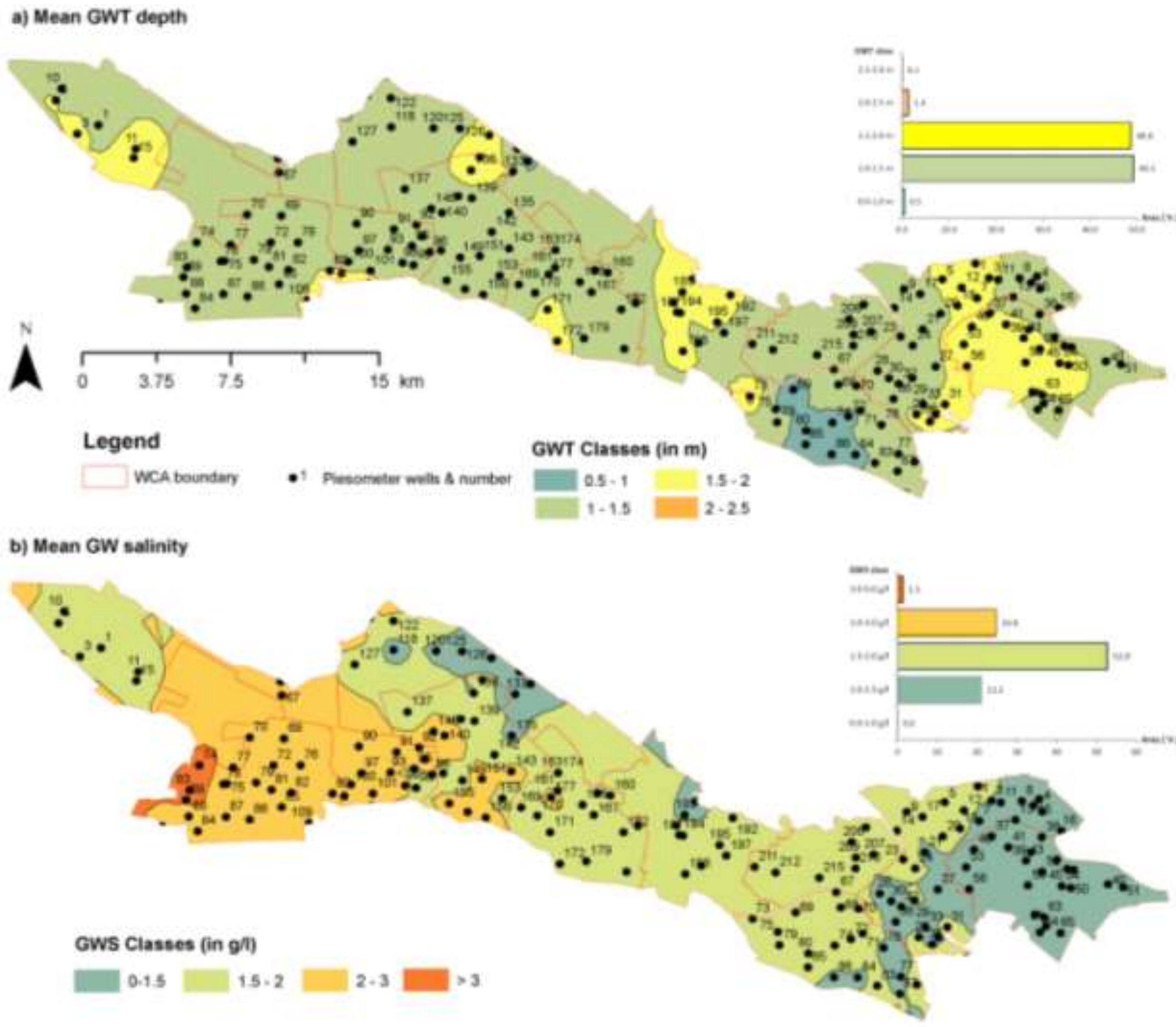


Figure 3: Average GW table depth (a) and salinity (b) during vegetation period (averaged for 1990-2004)

### *3.3. Groundwater contribution ($E_{gw}$) to ETo*

Calculated total *ETo* for the vegetation period during 1970-2007 was varied from 1090 to 1340 mm with average value being 1220 mm for that period. The mean value is higher than total water supply in Khorezm province (970 mm) during the period (Yakubov & Gaipnazarov, 2005).

Predicted $E_{gw}$ (Fig.4), ranging from 119 (sandy soils in non-irrigated areas) and 205 (sandy loam) to 360 mm (heavy loam soil) under GWT depth of 1.3-1.4 m (long-term vegetation period GWT was averaged within each soil texture class boundary) was within the range of values reported by Forkutsa (2006). In her study, the $E_{gw}$ was ranged from 115 mm (for sand) and 229 mm (for sandy loam) in Khorezm that has similar environmental condition. Using the same approach, Laktaev (1978) estimated $E_{gw}$ for the northern climatic zone that ranged from 65 mm (sandy loam) to 190 mm (heavy loam) under GWT of 1-2 m. Such low values of $E_{gw}$ in his study can be explained by consideration of reduced irrigation norm (500 mm) used instead *ETo*.

Based on the results, groundwater evaporation contributed 19-30 and 21-37% of the evapotranspiration (*ETo*) and water supply during the growing period in irrigated lands. These values are within the range of Yakubov & Gaipnazarov (2005) estimated Egw (32-44%) for Khorezm condition.

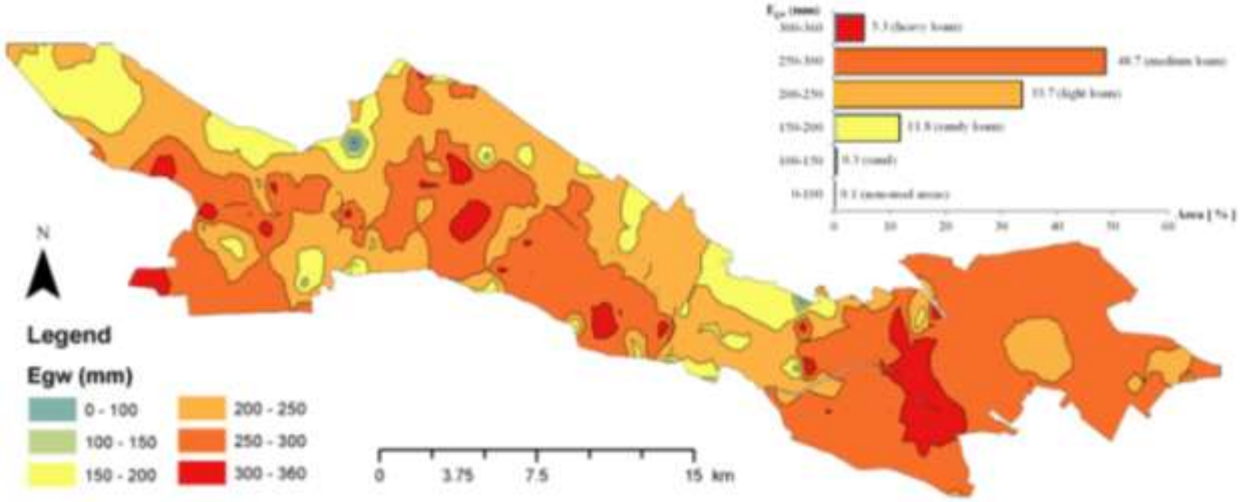


Figure 4: Groundwater evaporation map during the vegetation period (averaged from 1990-2004)

## 4. Conclusions

The GIS software, with available soil and hydrological data (e.g., GWT and salinity) was successfully employed to estimate the evaporation rates from shallow groundwater table during the vegetation period. The results suggest that surface irrigation may be reduced as shallow groundwater (< 1.5 m, 50% from total land area) with low salinity (< 3 g/l, 99%) contribute $E_{gw}$ from 205-240 mm (light soils) to 305-360 mm (medium  to heavy soils) to the root zone. The presented simulations indicate that classical approach proposed by Averyanov (1978) is able to assess the correct order of magnitude of groundwater contribution ($E_{gw}$) under various GWT depths and in different soil types that exist in study area. The results can be used to adjust the soil water balance in the root zone and optimize irrigation schedule for similar environmental conditions (weather, soil, hydrology etc.). Further, the method can be applied for all irrigated lands in Uzbekistan owing availability of regular data on GWT depth and salinity (e.g., ME), soil texture (e.g., SRISSA) and climate (e.g., Uzhydromet).

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