PROJECT

Transboundary water management adaptation in the Amudarya basin to climate change uncertainties

Report

2.3. Modeling crop water requirements in light of climate change

Project coordinator	Prof. V.A.Dukhovniy
Responsible	A.Sorokin
Executor	G. Solodkiy

Tashkent 2016

DEFINITION AND ABBREVIATION

PLANNING ZONE (PZ) – the territory of province or its part that has uniform soil and climatic characteristics and conditionally autonomous economic system.

IRRIGATED AREA – area irrigated artificially by irrigation infrastructure (canals, drainage) built specifically for these purposes.

DB - database

AMST – aeronautic meteorological station

REMO – model for climate forecast, based on greenhouse gas emissions

CALCULATION GRID - division of an irrigated part of PZ by squares. In our cases, these are squares 3 x 3 km. The size of a square is chosen in such a way so that to ensure uniformity of given square and depending on the maximum number of squares that the software can process. Further on, all calculations are linked with the cells of this Calculation grid.

TABLE OF CONTENTS

1. PROBLEM STATEMENT 4
2. POINTS OF THE TERMS OF REFERENCE 4
3. MODELING CROP WATER REQUIREMENTS IN LIGHT OF CLIMATE CHANGE ... 4
4. DESCRIPTION OF CALCULATION ALGORITHM 6
5. GIS-PREPARATION OF PROCESSING OBJECTS 7
6. CALIBRATION OF ETo 7
7. CALIBRATION OF RAINFALL 9
8. CALIBRATION OF AVERAGE TEMPERATURE 9
9. SOIL DATA 10
9.1. Research objective 10
9.2. Research tasks and their execution: 10
9.3. Research objects 10
9.4. Research method 11
9.5. Research results 12
10. DISTRIBUTION OF TEN-DAY GWT VALUES BY UZBEK PZs 23
11. BREAKDOWN OF GRID CELLS BY THE SOIL MAP OF UZBEKISTAN. DETERMINATION OF COEFFICIENTS IN KHARCHENKO FORMULA. CALCULATION OF GROUNDWATER CONTRIBUTION 23
12. ESTIMATION OF INITIAL TOTAL EFFECTIVE TEMPERATURE FOR ALL PROJECT CROPS 23
13. ALGORITHM FOR RECALCULATION OF SOWING DATES AND CROP DEVELOPMENT PHASES IN LIGHT OF CLIMATE CHANGE 23
14. LIST OF CROPS UNDER CONSIDERATION 24
15. CROP GROUPING 24
16. REVIEW OF RESULTS 25
CONCLUSION 26
APPENDICES 27
APPENDIX 1 28
APPENDIX 2 30
APPENDIX 3 31
APPENDIX 4 32
APPENDIX 5 33
APPENDIX 6 34
APPENDIX 7 35
APPENDIX 8 36
APPENDIX 9 37
APPENDIX 10 38
APPENDIX 11 39
APPENDIX 12 40
APPENDIX 13 41
APPENDIX 14 42
APPENDIX 15 43
APPENDIX 16 44
APPENDIX 17 45
APPENDIX 18 46
APPENDIX 19 48

1. PROBLEM STATEMENT

Calculate water requirements of crops grown in PZs that divert irrigation water from the Amudarya River. Here one should also account groundwater contribution, leaching and recharge irrigation requirements, and climate change impact on crop water requirements.

2. POINTS OF THE TERMS OF REFERENCE

For the following planning zones:

1	North Karakalpakstan
2	Khorezm
3	Bukhara
4	Karshi
5	Kashkadarya
6	Surkhandarya

calculate crop water requirements for all listed crops for 2000 - 2050.

The following planning zones:

7-8	Akhal – 2 objects
9	Dashoguz
10	Mary
11-13	Lebap – 3 objects
14	Upper Kafirnigan
15	Lower Kafirnigan
16	Pyandj
17	Vakhsh

are prepared for calculation of crop water requirements as new information becomes available and processed.

3. MODELING CROP WATER REQUIREMENTS IN LIGHT OF CLIMATE CHANGE

Below is the list of completed work:

- Created projects for each planning zone in Amudarya River basin.
- Inputted GIS data into the projects:
- - planning zones (PZ).
- - irrigated land contours of PZ.
- - representative meteorological stations for PZ (gis.ncdc.noaa.gov)
- - REMO climate nodes for PZ.
- - Long-term data on groundwater table (GWT) in irrigated part of PZ

- - Calculation grid of PZ irrigated part
- - Derived data on rainfall for PZ from the ClimateSERV site

f:\PEER\ReqWatPR*.*

Имя	Тип	Размер	Дата
[..]		<Папка>	25.10.2015 21:41
[AHALAK_1]		<Папка>	24.10.2015 23:53
[AHALAK_2]		<Папка>	25.10.2015 12:53
[BUKHARA_2]		<Папка>	25.10.2015 13:04
[DASHAVUZ_1]		<Папка>	25.10.2015 14:02
[DN_KAFIRNIGAN_2]		<Папка>	25.10.2015 15:01
[KARSHY_1]		<Папка>	25.10.2015 14:05
[KASHKADARIYA_2]		<Папка>	25.10.2015 14:12
[KHOREZM_1]		<Папка>	25.10.2015 15:09
[KKALPAK_NORD_1]		<Папка>	25.10.2015 15:06
[LEBAP_1]		<Папка>	25.10.2015 14:23
[LEBAP_2]		<Папка>	25.10.2015 14:24
[LEBAP_3]		<Папка>	25.10.2015 14:26
[MARY_1]		<Папка>	25.10.2015 14:39
[PANDJ_2]		<Папка>	25.10.2015 14:58
[SURHANDARIYA_2]		<Папка>	25.10.2015 15:08
[UP_KAFIRNIGAN_2]		<Папка>	25.10.2015 13:27
[VAKHSK_1]		<Папка>	25.10.2015 13:25

1. A project was created for each planning zone in form of a folder with data.

Because of their size, some planning zones could not be processed entirely and were divided into two (as Akhal zone) or three (as Lebap zone) parts.

2. Consequently, 17 separate objects of planning zones were processed.

3. Each project folder contains information similar to that shown for the «AHALAK_1» folder.

f:\PEER\ReqWatPR\AHALAK_1*.*

Имя	Тип	Размер	Дата
[..]		<Папка>	25.10.2015 21:41
[DEM]		<Папка>	18.10.2015 18:23
[DEM_HGT]		<Папка>	10.11.2015 11:32
[IRRZONE]		<Папка>	14.10.2015 14:44
[IRRZOP]		<Папка>	18.10.2015 12:57
[MST]		<Папка>	27.11.2015 16:23
[NODS]		<Папка>	12.10.2015 16:26
[RAB]		<Папка>	18.10.2015 19:02
[RAIN]		<Папка>	02.02.2016 12:19
[RAY]		<Папка>	23.02.2016 11:42
[SALT]		<Папка>	11.10.2015 20:55
[SETKA]		<Папка>	17.10.2015 21:03
[SOIL]		<Папка>	11.10.2015 20:55
[WRK]		<Папка>	18.10.2015 18:30
[ZOPLA]		<Папка>	14.10.2015 14:45
RWDB_Prj	mdb	245 919 744	28.02.2016 19:38

4. **DEM** and **DEM_HGT** folders contain information on elevation of planning zone

- **ZOPLA** folder contains Shape-file of planning zone,

- **IRRZONE** folder contains Shape-file of a fragment of Central Asia irrigated territory, which covers given planning zone.

- **IRRZOP** folder contains Shape-file of irrigated part of given planning zone derived by scissoring from the Central Asia irrigated territory of those fragments that do not fall into given PZ.

- **NODS** folder contains point Shape-file of REMO simulated climate nodes that fall into or adjacent to PZ.
- **RAB** folder contains irrigated part of planning zone divided by the live grid with 3 km step.
- **RAIN** folder contains average rainfall values for given planning zone for a period of time from 1981 to 2016 derived from the CLIMATESERV site.
- **RAY** folder contains Shape-file of administrative districts of given planning zone.
- **SALT** folder is designed for Shape-file of salinity in PZ. The data is not available.
- **SETKA** folder contains Shape-file of the live grid with the 3 km step. This grid covers the whole PZ.
- **SOIL** folder contains Shape-file of soil map, which covers given PZ.
- **WRK** folder is designed to store intermediate results of GIS processing.

4. DESCRIPTION OF CALCULATION ALGORITHM

Crop water requirements are calculated using the following formula:

$$RW = ETc - EfRain - GWC \qquad (1)$$

where:
RW – crop water requirements for certain period of time

ETc – evaporation from the surface of crop and soil under this crop

EfRain – effective rainfall

GWC – groundwater contribution

ETc is calculated by formula:

$$ETc = \sum_{i=1:n} ETo_i * Kc_i \qquad (2)$$

where:
ETo_i – reference evapotranspiration for i-day of calculation period

Kc_i – crop coefficient for i-day of calculation period

n – number of days in calculation period

i – sequence number of day in calculation period

ETo is calculated by Penmann-Monteith formula (FAO publication 56) and the Blaney-Criddle method.

Kc – crop coefficient determined for each day of the calculation period. It is derived from tables of the FAO publication 56.

EfRain - effective rainfall (mm). It is calculated by the formula of the United States Department of Agriculture Soil Conservation Service.

If monthly rainfall (MonPre) <= 50 mm

then

EfRain = (MonPre * (125 - 0.3 * MonPre)) / 125

If monthly rainfall (MonPre) > 50 mm, then

EfRain = 125 / 3 + 0.1 * MonPre (3)

***GWC* (mm) -** contribution from groundwater estimated empirically by Laktaev-Kharchenko formula.

Surf = Dep - Root difference between GWT and rooting zone in m

If Surf < 0.6 then

Surf = Dep difference between GWT and the soil surface in m

If Surf = 0, then
GWC = ETo
Otherwise

ex = Exp(Rb * (Surf))

GWC = Ra * ETo / ex (4)

where

Dep – groundwater table (m)

Root – depth of crop rooting zone at time of calculation (m)

Rb – soil texture related coefficient

Ra - soil texture related coefficient

The following OPERATIONS were conducted in each of projects:

5. GIS-PREPARATION OF PROCESSING OBJECTS

This implied identification of an irrigated part of PZ and its division by work matrix. Further all calculations were made for each cell of the work matrix limited by the irrigated contour of PZ. The screenshots of the results are shown in **APPENDICES 1** and **2**.

6. CALIBRATION OF ETo

Climatic data from the REMO model were derived by simulating greenhouse gas emissions that cause global warming. However, the model did not take into account local specifics of orography effect on meteorological parameters. Therefore there was a need to calibrate the REMO-derived data by using ground-truth data. To this end, we used the data of aeronautic meteorological stations (AMST) from **gis.ncdc.noaa.gov**. The calibration included the following steps.

- we selected such a time period, for which both REMO-derived data and AMST data were available. The selected period covered 1960 till 2014. Then ETo was calculated using REMO data for each object for the whole simulation period 1960 – 2050.

- ETo was calculated by using the Penman-Monteith formula and Blaney-Criddle method for each AMST for the period 1960 - 2014. AMST have no observations over solar radiation. In this context, solar radiation was estimated through coordinates of meteorological stations and a solar constant (FAO 56).

$$R_s = k_{RS} \sqrt{(T_{\max} - T_{\min})} * R_a \quad (5)$$

where

Rs – solar radiation (MJ m^{-2} day^{-1})

kRS –correction coefficient ($^oC^{-0.5}$)

Tmax - maximum air temperature (^oC)

Tmin - minimum air temperature (^oC)

Ra - extraterrestrial radiation (MJ m^{-2} day^{-1}) derived from Table 26 of the FAO publication 56.

Besides, airdrome conditions differ from crop field conditions; therefore, ETo values were reduced by 20% according to recommendations. However, the resulting ETo values were incorrectly contrast. The ETo values calculated by the Blaney-Criddle method were too smoothed. As a final result we took the average of these two methods.

- Five nearest aeronautical meteorological stations were chosen for each node of the REMO model.

- ETo values derived on the basis of these 5 respective stations' data were interpolated in each node of REMO. Interpolation was made by using the weighted average method, with the inverse distance between a node and meteorological stations as a weight.

$$ETo_{INT} = \frac{\sum_{i=1}^{5} (ETomst_i / R_i)}{\sum_{i=1}^{5} (1/R_i)} \quad (6)$$

where

ETo_{INT} - interpolated ETo value

$ETomst_i$ - ETo value calculated by using the i-station data

R_i - distance between the i-station and a REMO node

- Thus, for each REMO node and every ten-day period in the whole calibration period (1960 - 2014) we derived two ETo values: one directly from REMO data and another one as interpolation using meteorological stations' data. The calibration coefficients were determined from formula

$$Kk = ETomet \ / \ EToREMO \quad (7)$$

where

Kk – calibration coefficient

ETomet - ETo based on meteorological stations (mm day^{-1})

EToREMO – Eto calculated using REMO data (mm day^{-1})

- Then, ***Kk*** were averaged by years of the calibration period. As a result, for each REMO node we derived 36 (number of ten-days) calibration coefficients for correction of ETo for the period of forecast.

- Further, ETo values in REMO nodes were interpolated, based on calibration coefficients derived by the above mentioned method of weighted average for the whole period till 2050.

7. CALIBRATION OF RAINFALL

As mentioned earlier, for some reasons the rainfall data measured at aeronautical meteorological stations is not suitable for their use in calculation of crop water requirements. In this context, the rainfall data from **http://climateserv.nsstc.nasa.gov/** was used.
The moment when rainfall occurs is conditionally predictable among observed meteorological parameters. In autumn and winter, it is quite easy to predict accurately the place and time of rainfall because of stratus, whereas in spring and summer this is almost impossible since convective clouds dominating in this period of time depend on many local characteristics. Therefore, statistical methods are used for rainfall analysis and forecast; in particular, one considers large territories, ten-day and monthly rainfall, and moving average for a period.

The calibration of rainfall included the below steps:

- Conversion of rainfall from the ClimateServ to ten-day values.
- Smoothing ten-data rainfall by three points (ten-day) using the moving average method.
- Conversion of rainfall from the REMO model to ten-day values.
- Calculation of moving average based on ten-day REMO rainfall.
- Calculation of rainfall calibration coefficients based on smoothed rainfall values.
- Interpolation of rainfall from REMO nodes into grid cells by using the weighted average totaling method and the derived calibration coefficients. Effective rainfall was calculated as well.

8. CALIBRATION OF AVERAGE TEMPERATURE

In this Project, it is suggested to consider the impact of climate change on crop sowing dates and crop development phases. Ultimately, crop water requirements depend on those things. The major parameter is the temperature as the technique used for determination of sowing dates and

development phases is built on the total of effective temperatures needed for plant in each development phase.
Because decisions on sowing of crops are made within the boundaries of PZ, this entails the average temperature for PZ.

- Air temperatures from REMO (average daily) are averaged for ten-day period and then smoothed by the moving average method.
- Similar procedure is applied for air temperatures from AMST.
- The smoothed temperature values from meteorological stations are interpolated into REMO nodes by using the weighted average totaling method as described above.
- The temperature calibration coefficients are calculated by the weighted average temperature from meteorological stations and the smoothed temperature values in REMO nodes.
- Temperature values in REMO nodes are interpolated into the centers of grid cells by using the weighted average method and the derived calibration coefficients.
- The resulting temperature values are averaged by all grid cells for each ten-day period.

9. SOIL DATA

9.1. Research objective

Objective: Preparing the soil data for calculation of crop water requirements in the Amudarya Basin.

9.2. Research tasks and their execution:

The below work was done over the reporting period:

1. Collected materials on the soil cover of Amudarya basin, including middle and lower reaches.
2. Digitized soil map of the Uzbek part of the basin on a scale 1:500 000.
3. Analyzed data on soil texture.
4. Generated map of soil texture for the Uzbek part of the basin.
5. Digitized soil cover of the Turkmen part of the basin (lower and middle reaches) on a scale 1:1 000 000.
6. Prepared data on soil texture according to FAO classification.

9.3. Research objects

The Amudarya basin is the subject of this research. It is located in extremely arid zone within the boundaries of former Soviet republics, such as Uzbekistan, Tajikistan, most of Turkmenistan, and partially Afghanistan. The major part of the basin irrigated area is located in Uzbekistan (Fig.1).

Fig. 1. Map of Amudarya River basin

The territory of the basin can be divided into three morphological zones: mountains, deserts and oasis plains. The peaks of the Pamirs and the Tien Shan are more than 7,000 m above sea level. Annual precipitation is between 800 and 1,600 mm. The annual precipitation in the lower reaches - the Kara Kum desert, which covers most of the area of the basin - is only 100 mm. Moisture deficit as the difference between measured precipitation and evapotranspiration in the ancient oasis and submontane plateau is between 600 and 800 mm; in desert and steppe zone is between 1,400 and 1,600 mm. Geographically and geomorphologically the basin is divided into upper, middle, and lower reaches. In the upper reaches covering mainly the Tajik part the irrigated area is minor; thus, the focus is given to middle and lower reaches, where the following planning zones are located: Akhal 1, Akhal 2, Bukhara, Dashoguz, Upper Kafirnigan, Lower Kafirnigan, Khorezm, Karakalpakstan, Karshi, Kashkadarya, Lebap 1, Lebap 2, Lebap 3, Mary, Pyandj, Surkhandarya, and Vakhsh.

Multiple research efforts undertaken by Russian and Soviet scientists were dedicated to soil processes taking place in Amudarya Basin.

9.4. Research method

The research method is collecting information and making description of soil-climatic conditions in the Amudarya basin.

Soil maps were digitized and presented in GIS formats with attribute tables, including explanation of soil maps.

Based on the collected information, the highlighted soil contours were characterized in terms of texture. Taking into account that Kachinskiy's classification of soil texture applied in the Soviet soil school differs from FAO classification used in modeling crop water requirements, an expert analysis of the data and conversion from one classification into another one were done.

We considered:

- Soil in middle reaches
- Soil in lower reaches
- Soil in Amudarya prodelta

- Soil in the Uzbek part of the basin

The analysis of soil cover for the Uzbek part of the basin was made on the basis of the soil map of Uzbekistan. Since the map provides comprehensive information, the assessment of soil texture was made by expertise, using the soil legend.

9.5. Research results

To assess the relevance of two different soil classifications, one needs to have the analysis of soil texture and quantity of fractions of different size in order to convert from one system into another one. We have done this work before as part of the WUFMAS Project, where specific soil profiles were cut for research purposes throughout the Central Asia. Similar work was also undertaken under the IWRM Project in the Fergana Valley. Those results and other research outcomes allowed us to make a soil texture classification table (Table 1). In addition, description of soil genetic characteristics was also used in this work. As a result of expert assessment, GIS maps of granulometric composition and attribute tables for them were produced (Figures 2-9).

The results of granulometric composition assessment were mapped and paper maps were digitized. All these materials were prepared for modeling of crop water requirements by the REQWAT 2 model.

Table 1

Available water content and infiltration rate for different soil textures in Central Asia

Class by soil texture (USDA)		AWC (1) mm/m	Infiltration rate (2) mm/day
Z	Silt	160	144
ZL	Silt loam	160	192
ZC	Silt clay	170	48
ZCL	Silt clay loam	160	120
L	Loam	155	240
SL	Sandy loam	145	480
LS	Loamy sand	100	720
fS	Fine sand	80	960
cS	Coarse sand	60	2400
gS	Gravel sand	40	4800
SCL	Sandy clay loam	190	240
CL	Clay loam	180	192
C	Clay	210	12

Source: (1) WUFMAS Report 1997 and (2) Booker Tropical Soils Manual 1991

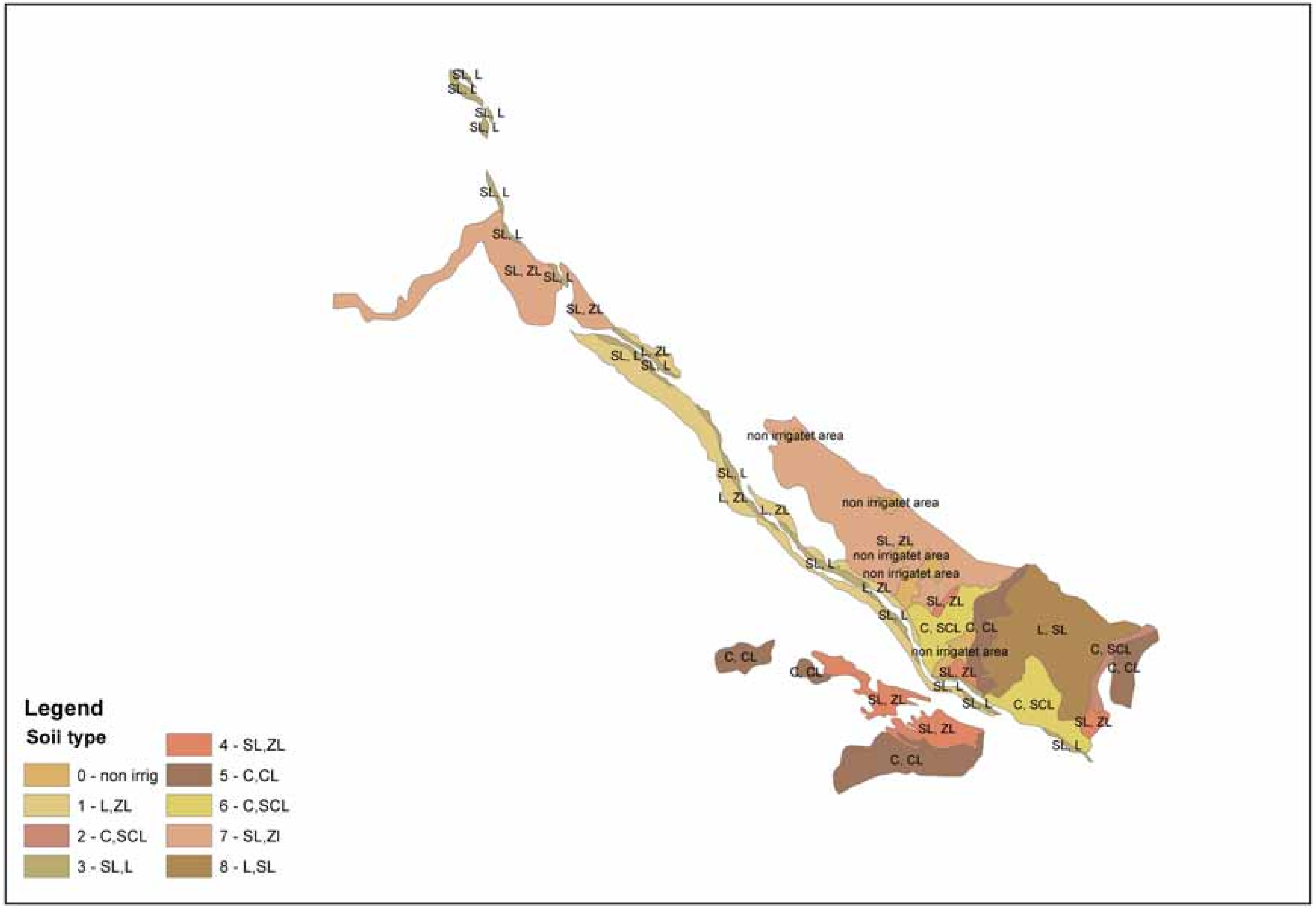


Fig. 2. Map of soil granulometric composition, Amudarya middle reaches

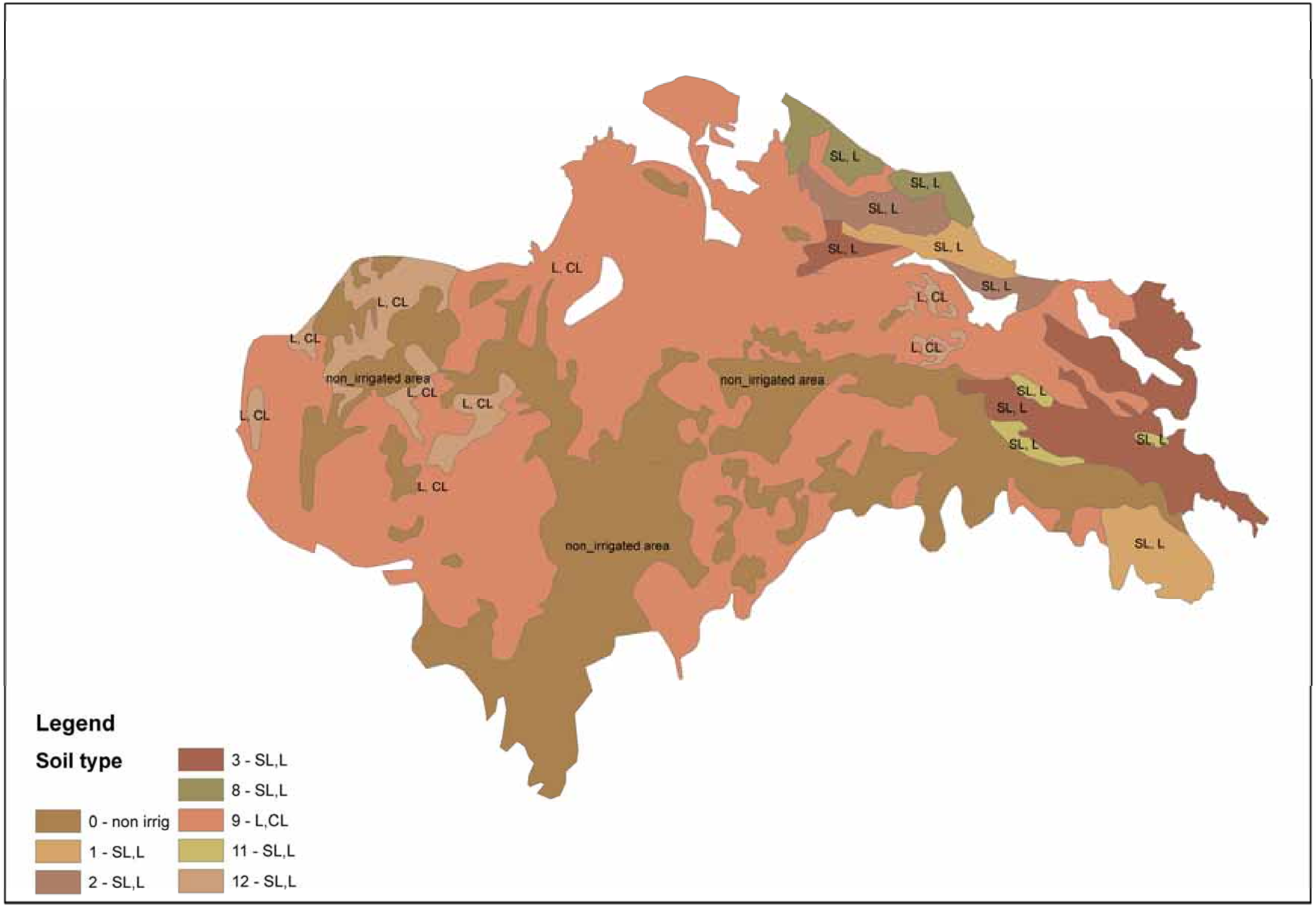


Fig. 3. Map of soil granulometric composition, Amudarya lower reaches

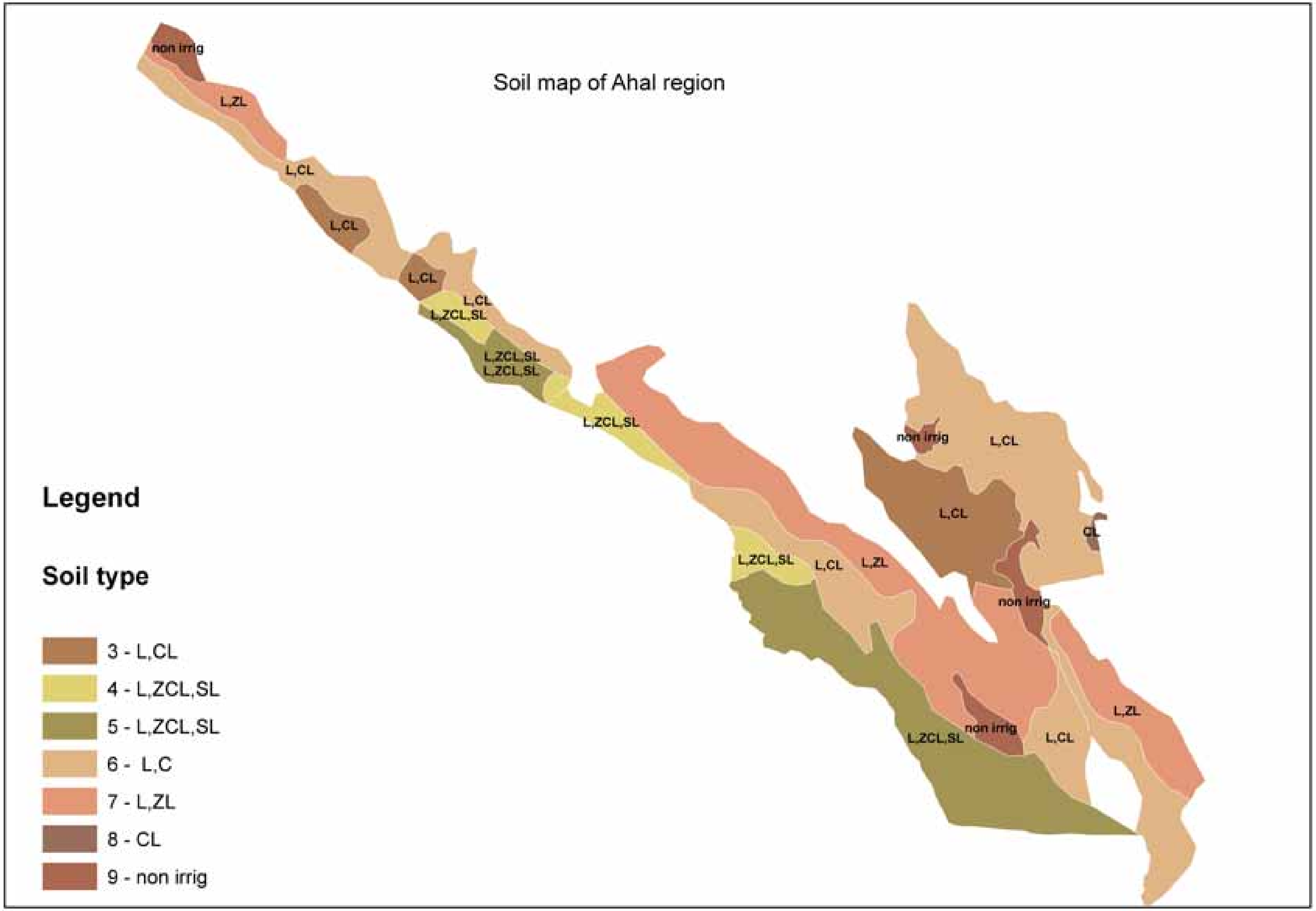


Fig. 4. Map of soil granulometric composition, Amudarya prodelta (Akhal)

Fig. 5. Map of soil granulometric composition, Amudarya prodelta (Mary)

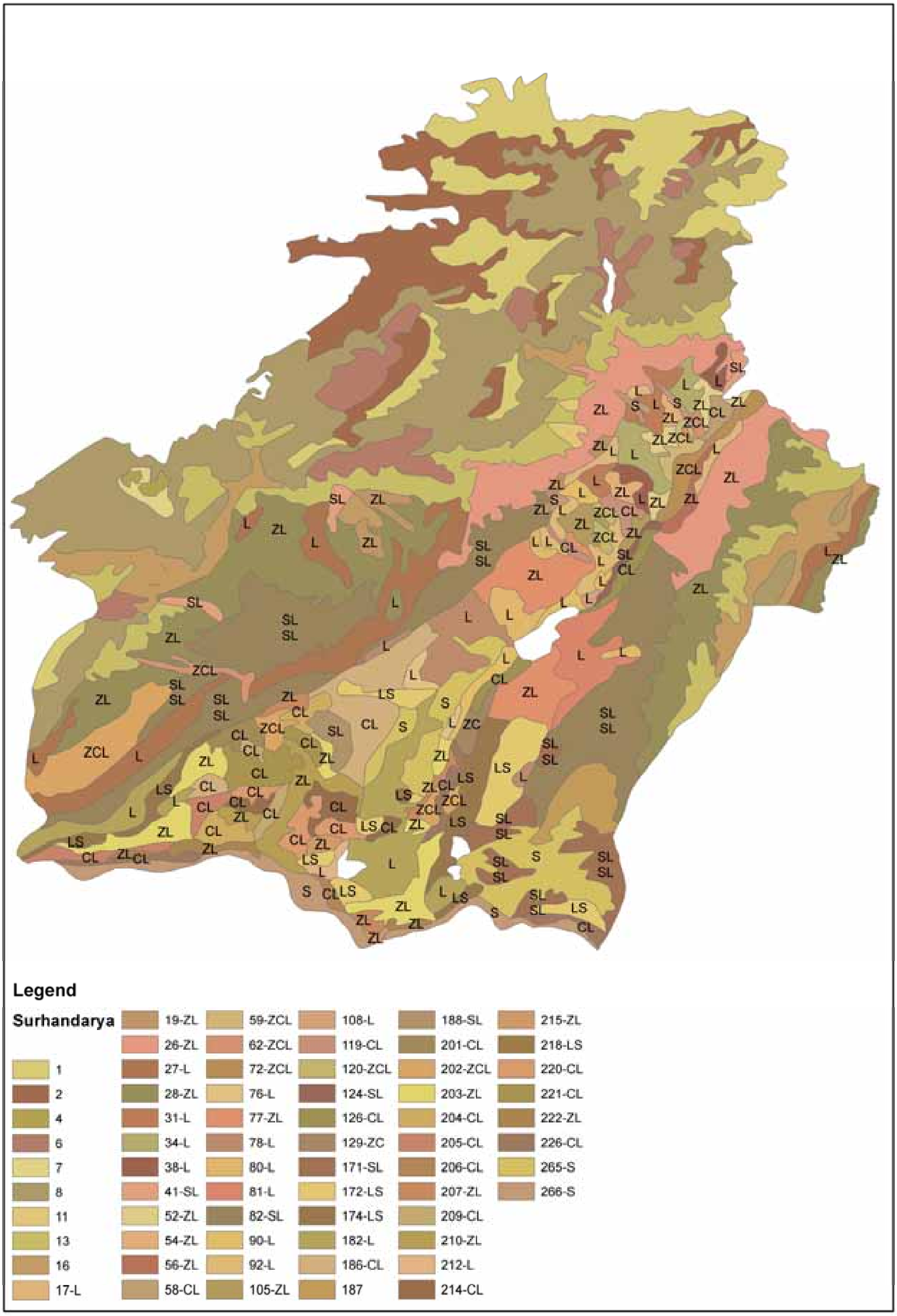


Fig. 6. Map of soil granulometric composition, Surkhandarya planning zone 10

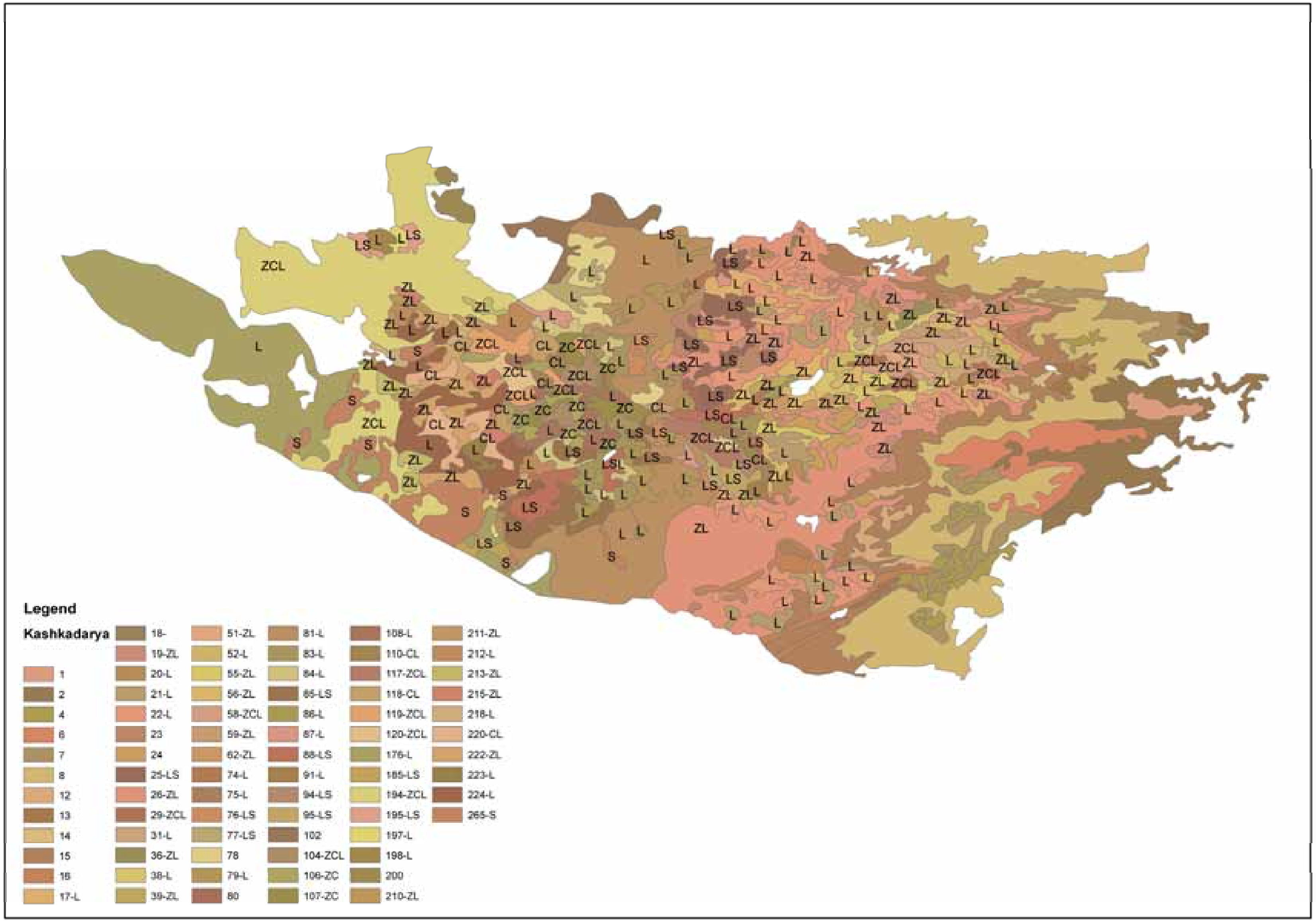


Fig. 7. Map of soil granulometric composition, Kashkadarya planning zone

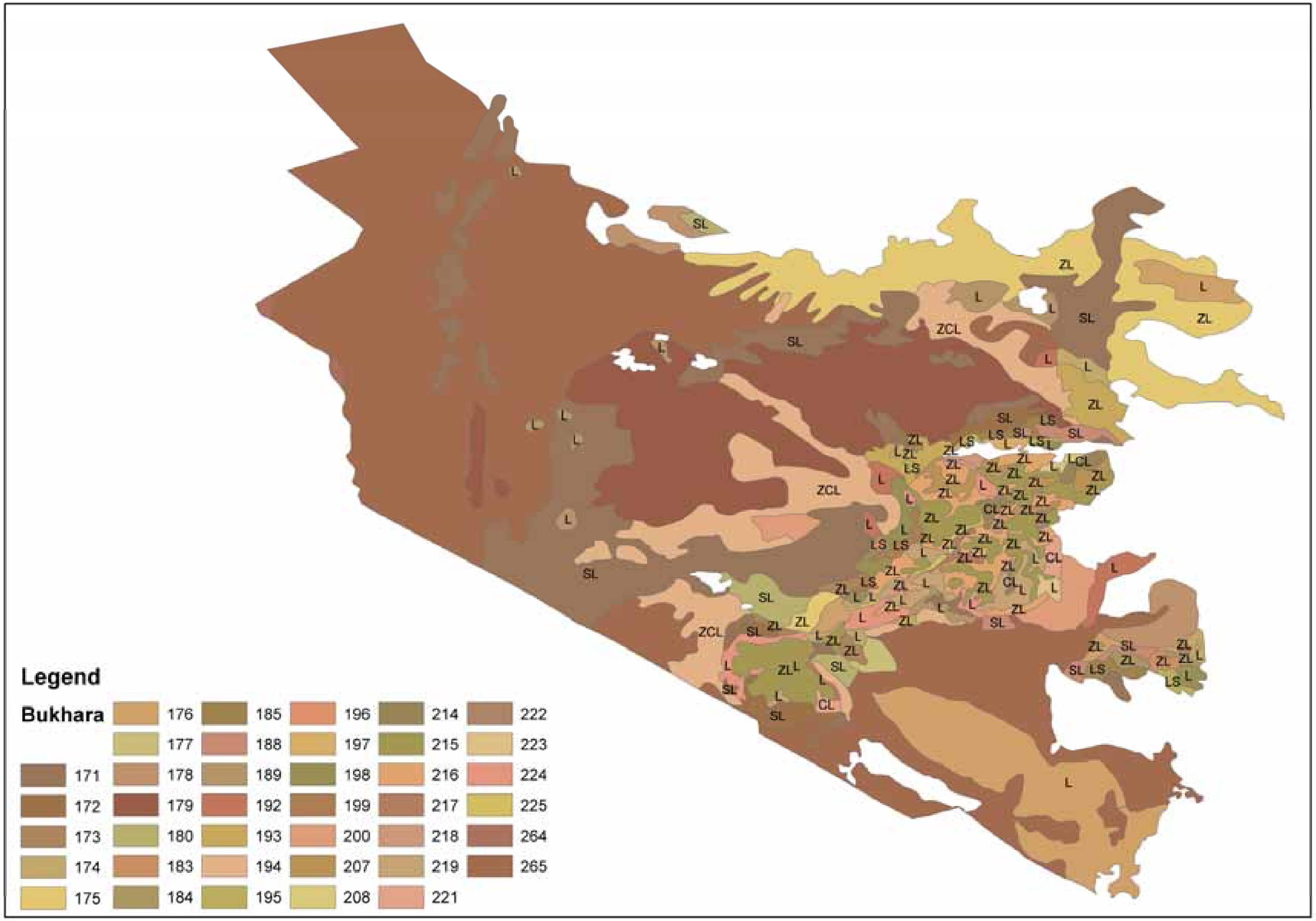


Fig. 8. Map of soil granulometric composition, Bukhara planning zone

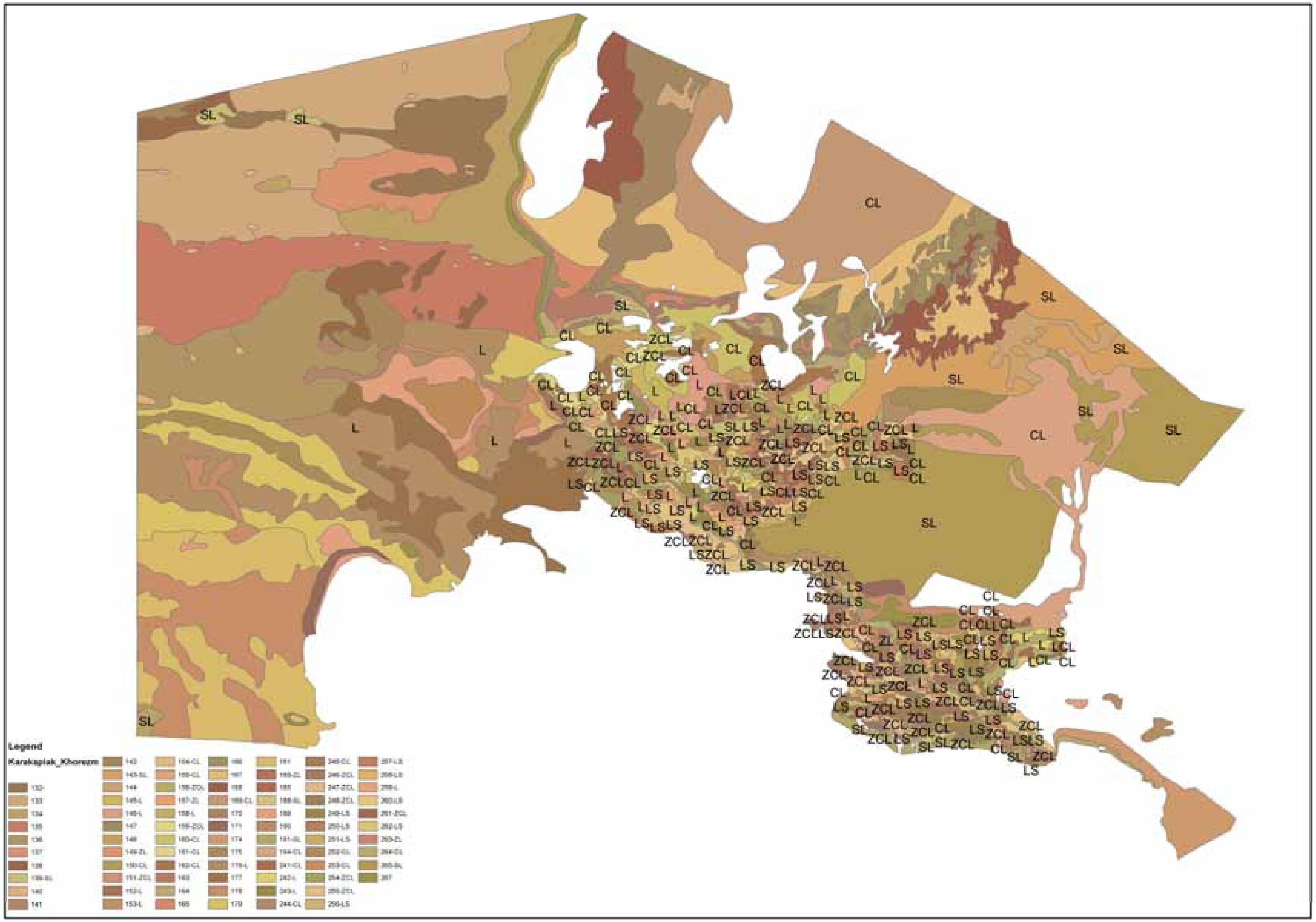


Fig. 9. Map of soil granulometric composition, Khorezm planning zone

10. DISTRIBUTION OF TEN-DAY GWT VALUES BY UZBEK PZs

Since GWT of planning zones in Uzbekistan is given as ten-day average values for districts, distribution of GWT by cells was done using GIS-methods (MapWinGis).

11. BREAKDOWN OF GRID CELLS BY THE SOIL MAP OF UZBEKISTAN. DETERMINATION OF COEFFICIENTS IN KHARCHENKO FORMULA. CALCULATION OF GROUNDWATER CONTRIBUTION

Similar breakdown of grid cells was done by the soil map.
As a result of those two operations, each grid cell is broken down into 1-4 parts with a unique GWT value and soil type (according to FAO classification). The coefficients in Kharchenko formula, **a** and **b**, are chosen depending on the soil type. Rooting depth is estimated for each crop by the time, when groundwater contribution is estimated. Further the actual groundwater contribution is calculated.

12. ESTIMATION OF INITIAL TOTAL EFFECTIVE TEMPERATURE FOR ALL PROJECT CROPS

Climate change was accounted in crop water requirements through the demand of crops for heat. Specifically, each plant needs a certain total effective temperature to complete its each development phase. Effective temperature is determined as the difference between the average daily temperature and the temperature at the beginning of growing season. We estimated total effective temperature for 25 crops considered by the Project.
The crop data was taken from reference books and on-line sources. All the data is arranged in a table, a fragment of which is shown in **APPENDIX 1**.

13. ALGORITHM FOR RECALCULATION OF SOWING DATES AND CROP DEVELOPMENT PHASES IN LIGHT OF CLIMATE CHANGE

First, we determine the point of time when the average daily air temperature is higher or equal to the crop sowing temperature during four days on end. Then, the total effective temperature for the first phase is estimated, and further for the following phases. The calculation was made for each year from the time span 2000 - 2050 for every project crop, excluding wheat and alfalfa. The total effective temperature was counted for alfalfa for each cut. As to wheat, the period of time when the temperature is lower than 5 degrees was excluded from consideration. In case of double-season crops, we eliminated the first phase of rice as planting of rice with seedlings is assumed and the last phase of maize for silage since maize is harvested as ears reach their milky ripeness.

14. LIST OF CROPS UNDER CONSIDERATION

For calculation of crop water requirements, the following crops were selected:

1. Cotton
2. Winter wheat
3. Rice
4. Maize for corn
5. Vegetables: potato, tomato, roots, legumes, cucurbits
6. Fruits: orchards and grape
7. Forage: maize for silage and alfalfa
8. Other: oil crops, sugar beet
9. Homestead plots
10. Legumes as double-season crops
11. Vegetables as double-season crops
12. Maize for silage
13. Rice as double-season crop
14. Beet as double-season crop
15. Potato as double-season crop
16. Cucurbits as double-season crop

Crop water requirements were calculated for each crop; then, crops were divided into groups of vegetables, orchard crops, forage, other crops and double-season crops. The percentage area covered by each crop in a group was taken on the basis of the data for Khorezm PZ.

15. CROP GROUPING

Statistical reporting in Uzbekistan emphasizes major crops (cotton, winter wheat, maize for corn, and rice) and the following crop groups (Table 2):

1. **Vegetables** – legumes, tomato, potato, melon, water melon, pumpkin.
2. **Fruits and berries** - grape, orchards.
3. **Forage** - alfalfa, maize for silage.
4. **Other** – sunflower, sugar beet, soybean.
5. **Double-season** – The double-season crops include those that ripen in the period of time from harvesting of wheat till the end of growing season. Given the conditions of our region, these crops include legumes, potato, sugar beet, cucurbits, maize for silage (harvested as ears reach their milky ripeness), and rice (planted with seedlings).

Since any double-season crops can be planted and their acreage is arbitrary, in this work we took the distribution of area under crops as in the Khorezm planning zone:

Table 2

Crops broken down into groups

№№	Crop	Area, thousand ha	%
1	**Vegetables**		
	Peanut	0	0.00
	Legumes	5.956	22.76
	Tomato	8.936	34.14
	Potato	5.18	19.79
	Melon	3.66	13.98
	Water melon	0.61	2.33
	Pumpkin	1.83	6.99
2	**Orchards and grape**		
	Table grape	2.32	17.03
	Orchards	11.3	82.97
3	**Forage**		
	Alfalfa	2.84	40.00
	Maize for silage	4.26	60.00
4	**Other**		
	Sunflower	5.9	45.00
	Sugar beet	2.6	20.00
	Soybean	4.59	35.00

The algorithm is developed in such a way that if any crop from the above groups is missing, it automatically recalculates the percentage share of other crops in a group, with the total percentage of 100 in each group. For example, soybean was not planted in the group "Other". Then, the percentage share of sunflower increases as 100/65 = 1.538, i.e. will be equal to 69.24 %. Accordingly, the sugar beet percentage will increase to 30.76 %.

16. REVIEW OF RESULTS

The results of calculation of crop water requirements with the use of the REMO model output allow stating that generally biological water requirements of crops will decrease slightly. In addition, the sowing dates will move back closer to the beginning of year.

Since upland rice virtually is not planted in Central Asia, rice water requirements were calculated with account of rice check flooding practices. This substantially increased rice water requirements.

Algorithm for calculation of rice water requirements

Rice growing involves applying water for flooding of checks to certain water depth and keeping of water at fixed level in the checks. Water losses in a check include evaporation (counted in rice evapotranspiration) and filtration into the soil. In general, water balance in a rice check is as follows:

$$dW = GL - ETo*Kc - Filt + Rain \qquad (8)$$

where
dW – quantity of water to be applied to a check to keep **GL** level
GL – a fixed water level in a check which needs to be kept for given period of time
ETo – reference evapotranspiration
Kc – crop (rice) coefficient average for given period of time
Filt – filtration for given period of time
Rain – rainfall for given period of time

Filtration, **Filt,** is calculated by Darcy law:

$$Filt = Kf*(dH / l) \qquad (9)$$

where
Filt – filtration losses
Kf – coefficient of filtration
dH – water level in a check
l – groundwater table

There are two opposite vertical water fluxes in the soil: filtration and capillary rise. Measured coefficient of filtration accounts the both fluxes; therefore, capillary rise does not appear in the check's water balance formula.

CONCLUSION

Thus, all available materials were prepared for calculation of crop water requirements. Calculations for planning zones (PZ) in Uzbekistan were made with account of groundwater contribution, and the same will be done for PZs in Turkmenistan. Calculations for Tajik PZs will be made without consideration of groundwater contribution, except the cases where necessary information, i.e. soil maps and GWT will be available.
The calculation results for Uzbek PZs are stored in the Project database.

APPENDICES

APPENDIX 1

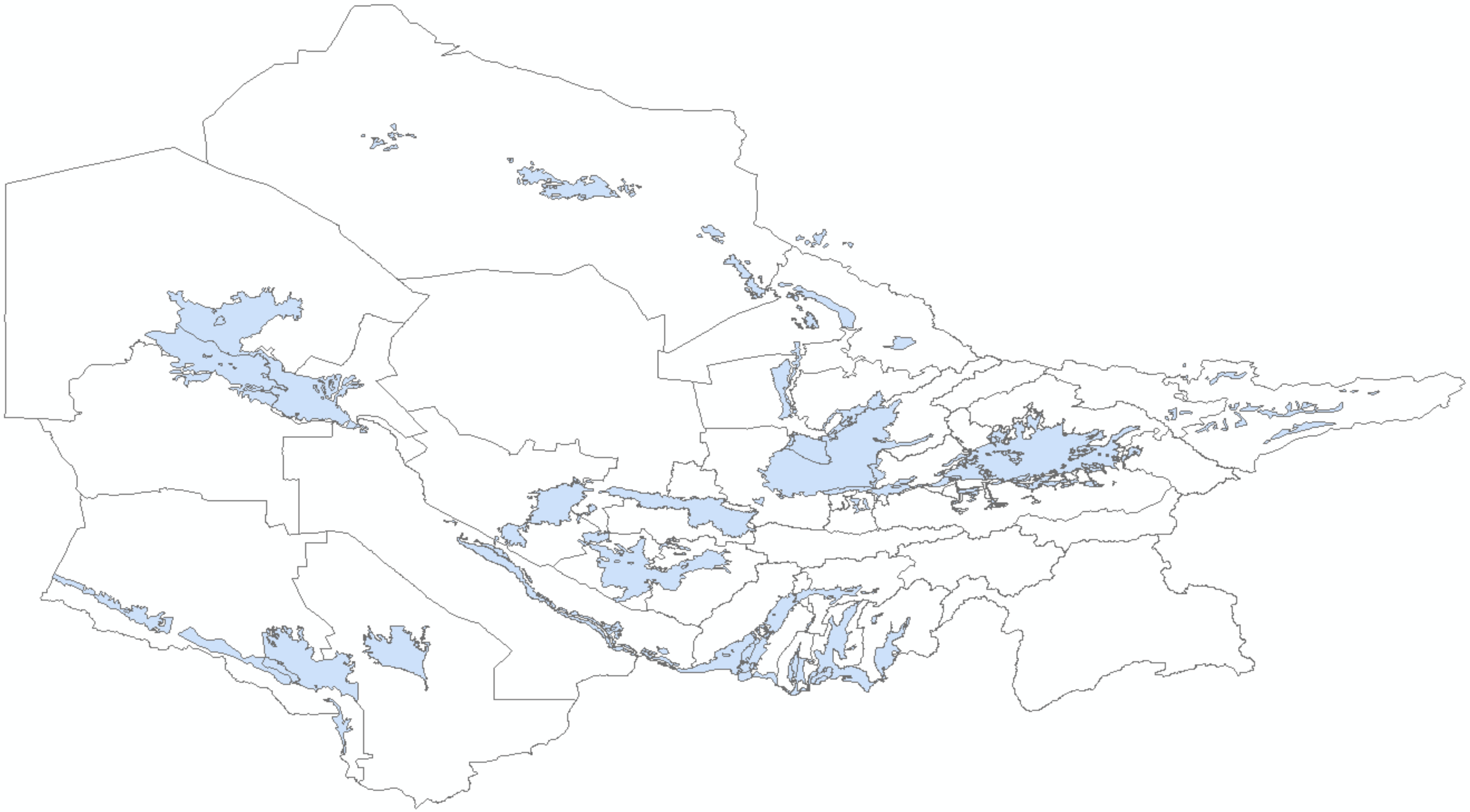
Total effective temperature by crop development phase

CropID	2	T sowing	T growing season	TET initial	TET development	TET yield formation	TET ripening	TET harvesting
1	Peanut	12.00	12	81.17	295.99	621.56	389.07	0
4	Legumes	12.00	12	29.48	199.03	463.92	306.29	0
7	Table grape	10.00	10	134.03	723.47	698.27	916.35	0
9	Cabbage	10.00	10	6.01	196.64	268.11	204.29	0
10	Potato	10.00	10	97.14	279.93	645.36	533.34	0
11	Maize for corn	10.00	10	64.43	312.65	562.27	527.26	0
13	Alfalfa	5.00	8	350.00	350.00	350.00	350.00	350
15	Small vegetables	9.00	10	110.49	246.65	414.51	251.05	0
16	Carrot	10.00	10	64.43	370.54	945.89	344.56	0
18	Sunflower	10.00	10	37.96	280.83	620.56	441.51	0
20	Winter wheat	5.00	5	0.00	0.00	82.95	178.35	0
22	Sugar beet	10.00	10	134.03	498.38	1467.89	172.71	0
24	Melon	15.00	15	95.30	227.80	595.27	335.47	0
25	Sweet pepper	10.00	10	134.03	428.93	639.44	353.37	0
26	Sorghum	10.00	10	64.43	312.65	645.36	533.34	0
28	Soybean	10.00	10	64.43	254.36	883.61	439.81	0
30	Pumpkin	13.00	13	97.20	295.89	309.68	222.25	0
31	Tomato	12.00	12	147.59	408.58	755.26	414.38	0
32	Water melon	15.00	15	71.03	205.55	322.63	381.53	0
36	Early cotton	10.00	10	85.00	420.00	450.00	730.00	0
37	Average cotton	10.00	10	100.00	460.00	500.00	880.00	0
38	Late cotton	10.00	10	100.00	500.00	550.00	1060.00	0
39	Maize for silage	10.00	10	97.14	337.83	587.46	17.83	0

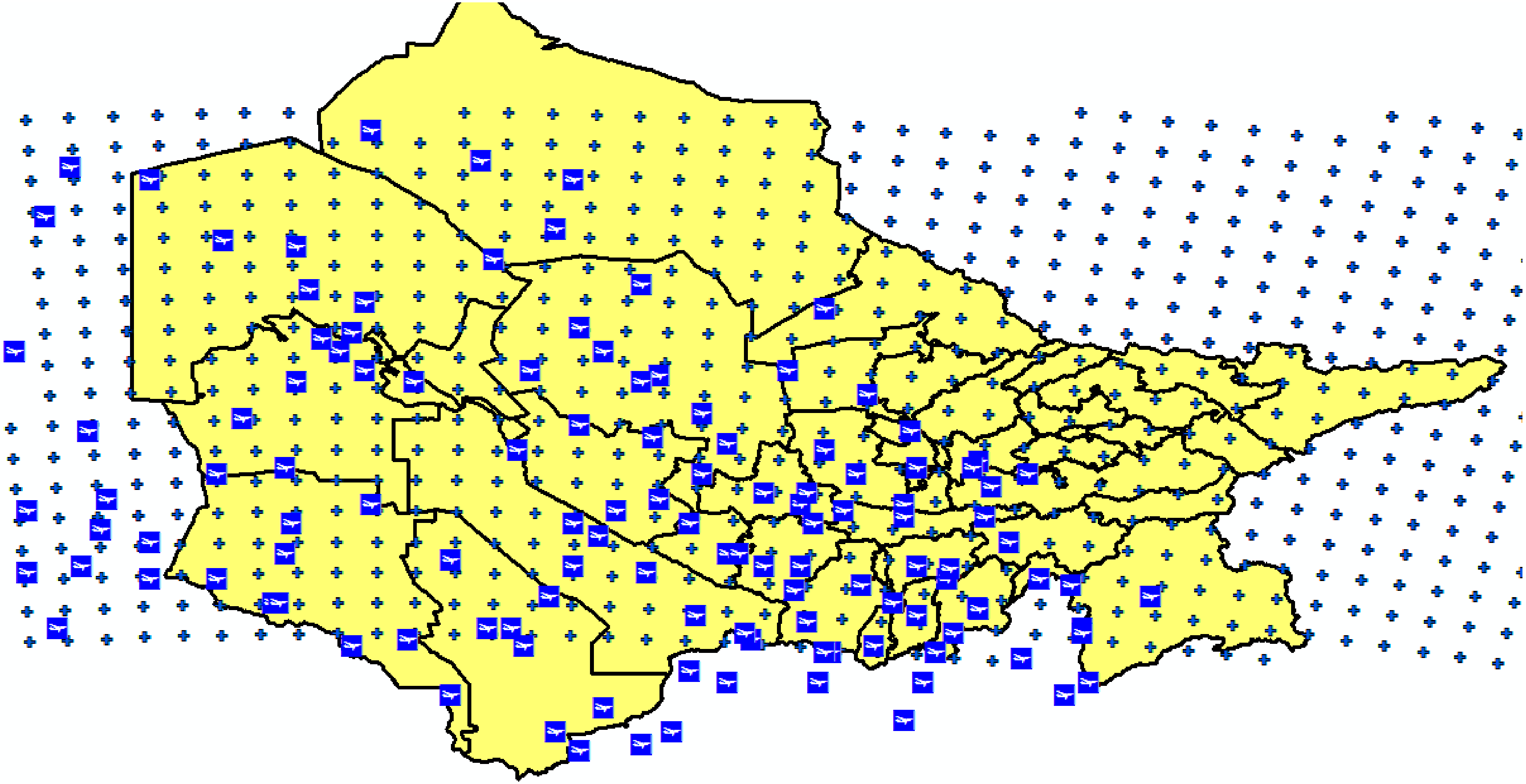
CropID	2	T sowing	T growing season	TET initial	TET development	TET yield formation	TET ripening	TET harvesting
40	Rice	15.00	10	270.00	620.00	640.00	250.00	0
41	Early rice	10.00	10	210.00	480.00	400.00	210.00	0
42	Late rice	10.00	10	350.00	770.00	920.00	280.00	0
51	Orchards	5.00	8	52.14	250.00	800.00	1500.00	0
53	Bushes	5.00	10	2709.65	743.64	269.45	441.98	0
204	Legumes – double season	10.00	10	322.70	199.03	463.92	306.29	0
210	Potato – double season	10.00	10	97.14	279.93	645.36	533.34	0
222	Beet – double season	10.00	10	134.03	498.38	1467.89	172.71	0
224	Cucurbits – double season	10.00	10	95.30	227.80	595.27	335.47	0
231	Vegetables – double season	10.00	10	147.59	408.58	755.26	414.38	0
239	Maize for silage – double season	10.00	10	97.14	337.83	587.46	0.00	0
240	Rice – double season	10.00	10	1.00	620.00	640.00	250.00	0
1000	Homestead plots	12.00	12	0.35	0.20	0.16	0.23	0

APPENDIX 2

CENTRAL ASIA IRRIGATED LAND



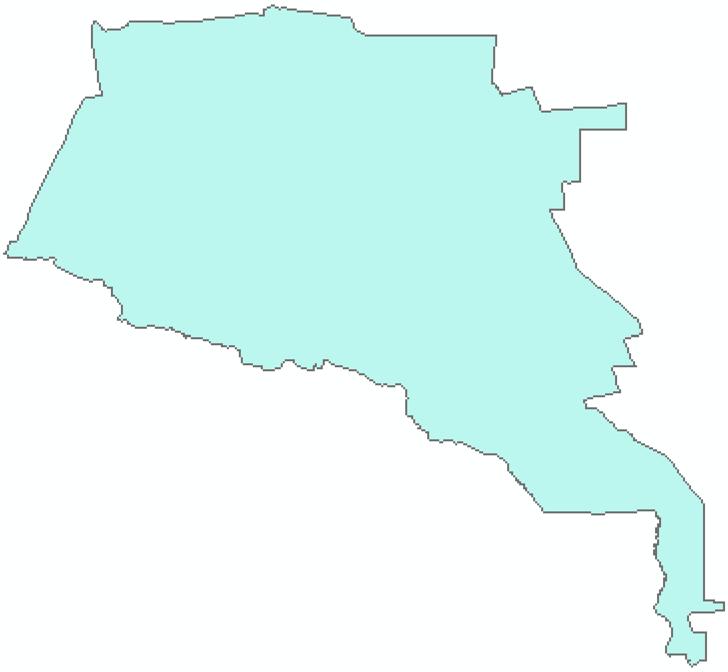
- Irrigated agriculture zones Uncolored contours – planning zones



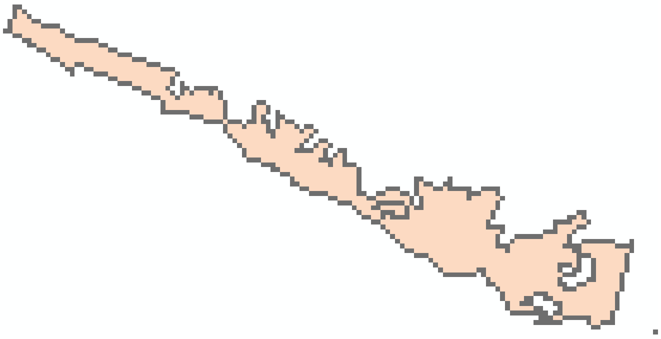
- REMO model nodes
- aeronautical meteorological stations
- planning zone contours

APPENDIX 4

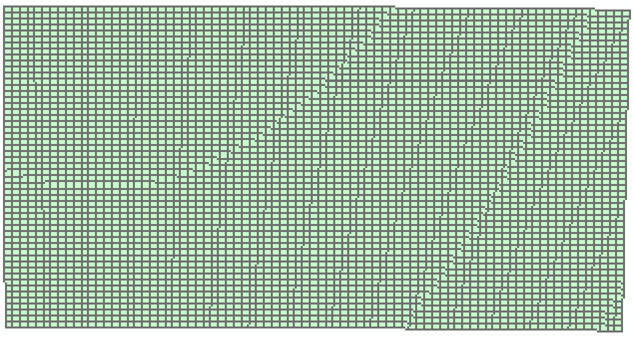
AKHAL-1



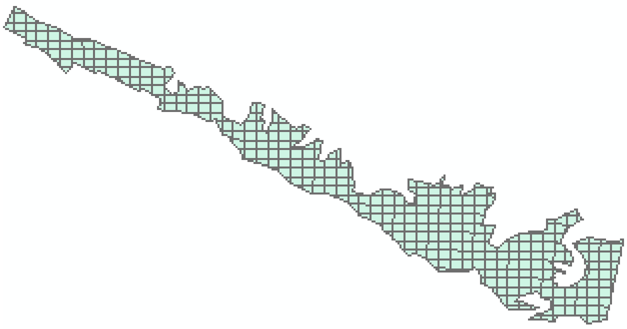
Akhal PZ



Irrigated area of PZ-1



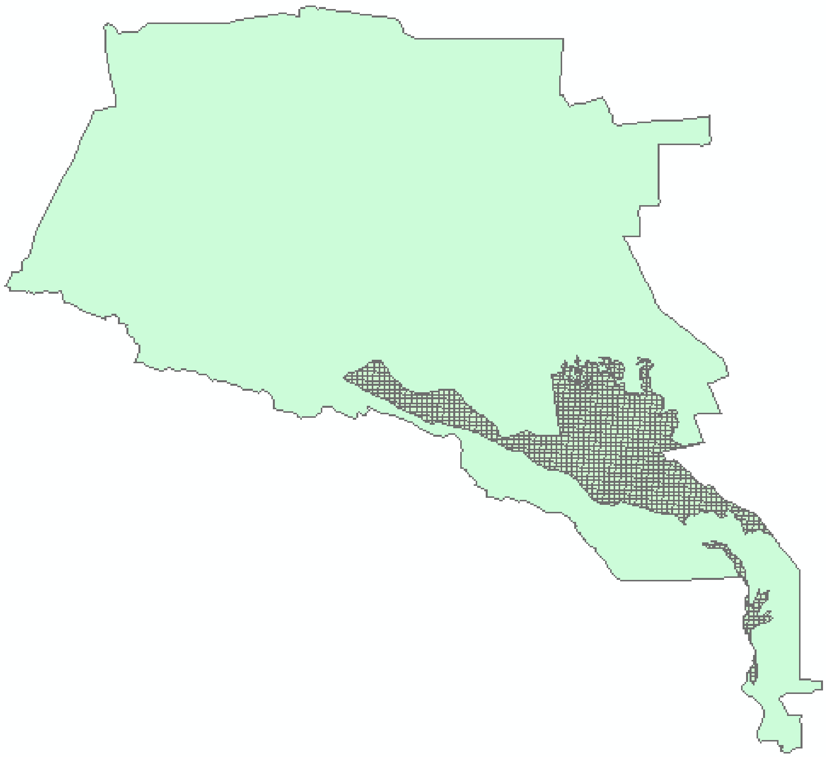
Work matrix of PZ



Irrigated area of PZ divided by the work matrix

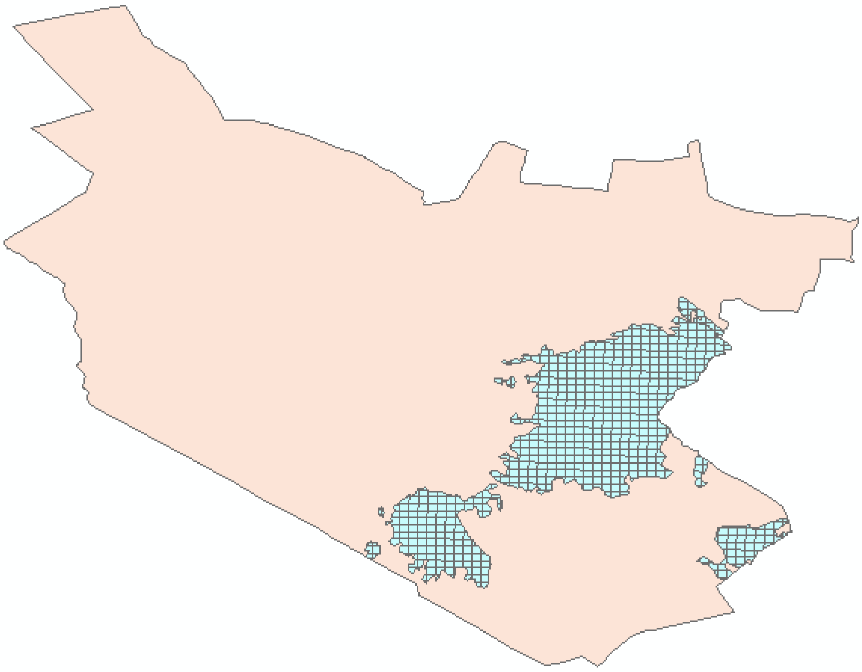
APPENDIX 5

AKHAL-2



Irrigated area of PZ divided by work matrix

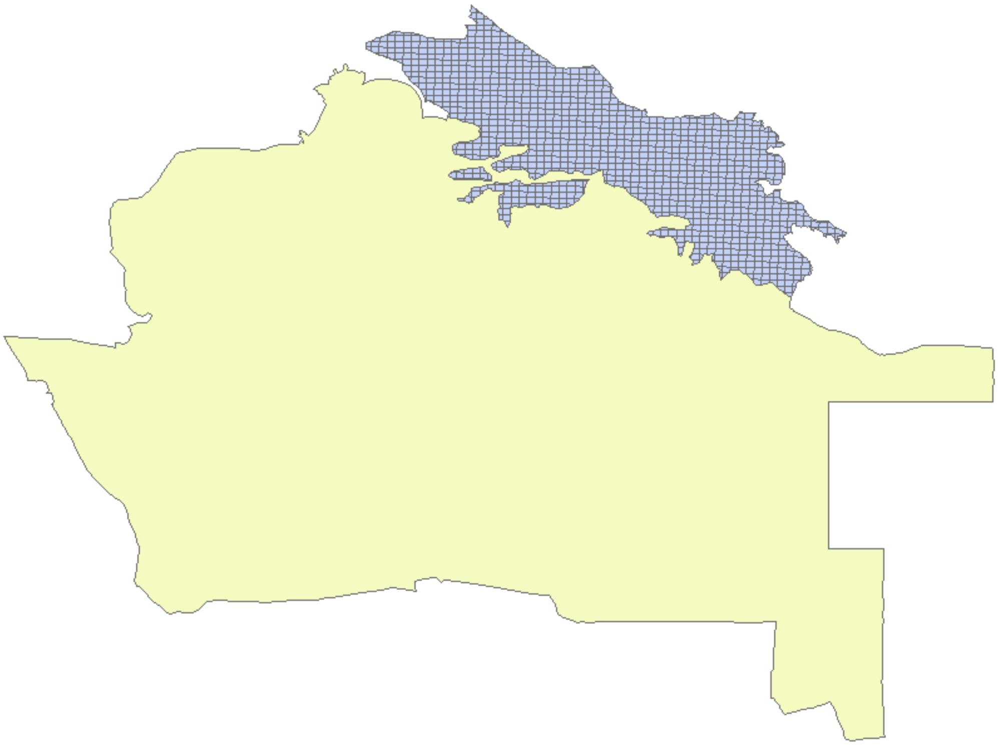
BUKHARA



Irrigated area of PZ divided by the work matrix

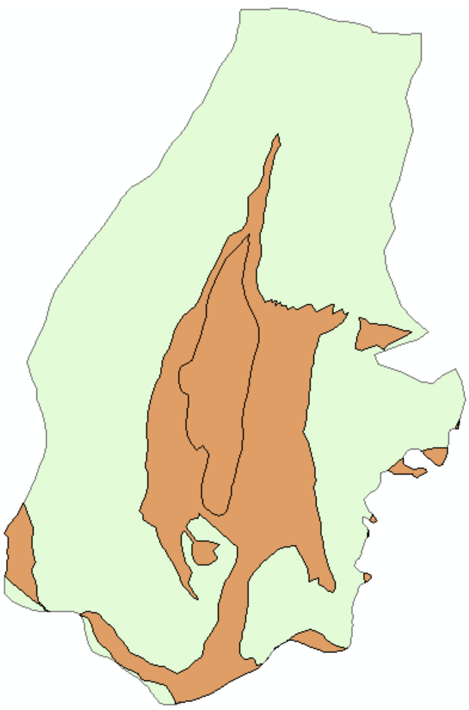
APPENDIX 6

DASHOGUZ



Irrigated area of PZ divided by the work matrix

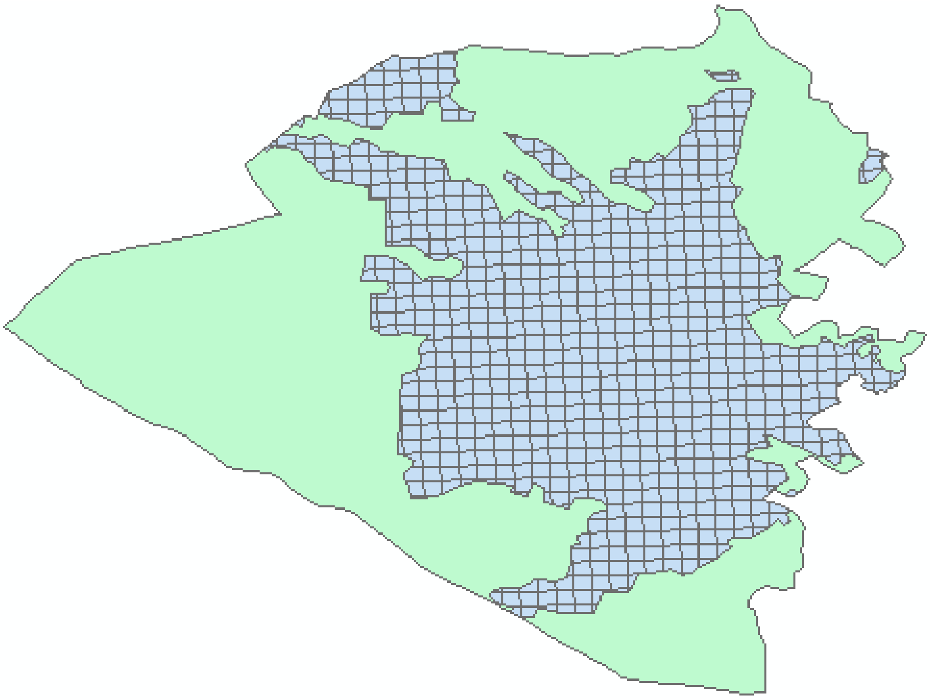
LOWER KAFIRNIGAN



Irrigated area of PZ divided by the work matrix

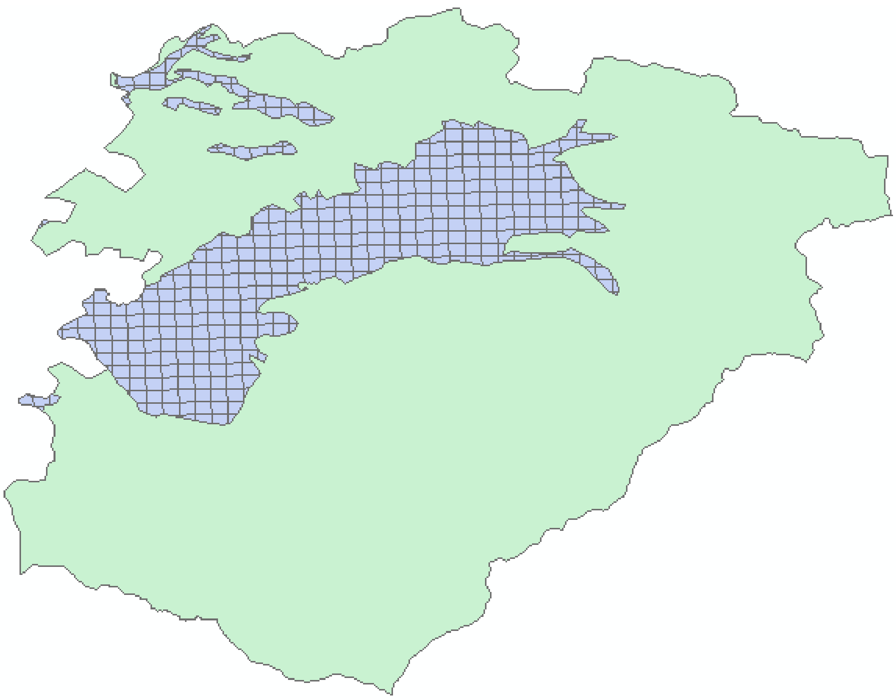
APPENDIX 7

KARSHI



Irrigated area of PZ divided by the work matrix

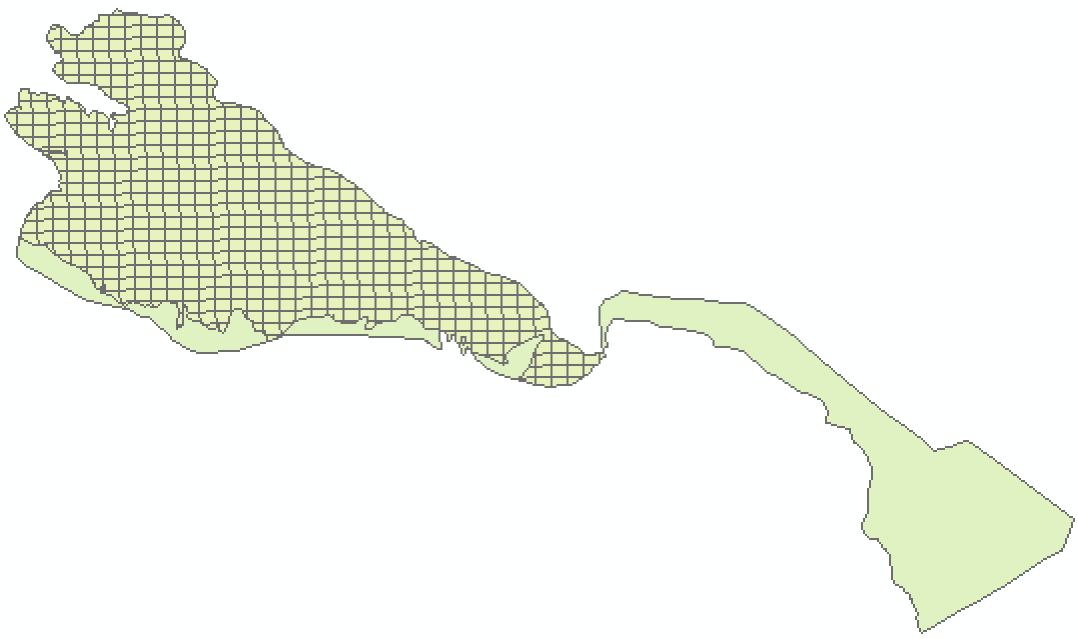
KASHKADARYA



Irrigated area of PZ divided by the work matrix

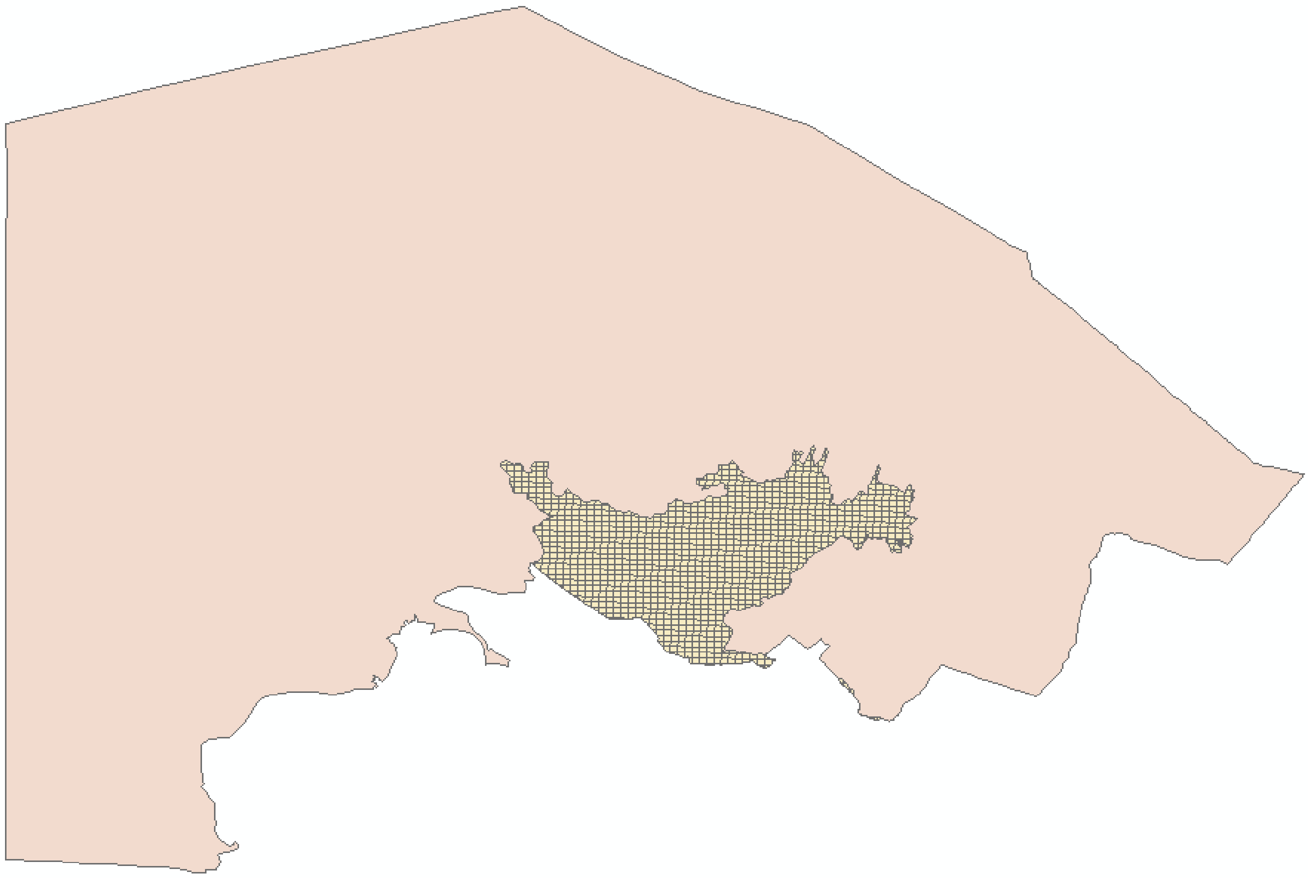
APPENDIX 8

KHOREZM



Irrigated area of PZ divided by the work matrix

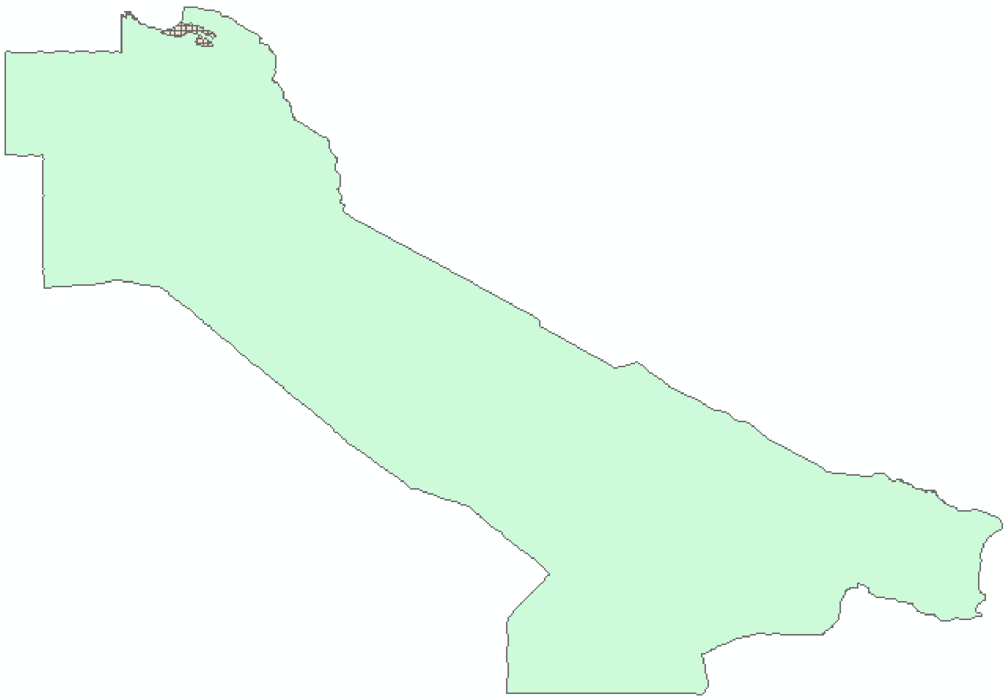
KARAKALPAKSTAN



Irrigated area of PZ divided by the work matrix

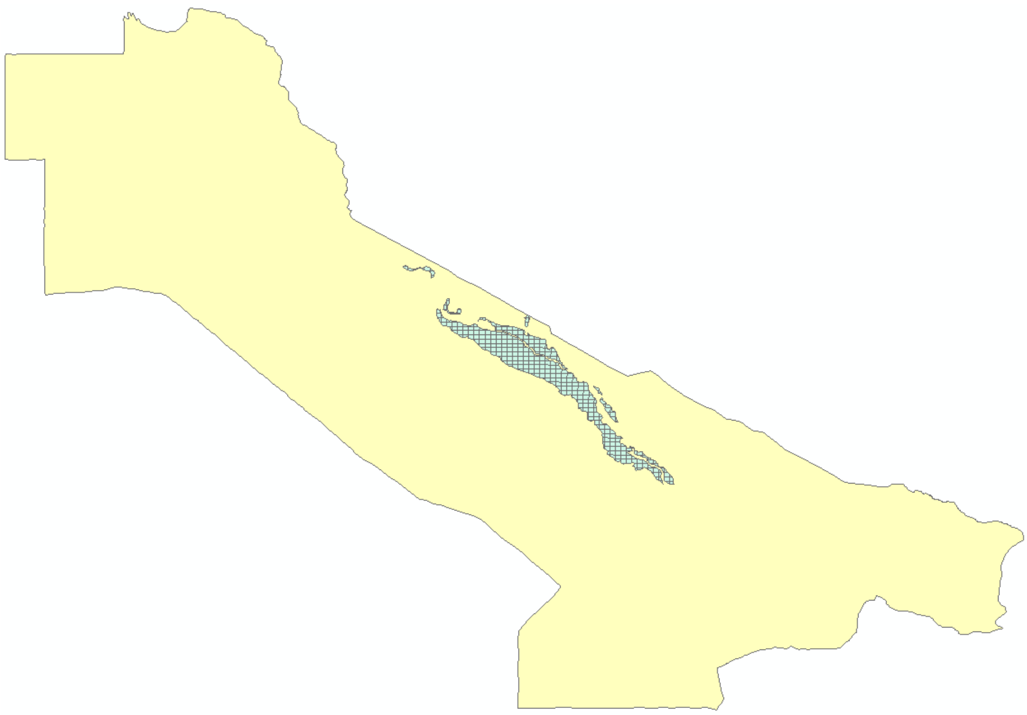
APPENDIX 9

LEBAP-1



Irrigated area of PZ divided by the work matrix

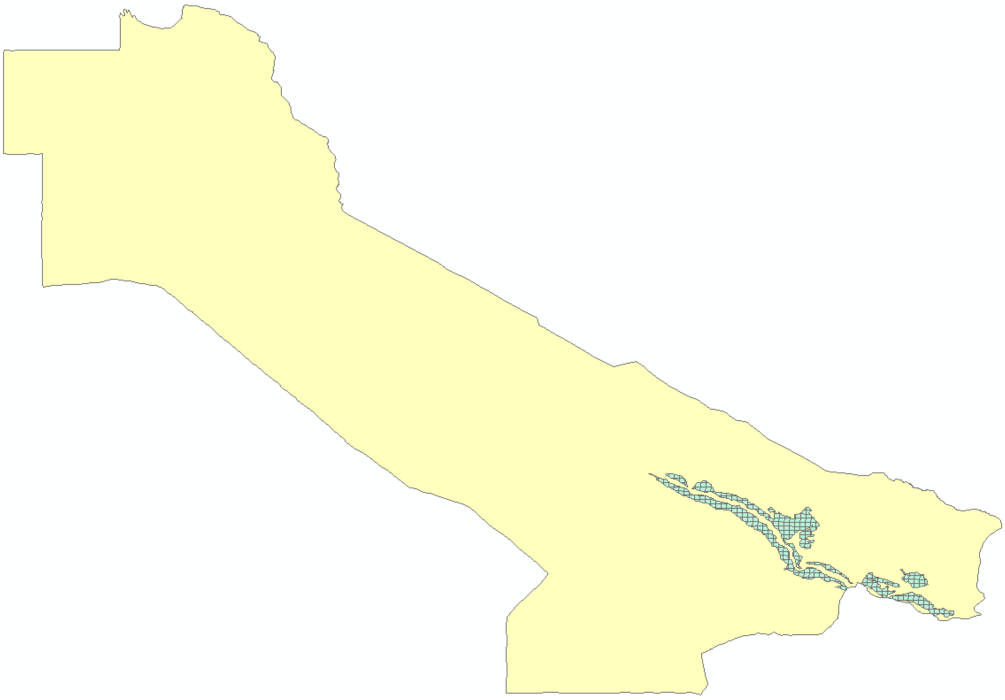
LEBAP-2



Irrigated area of PZ divided by the work matrix

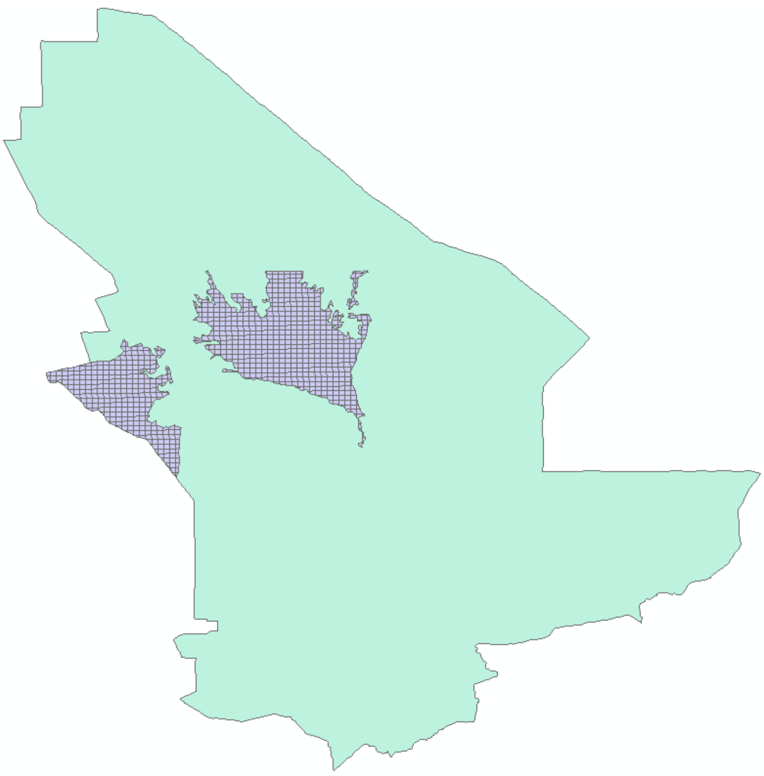
APPENDIX 10

LEBAP-3



Irrigated area of PZ divided by the work matrix

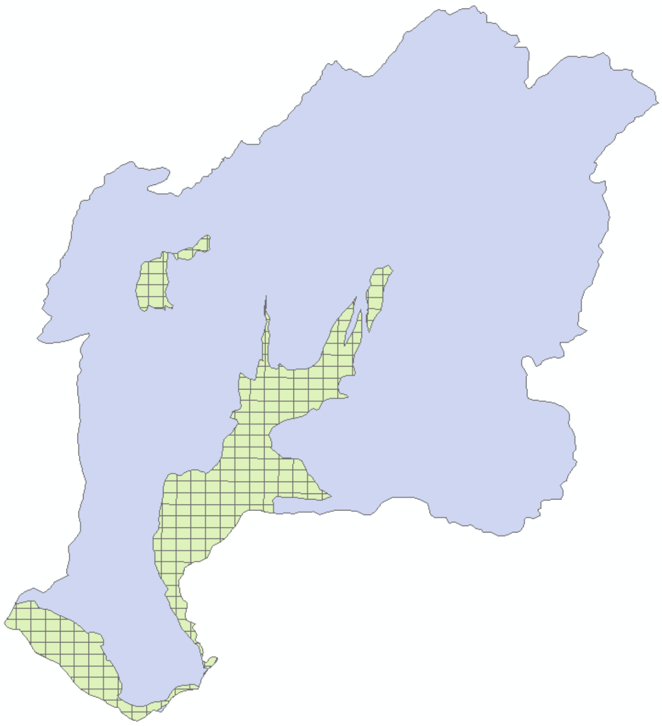
MARY



Irrigated area of PZ divided by the work matrix

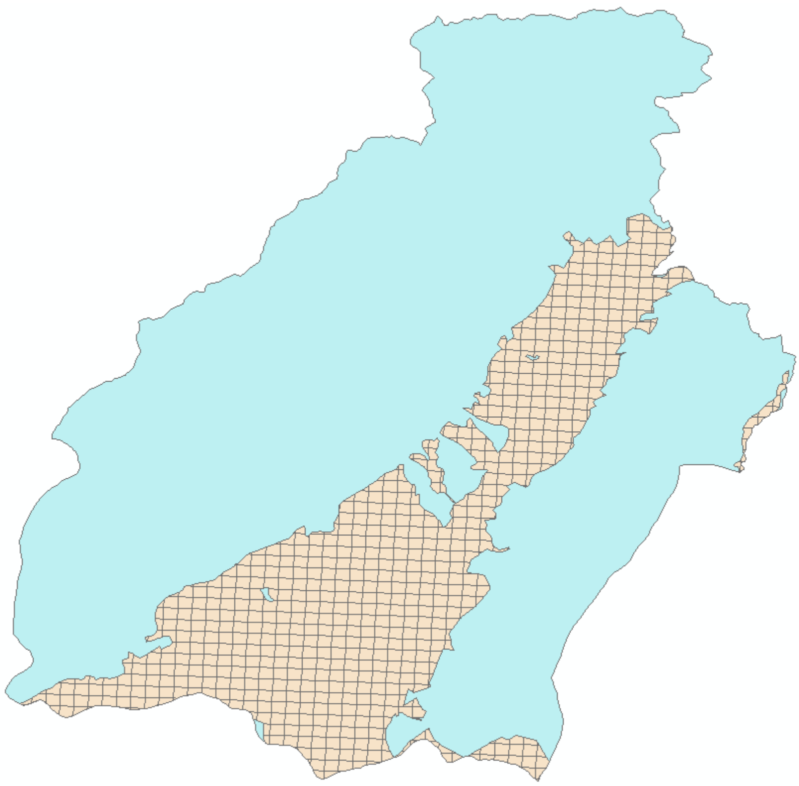
APPENDIX 11

PYANDJ



Irrigated area of PZ divided by the work matrix

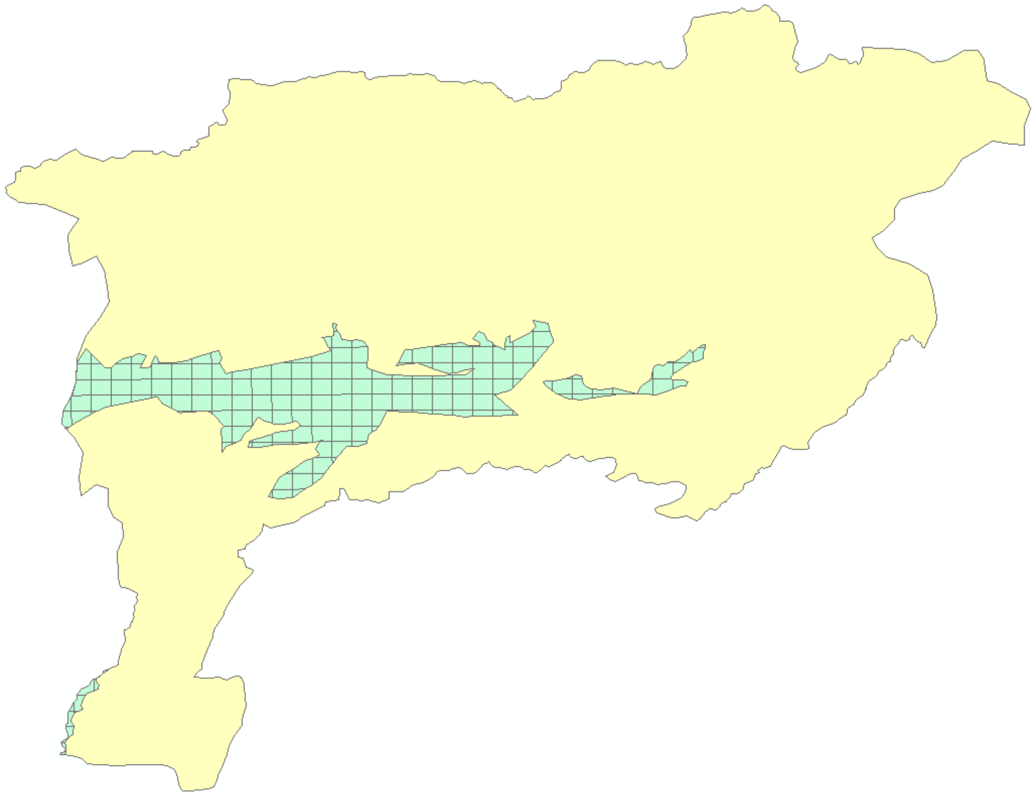
SURKHANDARYA



Irrigated area of PZ divided by the work matrix

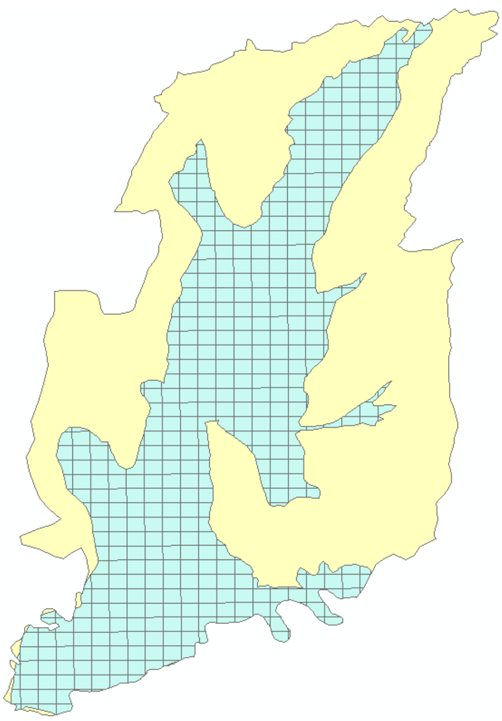
APPENDIX 12

UPPER KAFIRNIGAN



Irrigated area of PZ divided by the work matrix

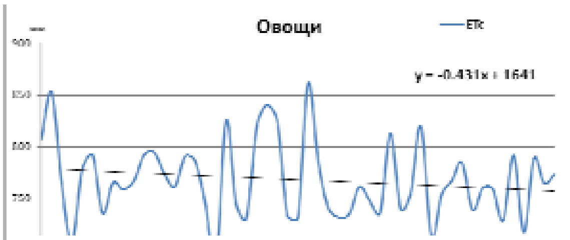
VAKHSH

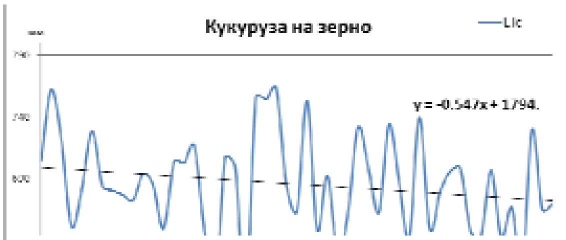


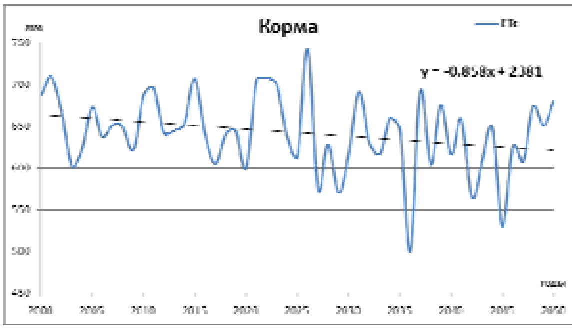
Irrigated area of PZ divided by the work matrix

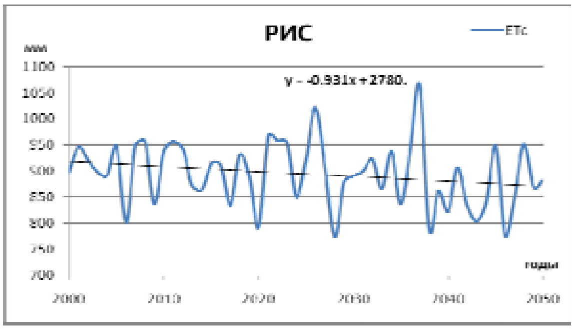
APPENDIX 13

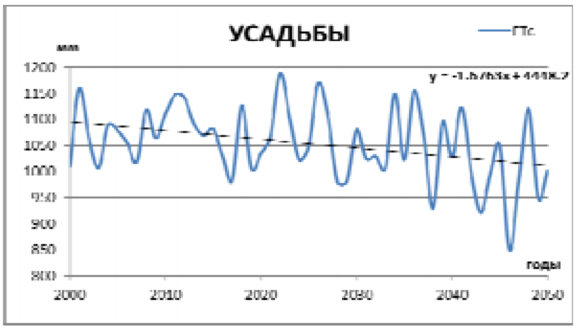
KHOREZM PZ   Dynamics of crop irrigation depth, mm





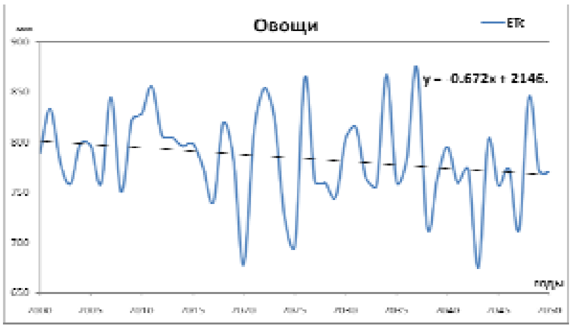


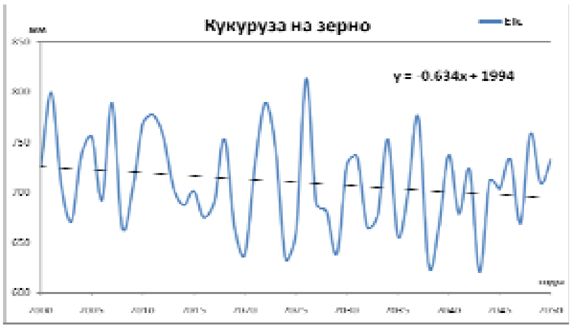


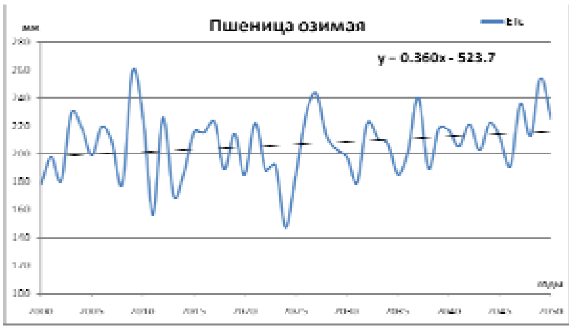


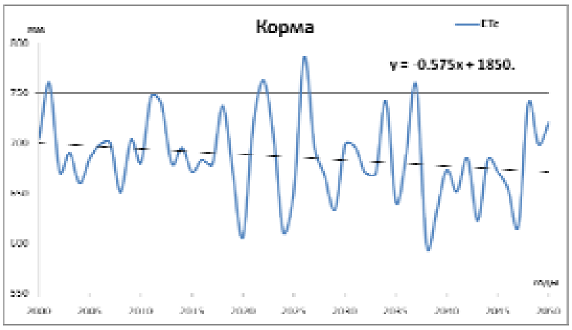
APPENDIX 14

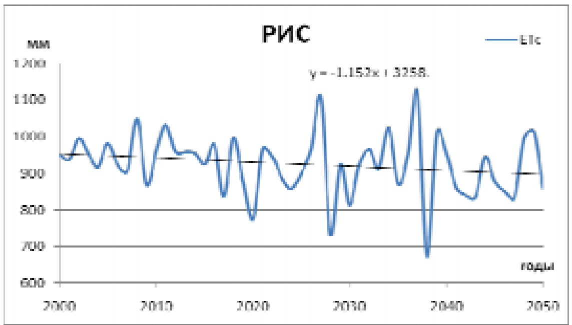
BUKHARA PZ   Dynamics of crop irrigation depth, mm

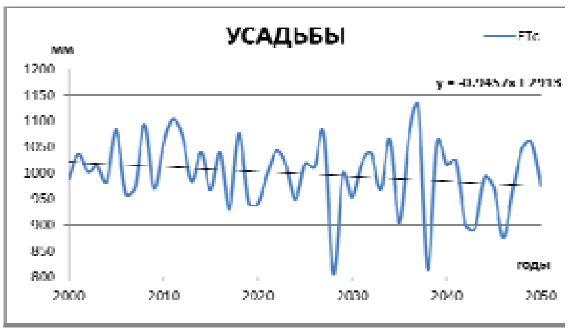






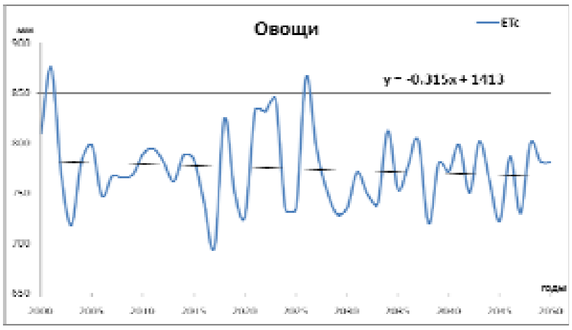


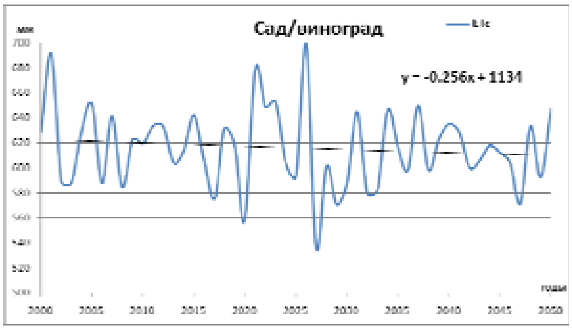


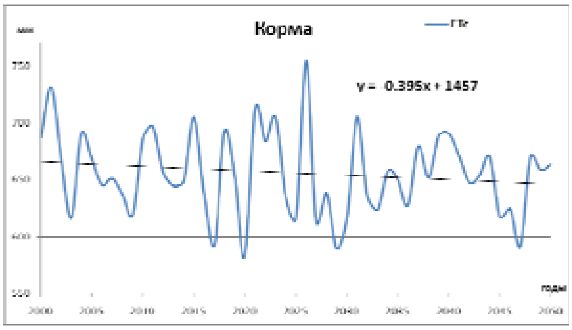


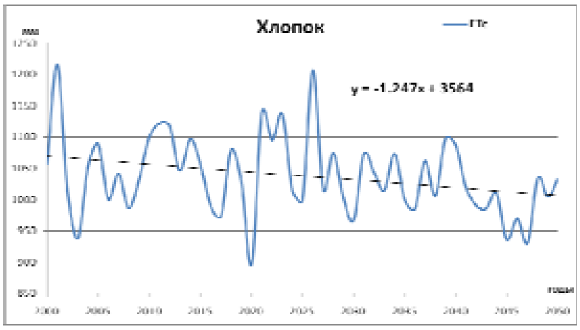
APPENDIX 15

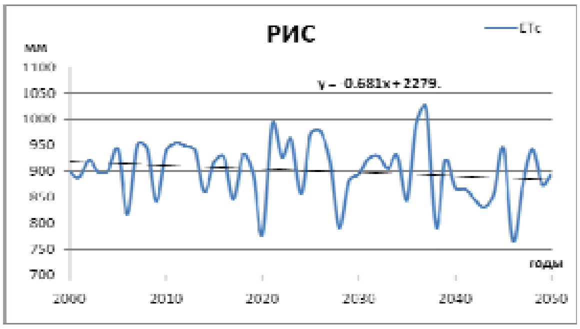
NORTH KARAKALPAKSTAN PZ Dynamics of crop irrigation depth, mm

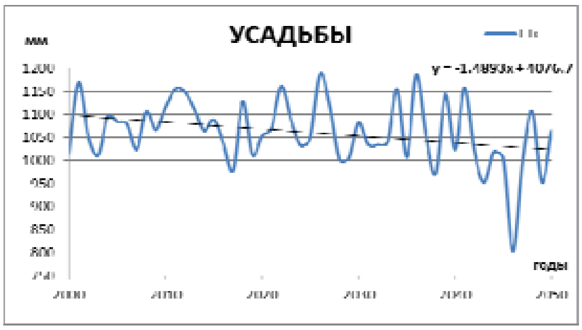






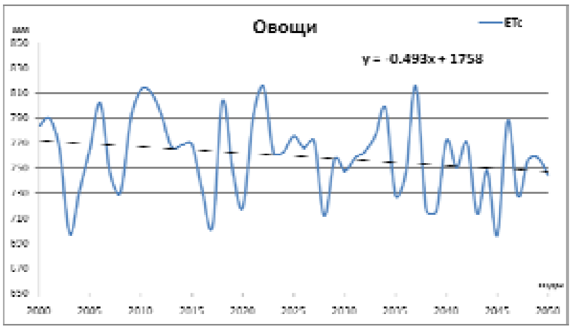


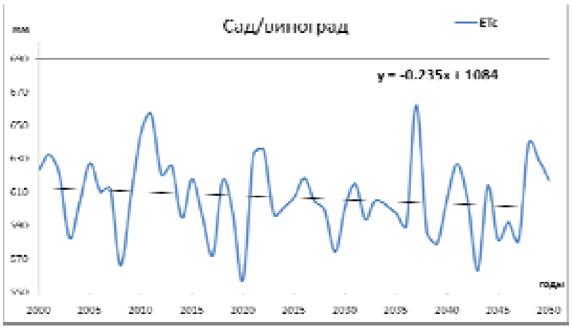


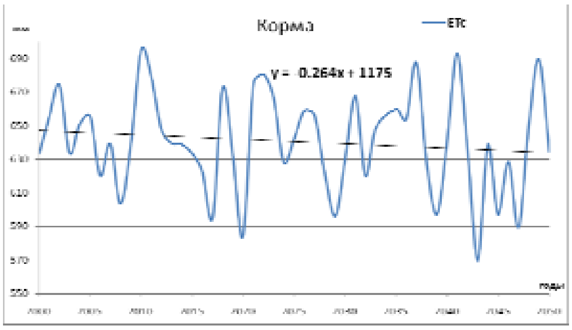


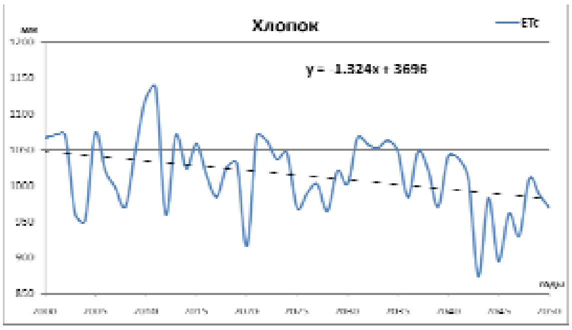
APPENDIX 16

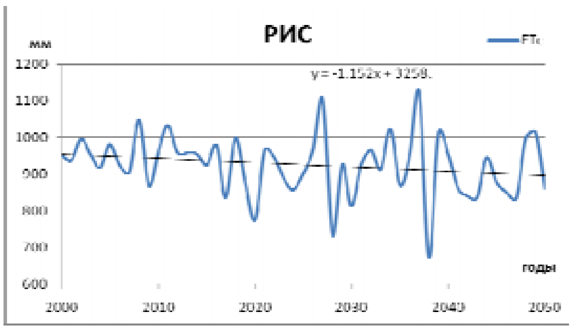
KARSHI PZ Dynamics of crop irrigation depth, mm

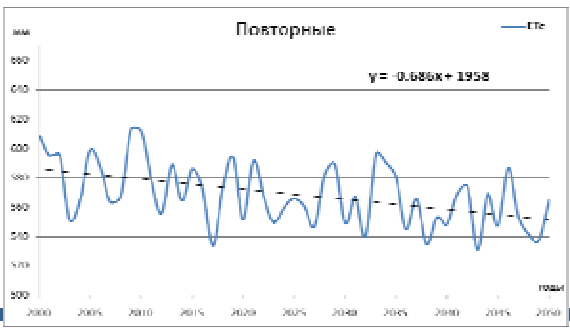


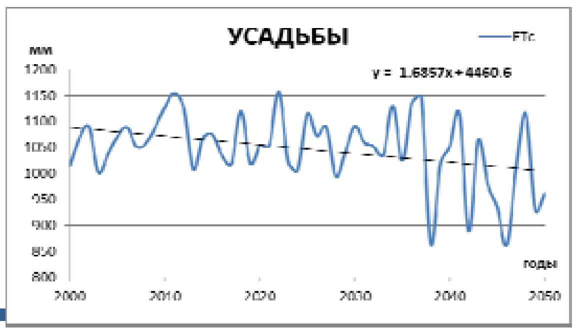








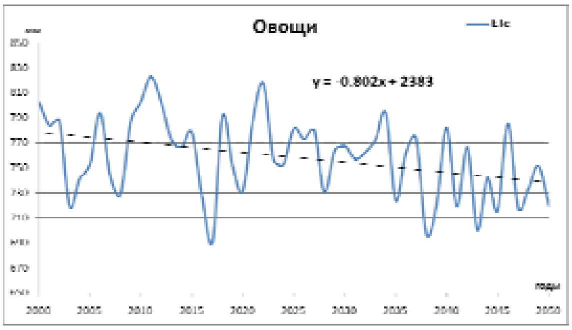


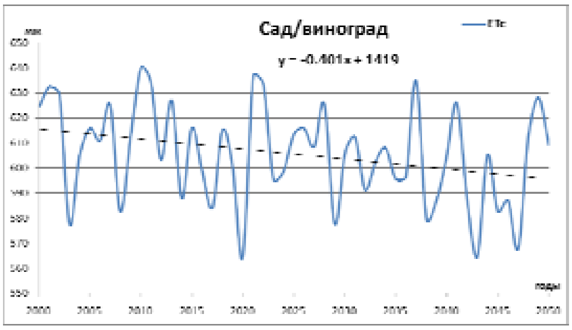


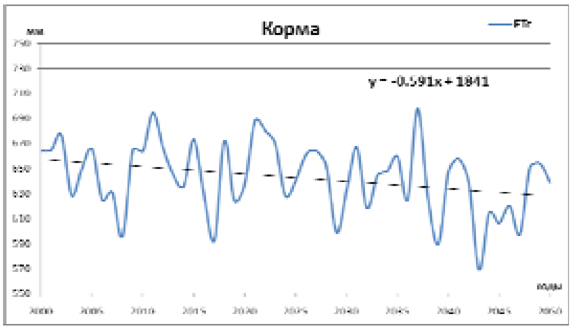
Prepared by G.Solodkiy

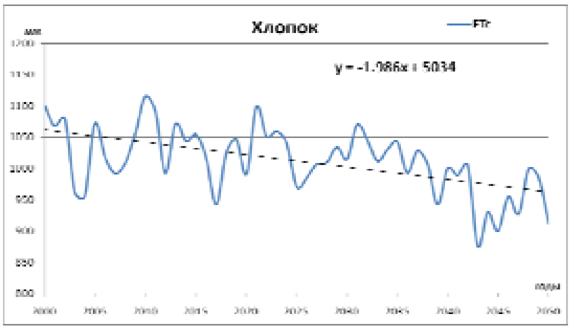
APPENDIX 17

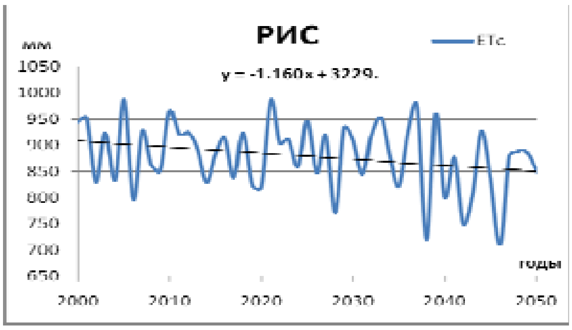
KASHKADARYA PZ   Dynamics of crop irrigation depth, mm

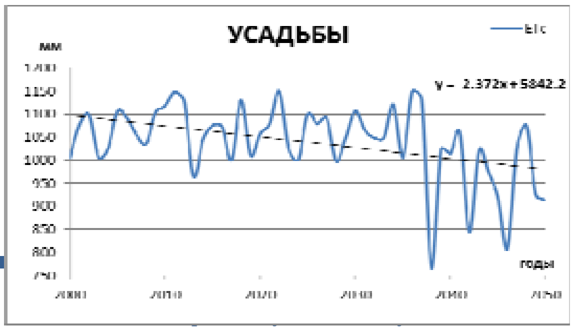






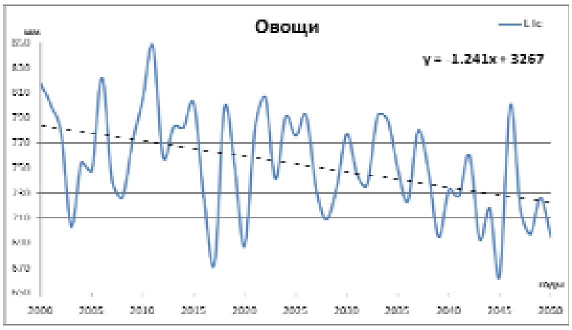


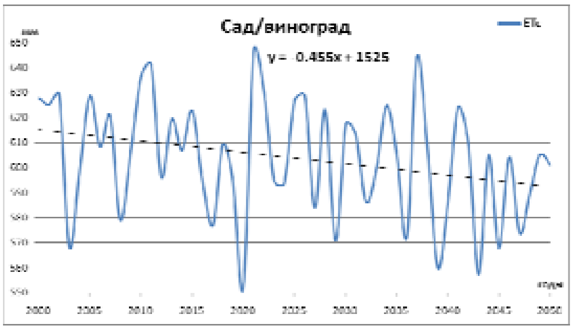


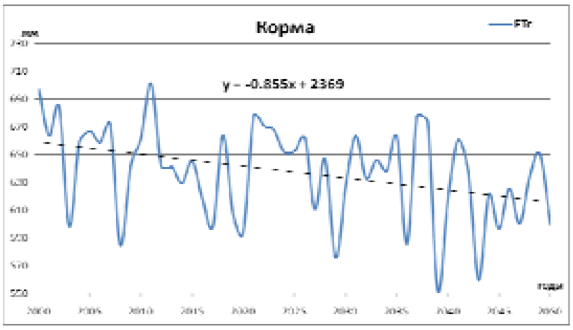


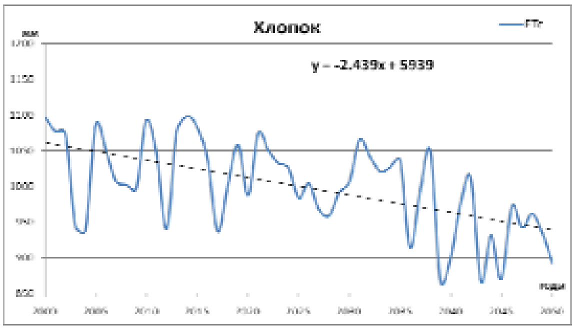
APPENDIX 18

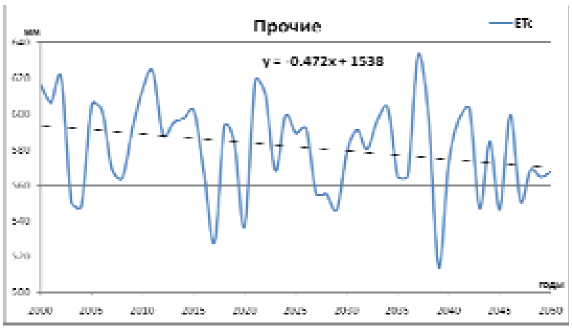
SURKHANDARYA PZ   Dynamics of crop irrigation depth, mm

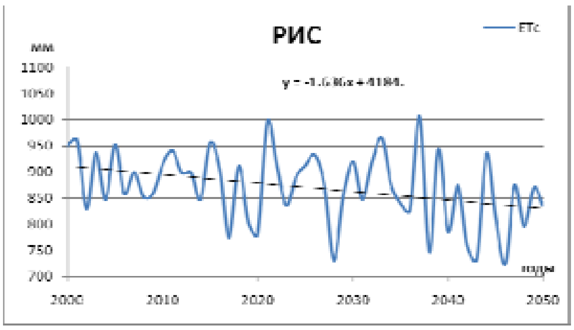


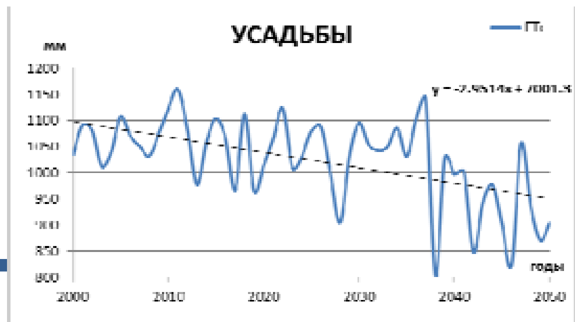












APPENDIX 19

Table of average "net - ETc" water requirements (m^3/ha) of crops and their groups and their dynamics over 2000 - 2050

	Karakalpakstan		Khorezm		Bukhara		Karshi		Kashkadarya		Surkhandarya	
	average	**growth**	**average**	**growth**	**average**	**growth**	**average**	**growth**	**average**	**growth**	**average**	**growth**
Maize/corn	6898	-313	6854	-279	7099	-323	6763	-305	6723	-555	6681	-638
Winter wheat	1745	-141	1500	-243	2068	184	1809	275	1789	169	1800	202
Cotton	6898	-313	10267	-702	10083	-379	10148	-675	10123	-1013	10002	-1244
Rice	9008	-347	8940	-470	9252	-588	8814	-500	8794	-592	8710	-830
Vegetables	7743	-161	7681	-220	7843	-343	7595	-251	7585	-409	7530	-633
Orchards/grapes	6158	-281	5939	-479	6506	-281	6069	-120	6055	-204	6038	-232
Forage	6561	-202	6422	-473	6856	-293	6407	-135	6428	-301	6375	-436
Other	5970	36	5915	-27	6273	-286	5870	108	5861	-39	5817	-241
Double-season	5816	-287	5763	-324	5922	-305	5687	-350	5655	-378	5647	-571
Homestead plots	10601	-759	10540	-855	9979	-482	10470	-859	10390	-1210	10250	-1505

Note 1: The algorithm for calculation of winter wheat water requirements needs further development. It is to be completed next year.

Note 2: Water requirements of homestead plots are taken equal to water requirements of tomato.