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CONDITIONS OF IRRIGATED LANDS IN UZBEKISTAN – AMU-DARYA RIVER CASE STUDY

R.N. Eshniyazov[1], R.E. Qurbanbaev[1], J. Mosiej[2]✉

[1] Karakalpak State University, Uzbekistan
[2] Warsaw University of Life Sciences – SGGW, Poland

ABSTRACT

Aim of the study
The article presents traditional, long-standing irrigation systems, and proposes changes in the dominant agricultural system in order to improve food security of the region. Considerable efforts and resources have been devoted to new forms of water governance at interstate level for water users' associations.

Material and methods
Due to the fact that the traditional technologies have been in operation for many years, simultaneous use of system solutions is required to improve the situation of the region in terms of food security. Much effort and resources have been devoted to new forms of water management at interstate level for user associations. The present paper discusses drainage of the Aral River and irrigation in the upper catchment areas of the Darya River, as well as employing case study methods.

Results and conclusions
The estimated average efficiency of irrigation systems was very low and did not change significantly over time. Irrigation was developed mainly by building new irrigation systems and, to a lesser extent, by reconstructing old ones. It is estimated that about 50% of abstracted irrigation water from rivers was lost due to seepage from channels and evaporation. In general, it can be concluded that the impact of large projects in the field of melioration had a positive impact on the development of agricultural regions. However, not all projects brought the expected benefits, for various reasons, including political pressure to increase biomass production by trying to use sometimes irrational and exaggerated volumes of irrigation that exceed the retention capacity of irrigated soil.

Keywords: Aral Sea Region, degradation of the environment, salinity of soils, irrigation, monoculture, cotton, low efficiency of water, increase of water level

INTRODUCTION

Uzbekistan is a landlocked country in Central Asia, with a total area of 447 400 km^2. In physiographic terms, the country can be divided into three zones: the desert (Kyzylkum), steppe and semi-arid region covering 60 percent of the country, mainly the central and western parts; the fertile valleys (including the Fergana valley) that skirt the Amu Darya and Syr Darya rivers; and the mountainous areas in the east with peaks of about 4 500 m above sea level (Tien Shan and Gissaro-Alay mountain ranges). Only 18 percent of the cultivable area, an estimated 25.4 million ha, is farmed – and this low percentage is due to

✉e-mail: jozef_mosiej@sggw.edu.pl

the water shortage. The most extreme contemporary example of the potential negative environmental effects of agriculture is the drying up of the Aral Sea due to the rapid increase in irrigated areas and the length of the irrigation networks in the past. The region's climate is hot and dry. Agriculture is fully dependent on an efficient irrigation system. The dominant agricultural and irrigation system in the region is the rotation of cotton planted in spring (April–May) with wheat sown after the cotton harvest (October–November).

The article presents the traditional irrigation systems that has been in operation for many years, and the proposes changes in the dominant agricultural system in order to improve food security of the region. Considerable efforts and resources have been devoted to new forms of water management at the interstate level for water users' associations.

PURPOSE OF THE RESEARCH

In this paper, we propose to build on our experience and research conducted in the region to suggest changes in the prevalent agricultural system – with the view to improving food security, sustainability, and resilience. Considerable efforts and resources have been allocated towards new forms of water governance at interstate level to water user associations. We believe that in addition to such measures, changes in the cropping system are necessary, specifically lessening Uzbekistan's reliance on cotton. Introducing legumes as double crops following the harvest of winter wheat (from July to October) can provide a first transition step towards greater crop diversification, which does not interfere with the State prescribed quotas on cotton and winter wheat. Appropriate investments in the repair of the irrigation and drainage infrastructures are also urgently needed.

CURRENT CHALLENGES

Once the fourth largest inland water body, the Aral Sea level has dropped 17 m and has lost more than 74% of its area and 90% of its volume. It is now divided into three parts, the Small Aral Sea in the North, and two large basins (Eastern and Western) in the South. It has been estimated that the amount of water inflow that would be required to restore the Aral Sea to its original size is 50 $km^3 \cdot year^{-1}$, a little less than half of the total annual renewable available water (Bortnik, 1999; Savoskul et al., 2004; Micklin, 2007; Adilbektegi, et al. 2019, Mosiej, 2019, Aladin et al., 2005, 2019; Amanbayeva et al., 2021).

At the moment, inflows into the sea are approximately 4 to 5 km^3/year from the Syr Daria River into the Small Aral Sea, and from 0 to 7 km^3/year for Amu Darya into the Large Aral Sea (Micklin, 2007). Since such an increase in inflow into the sea is unattainable considering the importance of agriculture (and therefore of irrigation water) in Central Asian economies, many have accepted the death of the Aral Sea as it once was (Allen et al., 2005, Mustafayev et al., 2020). In the North, the Kazakh authorities with the help of the World Bank have constructed a dam to retain water in the Small Aral Sea. Small Aral Sea level, a decrease in salinity and the resurrection of the commercial fisheries with the current inflows in the South have suggested the need to retain the water in the Western Aral Sea, which is deeper and thus has lower evaporation losses (Micklin and Allen, 1998, 2005). The authors predict that maintaining the western Aral Sea would require just over 8 km^3 of annual inflow, which is a much more attainable goal.

Furthermore, land degradation is now apparent throughout the basin. It is estimated that between 1990 and 2000, the proportion of the irrigated area affected by salinity has increased from 25 to 50% (Shabanov, 2002; Savoskul et al., 2004; Kurbanbajev et al., 2011, Artykov and Kurbanbajeva, 2011). Water is used to leach the salts out of the soil, but this in turn increases the salinity of the drainage water, and its quality decreases for downstream uses. In order to leach salts away successfully, drainage systems are necessary. Unfortunately, although 93% of the irrigated area has drainage installed, 32% of the open ditches are out of order, 46% of the subsurface drainage systems are no longer functional, and all of the vertical drainage systems are broken (Rahimbajev and Jesinbekov, 1977; Dukhovny et al., 2007).

At the same time, climate change introduces new levels of uncertainty. The limited information available suggests a predicted temperature rise of 1.5 to 2.75°C in the region (Dukhovny et al., 2007). Rainfall is also projected to increase, but the increase in evaporation due to the higher temperatures could more than offset the higher rainfall and result in lower soil moisture. In addition, the glaciers in the Himalayas are an important source of water for the two major rivers. Modelling (Savoskul et al., 2004) and satellite data (Khan and Holko, 2009) indicate that inflows have increased in recent years, but the snow cover thickness and snow cover area have decreased. Consequently, it is becoming urgent to implement new farming systems to reduce the abstraction of irrigation water and ultimately reduce agriculture's dependence on irrigation water. Possible solutions could include the change of crops (Gaybullaev et al., 2012).

On farms, water-saving technologies will play an important role in improving the sustainability of farming systems in the region. Surface irrigation is the most widely used irrigation technique and will likely remain so in the future. Technologies such as regulated deficit irrigation and staggered irrigation are appropriate and require no capital investment. Through regulated irrigation, the deficit farmers allow a certain degree of water shortage in the crops to allow the irrigated area to be increased (Graterol, 1993; Pereira et al., 2002; Kijne et al., 2003; Kozykeeva et al., 2018, 2020). Alternating furrow irrigation consists in supplying water to every second furrow, or alternating furrows between successive irrigations in order to stimulate root growth (Kang et al., 2000). Both of these techniques have been shown to significantly increase the water use efficiency of cereal crops. We have also shown that both of these techniques, both individually and in combination, can be used to grow legumes (common beans and mungbean) after winter wheat harvest in Uzbekistan. In 2004, the yield of common beans did not significantly decrease as a result of reducing the number of doses from 5 to 3. However, for mung beans the yields were highest with a single irrigation during the flowering period. Water consumption for these two crops were 1500 and 2200 $m^3 \cdot ha^{-1}$ for mung bean and common bean respectively, including a pre-planting irrigation. In comparison, average water consumption for winter wheat and cotton are 4790 and 7070 $m^3 \cdot ha^{-1}$ respectively (EC-IFAS, 1999). In another experiment, we grew a soybean crop (also after the harvest of winter wheat) with approximately 2500 $m^3 \cdot ha^{-1}$ (Bourgault et al., 2000b).

Horst et al. (2007) have demonstrated water savings of 44% or 3900 $m^3 \cdot ha^{-1}$ in cotton by using surge-flow irrigation (where irrigation water is delivered in interrupted high-rate pulses) with alternate furrow irrigation. If such savings were realized over the entire cotton growing area (approximately 1 million ha), and assuming that part of this water would be diverted to another 1 million ha in (for example) mung bean production, this would still leave 2400 $m^3 \cdot ha^{-1}$ (or 2.4 $km^3 \cdot year^{-1}$) of water saved for ecological purposes. Such calculations are obviously crude and simplistic, but they do point to real opportunities for the improvement of agricultural water use efficiency and crop diversification.

Diversification of agricultural products and the shift from cotton towards less water-intensive and more salinity-tolerant crops have been suggested earlier (Kotlyakov et al., 1992; Spoor, 1993; Aladin et al., 2005). For farmers, the cultivation of legumes and their export can be a real alternative to the cultivation and export of other crops. Export markets could develop and stimulate the agricultural sector, but this would require state intervention and political will. The current cotton production system is well structured as a legacy from the past and can be modified to accommodate other non-perishable crops such as cereal grains. There is also a small but growing international market for mung beans used for consumption or processing. Australian farmers have recently started growing mung beans, but most of this production is only suitable for processing. Mechanized agriculture cannot currently compete with the quality achieved by manual harvesting. Accordingly, Uzbek mung beans would have a market advantage. Spoor (1993) suggested the development of export markets for fruit and vegetables, and we agree with this suggestion, especially when it comes to grapes and watermelon. However, this system would likely require significant investment and infrastructure (for example for cooling and storage) and this would be complicated due to the large number of people growing these crops on domestic plots rather than in large co-operative and state-owned farms.

Another option would be to significantly increase the number of mulberry trees growing on the edge of farmland to reduce the problems of surface water stagnation as well as wind erosion and soil salinity. These trees can also be used in landscaping and silkworm farming based on mulberry trees.

AMU-DARYA RIVER CASE STUDY

Notwithstanding what we have said previously, there are examples of serious failures, which partly led to ecological catastrophes. We think that irrigation per se does not necessarily lead to land degradation. Even in the famous case of the Mesopotamian plains, the idea that ancient Sumerian irrigation caused irreversible salinity is far less evident than often assumed in the public discussion.

However, some irrigation projects in arid lands ended disastrously. One of the best-known examples is the former Aral Sea. Irrigated agriculture in the vicinity of the lake basin had been applied for many centuries. It was practiced mainly in the areas with rich soils, with a deep water table or with fresh groundwater where the irrigation requirements were minimal. The major part of the irrigated lands was located in river valleys, in deltas, and in foothills close to the mountains. The irrigated plots were small and widely separated from each other. Therefore natural drainage served well enough; whereas artificial drainage, in form of ditches, had been rarely used. The principal irrigated crops were cereals and alfalfa. They occupied more than half of the total irrigated area in the Aral Sea basin. Cotton occupied less than 20–30% and rice no more than 5–15% of the irrigated area, depending on the year.

During the twentieth century, the population of the Aral Sea basin doubled, and irrigation was intensively developed, leading to almost a tripling of the irrigated area. The basic sources of irrigation water are two large rivers, the Amu-Darya and Syr-Darya. Large irrigation systems covering hundreds of thousands of hectares were built mainly in the steppe and desert parts of the Aral Sea basin, far from the riverbeds, where the groundwater table was very deep (more than 30–50 m).

Cotton became the main crop, following the government's decision to increase raw cotton production. That led to increased irrigation requirements and to growing use of mineral fertilizers, pesticides and defoliants. In addition, the area of rice cultivation was significantly expanded.

The estimated average efficiency on the irrigation systems was very low and did not change appreciably over time. Irrigation was mainly developed by means of constructing new irrigation systems rather than reconstructing the old ones. About 50% of the irrigation water taken from the rivers was lost because of seepage from canals and deep moisture leaching in the irrigated fields. Even waterlogging took place, and the groundwater table sometimes rose to a depth of less than 1.5 m. Due to large amounts of soluble salts in the deep layers of the soils, and as a result of the disturbance of the natural groundwater balance, the worst case scenario became reality: saline groundwater rose to the surface. Later analysis of experimental data showed that the only way to save water and at the same time to prevent soil salinity is to keep the water table at the maximum possible depth (not less than 2.5–3 m), and use only water of good quality.

The growing irrigated area and inefficient water use made drainage construction and management of the huge amounts of agricultural wastewater a necessity. Formerly it was supposed that drainage would not only prevent soil salinity and waterlogging, but that it would desalinate groundwater as well. Then fresh groundwater could have been used for sub-irrigation. Additionally, it was supposed that the repeated use of drainage waters mixed with river waters would increase the effective use of limited water resources. However, it turned out that the salt concentration of drainage waters did not change much. Worse still, it appears that huge amounts of dissolved soil salts, pesticides, and nutrients were injected into the geological water circulation. This contaminated water was used not only for irrigation, but also for human consumption. Therefore a number of severe diseases among the population grew considerably, while the rise of saline groundwater under irrigation systems required increasing the amounts of irrigation to prevent soil salinity – despite the newly constructed drainage systems (Minajev, Maslov, 2002; Dukhovny et al., 2007; Adilbektegi et al., 2007).

Lower reaches of Amu Darya River occupy a vast territory, covering the whole areas of Khorezm and Karakalpakstan regions as well as Tashkhauz area of Turkmenistan. The size of the modern delta of Amu-Darya River, including Usturt Plateau and the Aral Sea, is nearly 14 million hectares (see: Fig.1).

Drying up of the Aral Sea and development of irrigation in the upper parts of Amu-Darya River basin, as well as regulation of the river flow have substantially affected the hydro-geological and melioration

Fig. 1. Map of Aral Sea Region

condition of irrigated lands of the region. As a result of water flow reduction from Amu-Darya, intensive process of desertification began, both in a zone of drained bottom of the Aral Sea, and in delta of the river. Under the existing conditions in the lower Amu-Darya, the situation regarding water resources remains tense and unstable.

The fundamental task today is to increase yields of agricultural products by vital melioration of irrigated soils. It is therefore absolutely essential to study hydro-geological and melioration conditions of the territory's lands in detail. The water melioration system in the lower Amu Darya is quarter complex of bedrocks in which subsoil waters are formed. Therefore the main attention is focused on the characteristics of upper water-bearing stratum.

The land of Karakalpakstan is represented by fourth period sedimentary rocks of alluvial origin with the depth from 10 to 35 m. Three soil complexes, which are sharply distinguished by structure, have been distinguished in this area. The first complex is riverbed sediment, which is mainly fine granular sand covered by over layered sandy loam and loamy soil. The depth of this complex is between 1.50–1.95 m, whereas the filtration coefficient is between 1.28–1.42 m/day.

The second complex is riverbed sediment of stray channels and temporal lakes. They may consist of one, two, or three layers. Water-bearing complex consists of thin and fine granular sand with the filtration coefficient between 5.2–7.5 m/day. This complex is covered by small-grained soil with the depth from 4.5 to 11.6 m. The water permeability of this soil is lower than in the area of riverbed sediments, and its filtration coefficient changes from 0.38 up to 0.96 m/day.

The third complex is submitted by lake sediment. Open-pit mine of this complex is combined by clay within which there are layers of sandy loam, rarely with layers of sand. The depth of this complex changes from 3.5 up to 12.5 m, and filtration coefficient – from 0.15 to 0.83 m/day.

In order to implement hydro-geologic and melioration measures and to determine soil saltiness, we have investigated land saltiness of seven regions of Karakalpakstan, which are: Amu-Darya region, Nukus region, Kegeyli region, Chimbay region, Karauzyak region, Takhnakupir and Muynak regions. For this experiment, selection of soil samples was collected across the area of 219 thousand hectares of irrigated land. 20% of samples were subjected to a complete cycle of analyses, and toxic salts in soil were detected and classified. Results of the experiment are given in the table below.

On the basis of chemical analyses applying water extraction method, we have determined the types and degrees of soil saltiness. Types of the soil salts in the investigated seven regions are mainly chloride-sulphate, rarely chloride, sulphate-chloride, or sulphate. The saltiness degree of the soil was determined as the sum of all toxic salts. Previously, such salt sampling in these areas was carried out in September–October of 2008. Upon comparing the results of the present testing with the previous results, the following changes were observed: the area of lands with no salt content in the soil increased to 3.63 thousand hectares, the area of soils with low salinity decreased to 5.29 thousand hectares, the area of lands with medium salt content increased to 3.74 thousand hectares, whereas the area of heavy salinity decreased to 2.28 thousand hectares.

Dynamical analysis of the whole irrigated land of the Karakalpakstan in the period 2000–2012 in terms of the amounts of salt in the soil leads us to conclude that the level of soil salinity still remains tense and unstable (see Table 2 above). During that period, the whole irrigated land area increased to 15 thousand hectares, i.e. to 2.9%, the area with soils without salinity increased to 70 thousand hectares, the area of faintly saline soils decreased to 94 thousand hectares, the area if medium salinity soils increased to 40 thousand hectares, and the area with heavy salinity soils remains almost constant.

Table 1. Soil salinity in the irrigated lands of seven regions of Karakalpakstan, thousand hectares

Regions	Whole irrigated land	No salinity	Low salinity	Medium salinity	Heavy salinity
Amu-Darya	38667	8948	9214	15486	5019
Nukus	26869	4624	8280	9762	4203
Kegeyli	39070	8180	10934	15310	4646
Chimbay	46709	9733	18481	12322	6173
Karauzyak	33689	8034	10434	10413	4808
Takhtakupir	33851	6956	13803	9913	3179
Muynak	540	14	119	192	215
Total	219395	46489	71265	73398	28243

Source: Statistical data 2000–2012

Table 2. Dynamics of the change in the whole irrigated land of Karakalpakstan in the period 2000–2012 in terms of the degree soil salinity (thousands hectare)

Year	Whole irrigated land	No salinity	Low salinity	Medium salinity	Heavy salinity
2000	500.09	49.52	244.10	158.55	47.2
2001	500.16	49.96	215.74	172.15	62.1
2002	500.20	73.80	169.73	192.22	64.45
2003	500.16	79.34	178.81	182.76	59.25
2004	500.10	92.99	180.81	169.94	56.36
2005	500.12	103.17	169.02	171.36	56.57
2006	500.40	105.13	158.45	175.86	60.96
2007	504.0	107.07	154.79	182.73	59.41
2008	504.53	106.19	157.23	183.97	57.14
2009	515.05	112.46	164.26	185.07	53.26
2010	515.29	113.30	154.03	196.63	51.33
2011	515.22	116.94	148.77	200.45	49.06
2012	515.22	119.25	150.17	198.85	46.93

Source: Statistical data 2000–2012

Thus, in 2012 almost 77% of all the irrigated lands of Karakalpakstan had saline soils, and only 23% had no salinity. From this we may to conclude that the existing hydro-geological and melioration conditions in a significant portion of irrigated lands of Karakalpakstan are characterized as unsatisfactory. This characterization is connected not only with a high level of underground waters, which leads to intensive evaporation, but also with high mineralization of underground and irrigation waters, which causes the salts to raise to the surface of the soil.

CONCLUSIONS

The estimated average efficiency of irrigation systems was very low, and did not change significantly over time. Irrigation was developed mainly by building new irrigation systems and, to a lesser extent, by reconstructing the old ones. It is estimated that about 50% of the abstracted irrigation water from rivers was lost due to seepage from channels and to evaporation. In general, it can be concluded that the large melioration projects had a positive impact on the development of agricultural regions. However, not all the projects brought the expected benefits, for various reasons, including political pressure to increase biomass production by trying to use sometimes irrational, overly high doses of irrigation that exceeded retention capacity of the irrigated soil.

The economic and environmental benefits of major drainage and irrigation projects should theoretically be environmentally and economically viable. Unfortunately, some projects did not bring the expected benefits, mainly for political reasons – such as pressure to increase yields. Examples of such undertakings include not only the Aral Sea, but also the large-scale swamp drainage projects implemented in the twentieth century in Eastern Europe (Belarus, Poland, Ukraine). On-farm water saving technologies will play an important role in improving the sustainability of agricultural systems in the region. Surface irrigation is the most widely used irrigation technique and will likely remain so in the future.

Reclaimed land areas, in particular irrigated land, comprises about 10–15% of the ploughed areas of the Earth, but they are responsible for about 30% of the production (in money terms). Hence, in order to supply the growing population with food, a constant input of new reclaimed land is required, in addition to the intensification of agriculture on the existing reclaimed land. According to UN experts, to resolve the global food problem, the irrigated area should be increased by 0.5% annually. At the same time, to ensure stable agriculture, the distribution of irrigated lands, in terms of natural-climatic zones, should be in excess of 20 to 25% in the arid zone, 10 to 20% in dry steppe; 5 to 10% in steppe, and 1 to 5% in forest-steppe.

Nowadays, vast irrigated areas are located in India, China, Pakistan, Egypt, Iran, USA, and Russia. Apparently, lack of available water resources will remain the principal limiting factor in the expansion of irrigated land. This applies to all the relevant countries, except for Brazil and Russia. Undoubtedly, the scale of new reclamation development will depend on population increase and global climate change, but the quantitative increase of irrigated and drained land will become less important than the quality of agricultural reclamation. As described above, in ancient times reclamation systems were complex, i.e. they were constructed in such a way that they were able to control not only water, but also nutritional, thermal and other environmental factors. Modern reclamation systems do not always possess such properties because, basically, only the regulation of water flow is controlled. Using ecological principles, it is possible to believe that creating more sophisticated reclamation systems will permit significant increases in crop production (not less than 30–50%) on the existing reclaimed lands, and this can reduce the gap between population growth and creation of new areas of reclaimed land. Today, the concept of complex reclamation regulation is sufficiently developed. The systems have been proven, and in future, they can only increase in size and importance.

We believe that, in addition to such measures, changes to the farming system are necessary, namely it will be essential to reduce Uzbekistan's dependence on cotton. The introduction of legumes as a double crop after the winter wheat harvest (July to October) could be the first step towards greater crop diversification that does not interfere with state quotas for cotton and winter wheat. Adequate investment in the repair of irrigation and drainage infrastructure is also urgently needed. Perhaps the most extreme contemporary example of the potential negative impacts of agriculture is the drying of the Aral Sea due to the expansion of irrigation networks in the Soviet period. Climate in the region is hot and dry. Agriculture is highly dependent on irrigation. The predominant system in Uzbekistan consists of rotations of cotton planted in the spring (April–May) with winter wheat planted around the cotton harvest (October–November).

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UWARUNKOWANIA NAWADNIANIA GRUNTÓW ROLNYCH W UZBEKISTANIE – STUDIUM PRZYPADKU RZEKI AMU-DARIA

ABSTRAKT

Cel pracy

W artykule przedstawiono tradycyjne, stosowane od wielu lat, systemy nawadniania oraz zaproponowano zmiany w dominującym systemie rolnym w celu poprawy bezpieczeństwa żywnościowego regionu. Opisano, jakie wysiłki zostały podjęte i jakie środki przeznaczono na nowe formy zarządzania wodą na poziomie międzypaństwowym dla stowarzyszeń użytkowników wody.

Materiał i metody

Z uwagi na fakt, że tradycyjne technologie funkcjonują od wielu lat, dla poprawy sytuacji regionu w zakresie bezpieczeństwa żywnościowego wymagane jest jednoczesne stosowanie rozwiązań systemowych. Wysuszenie Morza Aralskiego i rozwój nawodnień w górnych partiach zlewni rzeki Amu-Daria, a także regulacja przepływu rzeki istotnie wpłynęły na stan hydrogeologiczny i melioracyjny terenów nawadnianych regionu.

Wyniki i wnioski

Szacowana średnia wydajność systemów nawadniających była bardzo niska i nie zmieniała się znacząco w czasie. Rozwój nawodnień następował głównie poprzez budowę nowych systemów nawadniających oraz w mniejszym stopniu poprzez rekonstrukcję starych. Szacuje się, że około 50% wody do nawadniania pobranej z rzek zostało utracone w wyniku przesiąkania z kanałów i parowania. Ogólnie można stwierdzić, że oddziaływanie dużych projektów w zakresie melioracji miało pozytywny wpływ na rozwój regionów rolniczych. Jednak nie wszystkie projekty przyniosły oczekiwane korzyści, m.in. z powodu presji politycznej na zwiększenie produkcji biomasy poprzez próby stosowania niekiedy nieracjonalnych i przesadnych ilości nawodnień, przekraczających zdolności retencyjne nawadnianych gleb.

Słowa kluczowe: region Morza Aralskiego, degradacja środowiska, zasolenie gleb, nawadnianie, niska efektywność wykorzystania wody