ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ СОФИЯ

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OPTIMUM REGIONAL IRRIGATION REQUIREMENTS UNDER CHANGING CLIMATE IN BULGARIA

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ABSTRACT

Net irrigation requirements (***NIR***, mm) that fully satisfy crop development and yield formation are basic in irrigation systems design and management. Bulgarian practice usually adopts the irrigation scheduling developed by Zahariev et al. [1] that provide information on 31 crops and 97 irrigation regions (***IR***). Years, having probability of occurrence of an irrigation depth P_I=10, P_I=25 and P_I=50%, are considered. To cope with climate uncertainties and drought aggravation, simulations are performed for unified Agro-Climatic ***AC*** regions under past (1950-1980) and present (1951 – 2004) weather conditions. In former studies the irrigation scheduling simulation WinISAREG model is calibrated for maize using data from long-term experiments carried out in fields of diverse soil, climate and management conditions. Optimum ***AC*** regions are defined on the grounds of average reference evapotranspiration totals for July-August relative to the period 1951-2004 $ETo_{Jul-Aug}$. Thus, $ETo_{Jul-Aug}$ serves as an indicator of regional ***NIR*** and ***IR*** unification into ***AC*** regions. The impacts of soil properties are characterised by total available soil water ***TAW***, being “small” if TAW=116, “average” if 136<TAW<157 and “large” when 173<TAW<180 mm m^{-1}. ***NIR*** are computed by model application to soils of small and large TAW in each AC region and year of the period 1951-2004. Results indicate that when $ETo_{Jul-Aug}$ increases from 260 to 330 mm, ***NIR*** in “average” demand year (P_I=50%) increase from 160 to 310 mm for soils of “small” ***TAW***. Relative to

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1951 – 1980, unified observed irrigation demands are compared to those simulated. Results show that the former are mostly in the range of those derived by model simulations. It is concluded that the model takes better into account the impact of climate change and different ***TAW***. Maps illustrate findings of the study over arable country territory in "an average", "a moderately dry" and "a very dry" season.

1. Introduction

Net irrigation requirement that fully satisfies crop water requirements for development and yield formation is basic in designs and management of irrigation systems. Completely different is the problem of irrigation demand when a maximum economical return is aimed at. Conventional Bulgarian irrigation practice usually adopts the irrigation scheduling and demands developed by Zahariev et al. [1] that are based on experimental data relative to the period 1950 – 1980 and application of Delibaltov's crop evapotranspiration equition [2]:

$$ET = Z.\Sigma t^0 , \tag{1}$$

where Z – a coefficient that takes into account crop variety and development stage; Σt^0 – a total average daily air temperature over a decade, °C.

The book [1] consists predominantly of tables that provide information on the timing of a conventional application depth of 60 mm and the respective seasonal irrigation demand (***ID***) relative to 31 crops and 97 irrigation regions (***IR***). Three particular years having probability of occurrence of an ***ID*** P_I=10%, P_I=25% and P_I=50% are considered respectively. The huge volume of the book, however, hampers its practical application that makes advisable to reduce the number of regions.

Climate change and drought aggravation detected during the last 35 years have created uncertainties for irrigation management in this country [3; 4; 5]. Undoubtedly, they have influenced crop evapotranspiration, yield decrease due to water stress and corresponding net irrigation requirements to overcome these losses [6; 7; 8; 9]. In 1998 FAO published a new methodology on reference evapotranspiration calculation using the equation of Penman-Monteith [10]. Numerous climate parameters, as maximum and minimum air temperature and others are involved in the suggested relationship. Independent studies, carried out in different parts of the world, have shown that the validated ***ETo-PM-FAO56*** equation takes better into account the impact of variable microclimatic factors on reference and actual crop evapotranspiration [11; 12; 13; 14; 15]. The objective of the present study is to provide a practically oriented methodology on regional irrigation requirements optimization under the conditions of climate uncertainties in Bulgaria by applying the previously validated water balance and irrigation scheduling WINISAREG simulation model to maize crop [16; 17; 18; 19]. The unification of irrigation regions is based on the average reference evapotranspiration totals for July and August $ET_{0July-Aug}$ relative to the period 1951 – 2004.

2. Developed Methodology

Variability of soil characteristics is really substantial in this country [20]. Regarding crop irrigation scheduling and net irrigation requirement NIR, mm, however the impact of soil has been directly taken into account by Total Available Soil Water TAW mm m^{-1}. The latter is computed as a difference between soil water storage at Field Capacity (FC) and Wilting Point (WP). The impact of soil characteristics on net irrigation requirement has been taken into account by the difference mentioned above [4; 6; 15; 21]. The characteristic of “small” available soil water is related to the group of soil varieties having TAW=116 mm m^{-1}. The soils of “medium” water holding capacity are those of ***TAW*** within the range 135 – 157 mm m^{-1}, while those of “large“ ***TAW*** have a 173 – 180 mm m^{-1} difference between FC and WP.

Table 1. Net Irrigation Requirements of maize NIR [mm] depending on probability P_I of a NIR occurrence in the Unified Agro-Climatic (AC) regions of Bulgaria, 1951 – 2004

Average Reference Evapotranspiration ET_0 July – Aug [mm] for the periods 1971-2000г and (**1951-2004г**)	Agro Meteorological station (**MS**)	Probability P_I [%] of occurrence of a ***NIR***				
		10	25	50	75	90
230 (**260**) **Unified AC region I**	**Sofia**, Dragoman	280/230	230/180	**160**/110	120/70	80/30
250 (**275**) **AC region II**	Knezha, Pavlikeni, Targovishte, V.Tarnovo, G. Delchev, Dobrich, **Silistra**	300/240	240/190	180/130	140/90	90/40
270 (**285**) **AC region III**	Vidin, **Lom**, Obraztsov chiflik, Kyustendil, Rila, Kazanlak, Ivanova, Karnobat	320/260	260/210	200/150	160/100	90/40
	Varna	300/240	240/190	210/160	140/130	130/50
290 (**310**) **AC region IV**	**Pleven**	330/270	280/210	210/140	130/80	80/20
	Yambol, Sadovo, **Plovdiv**, Elhovo, Chirpan, Sliven, Burgas	370/310	310/260	250/200	190/135	100/40
310 (**330**) **AC region V**	Haskovo, Svilengrad, Petrich, **Sandanski**	380/310	360/300	**310**/270	280/210	240/180

Climate conditions are the main factor when computing crop water requirement for irrigation. In the present study they are characterized by average reference evapotranspiration ***ETo*** estimated by the Penman-Monteith equation according to the methodology of FAO 56 [10]. ***ETo*** had been already determined by using the required climate data monitored on a daily basis in 30 representative Agro-Meteorological (***MS***) stations in the country over the period 1971 – 2000 [22]. Average cumulative totals of $ET_{0July-Aug}$ were computed for three typical periods of crop development: March-October, April–June and July-August. The example developed below deals with grain maize. The main part of irrigation for this and many other summer crops usually takes part in “July-August”. Thus, it is accepted that the impact of climate on soil water balance and crop development under irrigated maize could be characterized precisely by using the average total of reference evapotranspiration over the period "July-August". For example, average total $ET_{0\ July-Aug}$ is 220 mm in the station of Dragoman, while it is 320 mm in the station of Sandanski, i.e. the difference is about 100 mm [22]. Thus, it makes sense to divide the plain country territory into five Agro-Climatic (***AC***) regions. The average values of $ET_{0\ July-Aug}$ relative to each of the unified regions over the period 1971 – 2000 are respectively: 230, 250, 270, 290, 310 mm (**Table 1**).

The average totals of $ETo_{\ July-Aug}$ presented within parentheses in the same Table 1, namely 260, 275, 285, 310 и 330, refer to the longer **1951 – 2004** period. They were delivered during our previous studies [4; 21; 23] using climate data on maximum and minimum air temperature observed in the Meteorological Stations (***MS***) of Sofia, Silistra, Lom/Varna, Pleven/Plovdiv and Sandanski respectively by National Institute of Meteorology and Hydrology. The ***ETo*** calculation procedures are those recommended by FAO56, applied after respective validation as described in [14; 15; 21]. Thus, each of the estimated $ETo_{July-Aug}$ value would differ by less than 10mm that is 4.5% from the average regional values given in Table 1. Presuming the requirements of irrigation practice, such deviations are completely acceptable.

Undoubtedly, when considering another crop like wheat, vegetables and others, the period of substantial climate impact on NIR should be completely different. It should be pointed out as well that when using field experimental data as a basis of validation for each evapotranspiration calculation method, estimation errors are unavoidable and not less than 10%.

Respective ***NIR*** were computed by application of the water balance and irrigation scheduling WinISAREG model after its validation to soil groups and climate stations representing the main agro-climatic regions of this country [21; 4; 23]. In addition to average reference evapotranspiration sum $ETo_{July-Aug}$, net irrigation requirement ***NIR*** relative to different levels of probability P_I [%] of a ***NIR*** occurrence 10, 25, 50, 75 and 90% is presented in table 1 as well. The latter takes into account the possible range of ***NIR*** variability for maize crop over more that 90% of the years within the period 1951-2004. The upper number in each cell of the table refers to the soil group of "small" ***TAW*** (116 mm m^{-1}) while the lower number is valid for the group of "large" ***TAW*** (173-180 mm m^{-1}). ***NIR*** relative to the soil group of "average" ***TAW*** is about 20 mm less than that simulated for soils of "small" water holding capacity ***TAW***=116 mm m^{-1} . Meteorological stations (**MS**) that provide the required climate data to Agro-Climatic (***AC***) region are listed in the second column of table 1 [22; 21; 23].

Referring to ***AC*** Regions III and IV of average total $ET_{0July-Aug}$ 285 and 310 mm respectively (Table 1), it is observed that ***NIR*** values relative to Varna and Pleven are separated by a dashed line from the others in the group since they differ by up to 50 mm from them.

When average total $ETo_{Jul-Aug}$ increases from 260 to 330 mm, ***NIR*** in "average" demand year (P_I=50%) increases from 160 to 310 mm when soils of "small" ***TAW*** are considered. Such range of deviation is substantial and reflects the impact of climate uncertainty on maize irrigation in this country. When net irrigation requirements ***NIR*** relative to the soils of large water holding capacity and the very wet years (P_I >90%) are less than 40mm, it is acceptable not to irrigate than.

3. Result and Discussions

3.1. Estimation of Net Irrigation Requirement by Using WINISAREG Model and Experimental Data

Net irrigation requirements ***NIR, mm,*** for maize crop computed by using the validated WinISAREG model [18] are compared with that estimated on the grounds of a 9-year irrigation experiments carried out in Tsalapitsa field, Plovdiv region [24]. The probability curve of a ***NIR*** occurrence presented in Fig. 1 is built upon simulation results over a 54-year period (1951 – 2004).

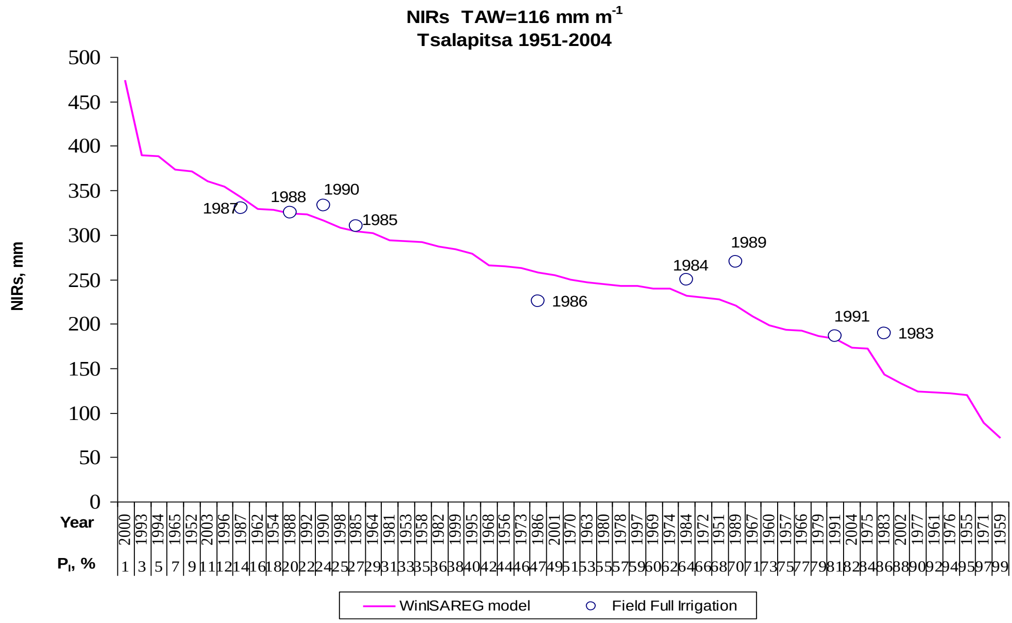


Figure 1. Probability curve of a Net irrigation requirement (NIR, mm) occurrence at Tsalapitsa experimental field, an alluvial soil of small total available water TAW=116 mm m^{-1}, 1951 – 2004

In that case monthly precipitation data observed at Tsalapitsa field (1970 – 2004) were extended to the longer period (1951-2004) by using a previously derived statistically significant correlation between available data observed in Plovdiv and Tsalapitsa (R^2=0,74) resulting in a regression coefficient *b*=0,89 [25]. Correlations for extending average monthly maximum T_{max} and minimum air temperature T_{min} were derived in a similar way, producing quite significant correlations (R^2=0,96 – 0,997) with a regression coefficient *b*=0,926 – 0,974.

Respective net irrigation requirements for maximum yield during each experimental season over 1983 – 1991 are plotted as well but in open symbols (o) in the same Fig. 1. It is observed that, except for the ***NIR*** in two of the wet seasons in 1989 (P_I=70%) and 1983 (P_I=85%), model simulation results practically coincide with the experimentally based ones [24] (Fig. 1).

Thus, computed ***NIR*** relative to the period mentioned above, are acceptably precise and could be used in the irrigation practice. Observed deviation in two of the wet years having probability P_I=70% and P_I=85% (about 40 mm) is logic since the studied 54-year period is much more representative than that of a 9-year field experiments (Fig. 1). The results also indicate that the extreme values of ***NIR*** are registered during the longer 54-year period only and do not occur during the period of field experiments.

Results in Fig. 2 refer to the empirical probability curves of a net irrigation requirement ***NIR*** occurrence under fully irrigated maize in Plovdiv, computed by WinISAREG simulation model when the impact of three soil groups of different ***TAW*** is considered**.** The highest curve refers to a soil of “small” ***TAW*** of 116 mm m^{-1}, as the soil in Tsalapitsa is. The results are based again upon the 1951 – 2004 period (54 year).

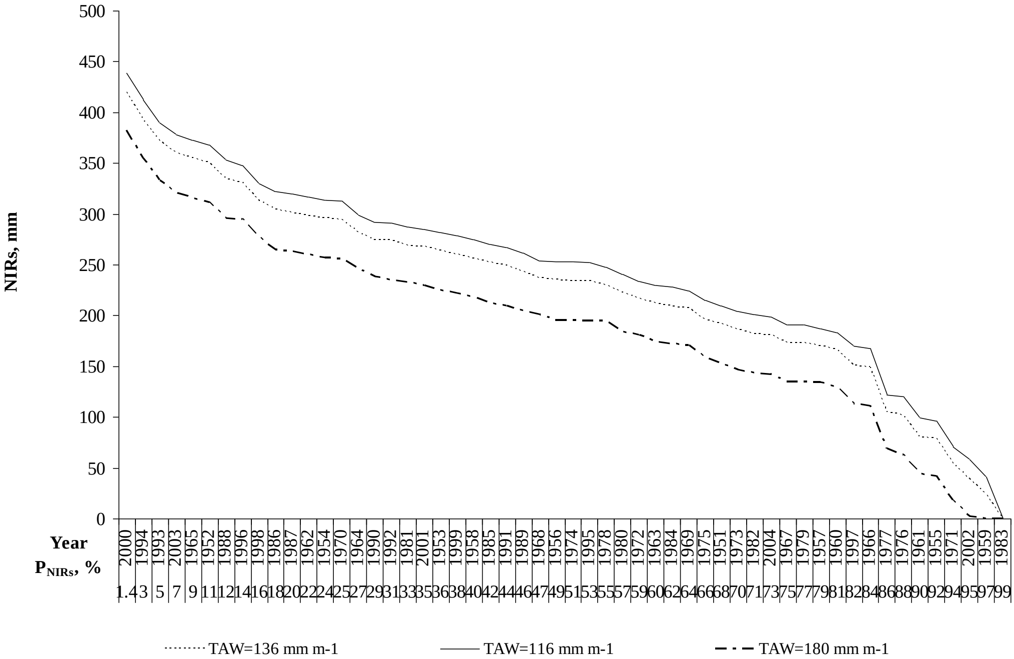


Figure 2. Probability curves of a Net Irrigation Requirement (NIR, mm) occurrence as influenced by "small", "average" and "large" Total Available Soil Water TAW (mm m^{-1}), Plovdiv, 1951 – 2004

The figure also shows that maize cultivation in soils of "large" ***TAW*** (180 mm m^{-1}) leads to much less ***NIR*** than that relative to soils of "small" TAW.

3.2. Comparing Irrigation Requirements by "Zahariev et al." and those Computed by Using WinISAREG Model

It is well deserved to find out the difference between the experimentally based seasonal irrigation depths [1] and those obtained after unification of relevant model simulation results [4; 21; 23] in five Agro-Climatic regions (***AC***). For this purpose Table 2 and Maps of Net Irrigation Requirement relative to different climatic years are composed (Figs. 3a, 3b, 3c). The latter also mark the location of ***MS***, ***IR*** and unified ***AC*** regions used in the study.

In contrast to the object of our study based upon model simulations over the 1951 – 2004 period in Table 1, Table 2 is related to the shorter 1951-1980 period that represents the "past" weather conditions. Table 2 consists of data on seasonal irrigation depth estimated in 30 Irrigation Regions (***IR***) during the years of probability of a seasonal depth occurrence P_I =10, P_I =25, P_I =50% [1]. The table also presents the net irrigation requirement simulated over the past 1951 – 1980 period when the impact of soils of "small" (116) and "large" (173 – 180) total available water TAW mm m^{-1} has been taken into account.

It is observed that in ***AC*** region IV of average total $ETo_{Jul-Aug}$=292 mm the seasonal irrigation depth in "average" irrigation demand year (**P_I=50%**) is 240 mm at ***IR*** Plovdiv, Elhovo, Sliven and Yambol by "Zahariev" [1] while the ***NIR*** simulated by WinISAREG model application to soils of diverse water holding capacity is within the range 230 – 170 mm. Regarding the dry year (P_I=10%), experimentally based irrigation depth by "Zahariev" is 300 mm as a whole compared ***IR*** [1], while in model simulation it is within the range 320 – 260 mm.

Table 2. Comparing irrigation demands by "Zahariev – 1986" and WINISAREG model, 1951 – 1980

Average seasonal ***ETo*** $_{Jul\text{-}Aug}$ **(mm), 1951-1980r**	Source	Agro-Meteorological station [***MS***]and Irrigation region (***IR***)	Net irrigation requirements ***NIR***, mm, with probability P_I [%]		
			P_I =10%	P_I =25%	P_I =50%
258 **AC region I (●)**	Mathematical model	Sofia	300/250	230/180	160/110
	„Zahariev "	Elin Pelin IR 53	240	180	180
		Sofia IR **52**	**300**	**240**	**180**
272 **AC region II (●)**	Mathematical model	Silistra	285/230	235/175	190/140
	„Zahariev "	Pavlikeni IR **29**, Targovishte IR**37**, Knezha IR**15**,V.Tarnovo(Karsisen IR**28** and G. Oryahovitsa IR **30**), G. Delchev IR **67**;	**300**	**240**	**180**
		Silistra IR 43	300	300	240
281 **AC region III (○)** / **272**	Mathematical model	Lom	290/230	240/190	190/140
		Varna	250/**190**	220/170	205/150
	„Zahariev "	**Kazanlak IR 86;**	**240**	**240**	**180**
		Kyustendil IR60,Rila IR62, Varna–Markovo IR 46;	300	240	180
		Varna–Provadia IR 48,	300	240	240
		Vidin IR 1, Varna-Goren Chiflik IR 47;	**300**	**300**	**240**
		Lom IR 5	360	300	240
286 **AC region IV (●)**	Mathematical model	Pleven	325/270	245/190	190/130
	„Zahariev "	IR 17-22:Sadovec (**17**);	300	240	180
		Levski (**22**);	300	300	180
		Dolna Mitropolia (**18**), Novachene (**20**);	**300**	**300**	**240**
		Gulyantsi (19), Belene (21)	360	300	240
292	Mathematical model	Plovdiv	320/260	280/220	230/170
	„Zahariev "	Sliven IR89, Yambol IR91;	300	240	240
		Plovdiv IR**72**, Elhovo IR**92**)	**300**	**300**	**240**
315	Mathematical model	Stara Zagora (IR 85)	320/280	300/250	250/200
	„Zahariev "	Stara Zagora	300	240	180
326 **AC region V (●)**	Mathematical model	Sandanski IR 65	380/320	350/300	300/240
	„Zahariev"	Haskovo IR 83;	**360**	300	240
		Petrich IR**66**, Svilengrad IR**81**;	**360**	300	**300**
		Sandanski IR **65**	**360**	**360**	**300**

Similar results are found in the remaining ***AC*** regions of average total ***ETo*** $_{Jul\text{-}Aug}$ 258, 272, 281, 286 and 315 – 326 mm (**Table 2**). Diversity of irrigation depth in some of the examined ***AC*** regions, for instance those around Varna, is possibly due to the remoteness of ***IR*** from the ***MS*** (o, Fig. 3) or to the spatial variability of precipitation. In most of the cases however the seasonal irrigation depth [1], after ***IR*** unification into five ***AC*** regions, is within the range of ***NIR*** found by the application of validated WinISAREG model.

Considering the ***AC*** regions I and II of 258<$ETo_{Jul\text{-}Aug}$ <272 mm, the irrigation depths of 300, 240 and 180 mm observed by [1] are valid in eight of ten ***IR*** and quite close to that simulated for Sofia and Silistra by the model (Table 2, Fig. 3).

Referring to ***AC*** region III of 272<$ETo_{Jul\text{-}Aug}$ <281 mm, the combinations of seasonal irrigation depth rise to five in totally eight irrigation regions ***IR*** increasing from 240, 240 and 180 mm at ***IR86***Kazanlak to 300, 300 and 240 mm at ***IR1***Vidin and ***IR47***Varna-Goren Chiflik. The maps also show that ***IR46-48***Markovo, Provadia and Goren Chiflik (o, Fig. 3) are far off the coastal zone by 50 – 70 km. As a result the irrigation depth by “Zahariev-1986” surpasses the simulated one if using Northern-Black Sea climate data observed in the ***MS*** Varna (Table 2). The “Zahariev” irrigation depth surpasses the simulated one by 110 mm in the dry year (P_I=10) and only in the case of soils of “large” ***TAW***. The difference however becomes smaller (20 – 50 mm) for soils of “small” ***TAW***.

Regarding ***AC*** region IV of 286<$ETo_{Jul\text{-}Aug}$ <292 mm, the combinations of irrigation depth are four at the ***IR17-22***Pleven (Table 2, Fig. 3). Table 2 shows that experimentally based seasonal irrigation depths of 300, 300 and 240 mm at a probability level P_I=10, P_I=25 and P_I=50% [1] occur in half of the studied ***IR*** of ***AC*** region IV.

Relative to ***AC*** region V of $ETo_{Jul\text{-}Aug}$=326 mm, the irrigation depth increases by 60 mm during the dry year [1] if compared with the respective relative to the former ***AC*** region IV. In the average demand year however the seasonal irrigation depth increases only in the southernmost ***IR66***Petrich, ***81***Svilengrad and ***65***Sandanski (Table 2).

Finally, it could be concluded that net irrigation requirement ***NIR*** simulated by the validated WinISAREG model varies in a larger range than that published by Zahariev et al. [1]. Thus, the model takes better into account the impact of variable water holding capacity of the soil and climate uncertainties in this country.

3.3. Mapping and Analyses of Irrigation Requirements

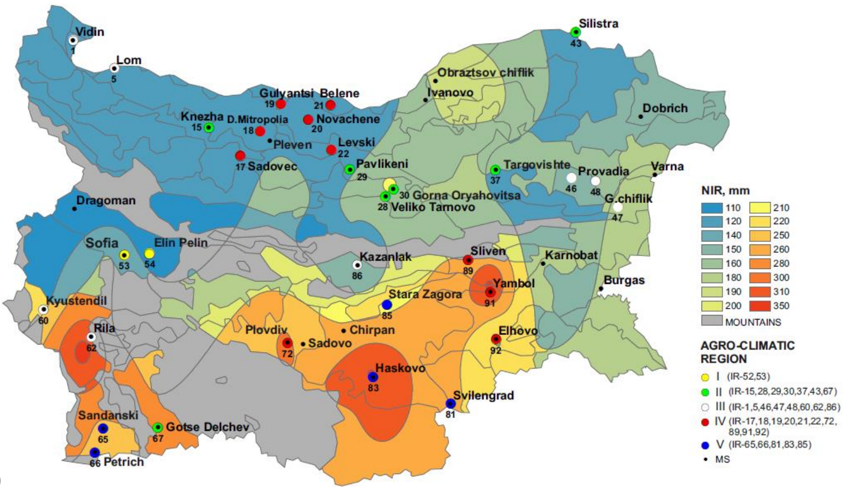
It is of great interest to follow the dynamics of “wet” and “dry” areas on maps representing Net Irrigation Requirement distribution in a country scale relative to the year of “average”1970, “moderate”1981 and “extremely"2000 irrigation demand in the 1951-2004 period (Figs. 3a, 3b, 3c). Symbols and names of ***MS***, numbers of ***IR*** [1] unified in five Agro-Climatic ***AC*** regions according to average total $ETo_{Jul\text{-}Aug}$ are plotted as well (Figs. 3a, 3b, 3c).

Spatial distribution of ***NIR*** in Fig. 3a proves that 1970 is really “average” in terms of irrigation requirements over II, IV and V ***AC*** regions in South Bulgaria. However, it is rather “wet” for ***AC*** regions I (Sofia), II, III and IV (Central and North-West Bulgaria). The same is indicated by the probability curves of occurrence of a ***NIR*** relative to different locations showing that probability P_I in 1970 is within the range 45 – 60% for Tsalapitsa, Stara Zagora, Sandanski and Sofia while P_I=25% for Plovdiv (Figs. 1 and 2) [4; 21; 23]. It is observed also that in 1970 the dominant code over the Thrace, South Bulgaria, is “brown” of ***NIR***=250 mm and “orange” of ***NIR***=300 mm, indicating a higher drought intensity around Haskovo, Yambol and Rila. “Yellow” code of ***NIR***=220/230 mm spreads over the ***IR*** of Elhovo and Stara Zagora, while a “green” code of ***NIR***=180 mm pervades along the Black Sea coastal area.

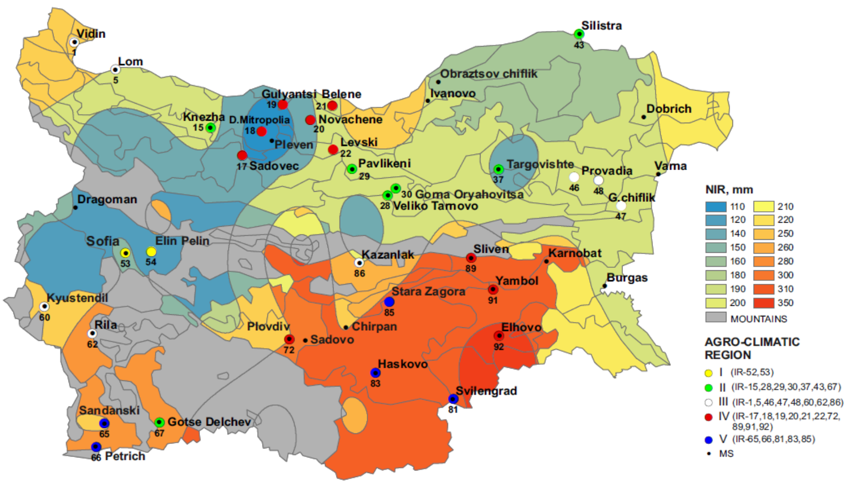
In 1970 the “blue” code of 110<***NIR***<120 mm prevails in ***IR52***Sofia and ***IR53***Elin Pelin (***AC*** region I), over Central and North-West Bulgaria (***AC*** regions II, III, IV) and also around ***IR43***Silistra and ***IR37***Targovishte. Logically, such a low irrigation requirement has a high level of probability of occurrence in ***IR17-22***Pleven, ***IR5***Lom (P_I=90 – 95%) and ***IR43***Silistra (P_I=70%) [4; 21; 23]. Net irrigation requirement increase to 150 – 180 mm at probability level P_I=85% in ***IR46-48*** around Varna.

During the “moderately dry” 1981 (Fig. 3b) the whole territory of ***AC*** regions IV (Plovdiv, Sliven, Yambol, Elhovo) and V (Stara Zagora, Haskovo and Svilengrad) in South Bulgaria is caught by a high intensive drought of “orange” code for ***NIR***=350 mm. On the contrary, the “blue” wet zone of 110<***NIR*** <120 mm shrinks substantially in North Bulgaria to ***IR***17, 18, 19 and 20 around Pleven and ***IR***37 Targovishte. The ***IR*** of Knezha, Belene, Levski and Pavlikeni in ***AC*** regions II and IV pass over to the zone of a higher ***NIR***=190 mm. A typical feature of 1981 is that in North Bulgaria dryness sweeps the lands around Vidin, between Ivanovo and Belene (***NIR***=250 mm) and near by Shabla (***NIR***=210 mm).

During the “extremely dry” 2000 the “blue” zone of “small” ***NIR*** disappears, while drought intensity increases all over the country (Fig. 3c). As a result, Net Irrigation Requirement reaches the record 490 mm in ***AC*** regions IV (Sliven) and V (Stara Zagora), 440 mm in Kazanlak, Yambol and Svilengrad, 410 mm in Plovdiv, Elhovo and Rila and 390 – 340 mm in ***AC*** region I (Sofia). The “yellow” code of ***NIR***=240 – 290 mm dominates the extreme East and West regions of North Bulgaria. “Brown” zone of ***NIR***=410 mm appears in ***IR***15Knezha, 28Veliko Tarnovo, 30Gorna Oryahovitza and Obraztsov chiflik, while the “green” code relative to ***IR***18-22Pleven, ***67***Targovishte, ***43***Silistra and ***46-48*** Varna point out to ***NIR***=310 – 330 mm.



a)



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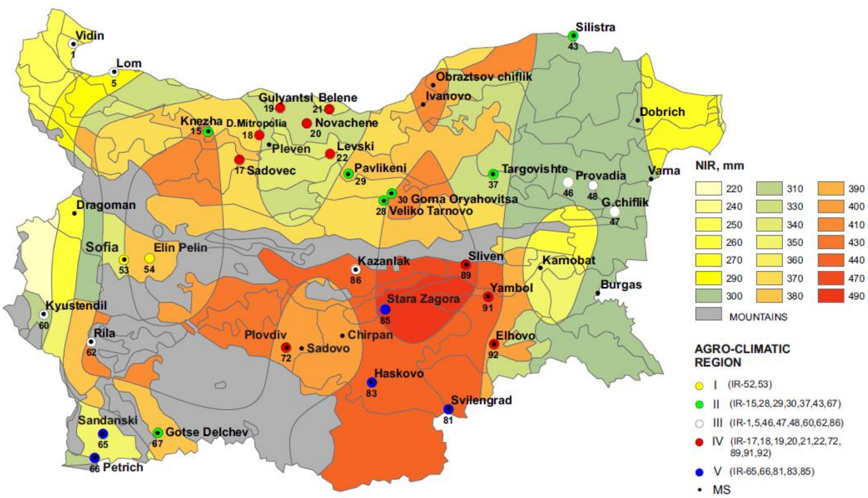

c)

Figure 3. Map of Meteorological Stations MS (.), Unified Irrigation Regions IR [1] and Agro-Climatic AC Regions (, , , ,) (Tables 1 and 2) and Net Irrigation Requirements of maize (NIR,mm) relative to: a) an "average" 1970; b) a "moderately dry" 1981 and c) the "extremely dry" 2000, 1951 – 2004

The main difference between methodology presently developed and that of Zahariev et al. [1] is the number of defined irrigation regions ***IR***. Regarding "Zahariev", their number is 97 while our results are related to only five unified Agro-Climatic regions and three soil groups in terms of soil water holding capacity. In this way, the information derived by the proposed methodology consists of only one page per crop (Table 1). Thus, if 31 crops are considered, including the Methodology section, only 35 pages will be required instead of more than 640 p. in [1]. Such a multiple reduction of information on net irrigation requirements will facilitate considerably its use and practical application in this country.

An advantage of the developed methodology is also that the built probability curves of occurrence of a ***NIR*** are within the range 2 %< P_I <98 %, such as the book [1] does not comprise. That sort of ***NIR*** provides an opportunity to evaluate economical income of irrigation all over the range of climate variability and change in this country [4; 23]. In addition, maps of spatial ***NIR*** distribution and unified Agro-Climatic regions relative to maize crop have been worked out.

4. Conclusion

1. The book of Zahariev et al. (1986) provides information on seasonal irrigation depth relative to 31 crops and 97 Irrigation Regions (***IR***) at three levels of probability of occurrence of a depth, namely: 10, 25 and 50% [1]. Data are based on empirical results relative to the period 1950-1980 and had been used in design and exploitation of national irrigation systems till 1990.

2. Net irrigation requirements ***NIR*** relative to maize crop are determined on the basis of a 54-year climate data (1951 – 2004) for three groups of soil by using the previously validated WinISAREG simulation model [16 – 19]. Climate variability and change during the specified period have been accounted for.

3. A methodology that defines net irrigation requirements for maize relative to five unified Agro-Climatic regions and three levels of total available soil water is developed. Irrigation regions' unification over the arable country lands is based on average reference evapotranspiration totals $ET_{0July-Aug}$ computed by the Penman-Monteith equation [10].

4. Regarding the remaining irrigated crops, the number and borders of Agro-Climatic regions, as well as the value of respective average ET_0 totals, will be different.

5. Net Irrigation Requirement is presented within the range $10\% < \boldsymbol{P_I} < 90\%$ of probability of a ***NIR*** occurrence (Table 1). That makes possible to build probability of exceedance curves for ***NIR*** in the whole range of present climate variability and change in Bulgarian plains.

6. Created maps of Net Irrigation Requirement and unified Agro-Climatic regions visualize finding of the study.

7. Considering the study objectives, accuracy of net irrigation requirements found by the developed methodology is completely satisfactory. At the same time, it reflects the impact of present climate uncertainties. Multiple reduction of required information facilitates methodology use in design and exploitation of the irrigation systems.

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ОПТИМАЛНО РАЙОНИРАНЕ НА НАПОИТЕЛНИТЕ НОРМИ ПРИ ПРОМЕНЯЩИЯ СЕ КЛИМАТ В БЪЛГАРИЯ

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Ключови думи: *регионални напоителни норми, еталонна евапотранспирация ETo, модел WinISAREG, климатични промени*

РЕЗЮМЕ

Нетните напоителни норми (***NIR***, mm), които задоволяват напълно нуждите на селскостопанските култури, са в основата на проектирането и управлението на напоителните системи. В българската земеделска практика традиционно се използват поливните режими и напоителните норми на Захариев и кол. (1986), които се отнасят за три години с обезпеченост на напоителната норма P_I=10, P_I=25 и P_I=50% от периода 1950 – 1980. За справяне с проблемите в напояването, предизвикани от климатичните промени и тенденциите към засушаване, в настоящото изследване моделът за симулиране на водния баланс и поливния режим WinISAREG е приложен за пет обединени агроклиматични ***AC*** района при условията на климата в миналото (**1950 – 1980**) и настоящето (**1951 – 2004**). При наши предишни изследвания WinISAREG е калибриран за царевица на основата на данни от дългосрочни експерименти, проведени в полета, представляващи разнообразни почвени, климатични и управленчески условия на напояването у нас. Оптималните ***AC*** райони са дефинирани на основата на осреднената сумарна еталонна евапотранспирация за юли и август $ET^o_{Jul\text{-}Aug}$ за периода **1951 – 2004.** По този начин осреднената сумарна $ET^o_{Jul\text{-}Aug}$ е приложена за обединяването на напоителни райони по "Захариев" в пет Агроклиматични (***AC***) района и е използвана за индикатор на регионалната нетна напоителна норма ***NIR*** (Табл. 1). Влиянието на свойствата на почвата върху нуждите от напояване са характеризирани чрез използваемия воден запас ***TAW***, mm m^{-1}, който е "нисък" ако ***TAW=116*** mm m^{-1}, "среден" ако 136<***TAW***<*157* и "висок", когато 173<***TAW***<*180* mm m^{-1}. Съответните ***NIR***, mm, са изчислени за всяка година от периода 1951 – 2004 чрез приложение на модела WinISAREG за всеки ***AC*** район при групите почви с „нисък" и „висок" ***TAW***. Резултатите показват, че когато осреднената регионална сумарна $ET^o_{Jul\text{-}Aug}$ нараства от **260** до **330 mm** за земеделската територия на страната, съответната напоителна норма на царевица ***NIR*** се увеличава от **160 на 310 mm** за почвите с "нисък" ***TAW*** през "средна" година ***(P_I=50%)***. По отношение на климата в миналото **1951 – 1980,** традиционните напоителни норми на „Захариев" са обединени и сравнени със симулираните (табл. 2). Резултатите показват, че в повечето случаи нуждите от напояване по "Захариев" са в диапазона на изменение на симулираните ***NIR***. В

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заключение, моделът отразява по-точно влиянието на колебанията и промените на климата и на различията във водозадържащия капацитет на почвата ***TAW***. Карти с обозначено местоположение на Агрометеорологичните станции и Поливните райони, както и на обединените Агроклиматични райони онагледяват получените резултати за територията на страната и показват ясно настъпилите промени в очертанията на “влажните“ и “сухи“ зони, характеризирани чрез нетна необходимост от напояване ***NIR*** през “средна“ (1970), “умерено-суха“ (1981) и “екстремно суха“ (2000) година за 54-годишен период.