

Yemen Optimum Agricultural Map to Water Conservation

Abdullah Yaya and Adel Al-Weshali

Agric. Eng. Dept., - Fac. of Agric., Univ² of Sana'a, Yemen

Abstract

The annual water consumption of Yemen is estimated as 3.4 billion cubic meter, with a shortage of 26% which withdraws from ground water storage through more than 50,000 wells. This decreases ground water level (0-6m/year). The agricultural production represents 21% of national return, where it consumes 90% of water. This due to, farmers depend upon traditional irrigation systems (35% efficiency) without any information about the exact crops water requirements. This research aims to redistribute the agricultural activity (crop, location and season) from water conservation vision. The research had been conducted on Yemen's five climates areas (12 zones) and (247 crop/season) by determining each crops water requirements and irrigation water scheduling, predicted yield depending only upon rainfall quantity of water to be applied using different modern irrigation systems. Calculations had been done depending on data each of area climate, crop coefficients and soil type by using a computer program (FAO). Several new economical and food crop indicators (Productivity, Price, Rarity and Stomach), environmental and agricultural area indicators (irrigation requirement, groundwater, water requirement, rain and yield without irrigation) had been used for determining optimum crops (economical- food-environmental-water) of area and optimum areas (environmental -water) of crop in Yemen. Data shows – as sample- that the optimum crops to be cultivated in Zabid area or other similar areas are pulses (season 15day/7month), Sorghum.15/7, Sesame.15/8, Millet.1/9, melon.1/4, Vegetable.15/10, Tomato.15/9, Maize.15/9, Sesame.1/1, Onion.15/10, Melon.1/1, Millet.1/3 and tobacco15/10 respectively. Also, It is recorded the pest environmental area to cultivate each of Sorghum15/7 cotton1/8 sesame15/8 and date-palm15/11. In addition, it is recorded optimum area for cultivating Sorghum15/7 and sesame15/8.

Keywords: irrigation scheduling - optimum agriculture - water conservation - water requirement – Yemen.

Introduction

Climatically, Yemen situated under dry zone located between latitude 12° and 20° northern and longitude 41° and 54° eastern. Area of Yemen is estimated as 550000 km², where its population estimation is 20 million approximately. The cultivated area of Yemen is estimated to be about 1,188,888 ha (hectares) of which 54% is depending on rainfall, while 46% is irrigated by groundwater (407896 ha.), surface water from seasonal water floods (89363 ha.) and the latter (33924 ha) are irrigated by springs (Agricultural Statistical Year book, 2004). Agriculture contributes represents 21% of the gross domestic product in Yemen, and employs 60% of Yemeni population. The main agricultural crops products in Yemen are; fruits (mango, grape, citrus, banana,

papaya and date), vegetables (tomato, potato, water and sweet melon, onion and cucumber), cereals (maize, wheat, sorghum and barley), high value crops (sesame, cotton, tobacco and coffee) and qatt. The rainfall is considered as the mean water resources in Yemen and the average annual rainfall ranges from less than 50 mm in the coastal areas and the deserts to 200-400 mm on the slopes of the highlands and more than 1000 mm on the western slopes of the mountains. The annual water consumption is estimated as 3.4 billion cubic meters. More than 90% of annually consumed water goes to meet agriculture demand out of this only 40% is actually used by plants and the remaining water resources are wasted either as deep percolation or as evaporation. The annual renewable water is estimated as 2.5 billion cubic meters (1.5 billion m³ as surface water and 1 billion m³ as ground water), so the overdrew is about 0.9 billion m³ withdrawer every year from the conserved ground water stoke throw more than 50 thousands wells that had been drilled. The disturbing ground water withdraw caused rapidly and high drawdown in ground water level in several ground water basins as in Sana'a basin (6-8 m(meter)/year), Tehama (1-3 m/year), Sadah (5-6 m/year), Amran (3 m/year), Taiz (1.75-2 m/year) and Abien (0.2-1 m/year) (statistical year book 2004). Concerning irrigation operations used in Yemen, the absolutely depending on traditional irrigation systems as surface irrigation – marked with inappropriate applying - resulting in low irrigation efficiency and decreasing the water use to 35%. From all above reasons coming the goals of this research. It aims to redistribute the agricultural activity (crop, location and season) from water conservation vision depending on historical climate data of each area, crop coefficients and soil type by using a computer program (FAO). The research had been conducted on Yemen's five climates zones (12 areas) and (247 crop and season), and realize research's goals the next logic method steps had been followed:-
Step 1: FAO computer program was used for determining each of:

- 1- The theoretically crops water requirements, based on metrological data, crop coefficients and soil type for each area and each season.
- 2- Estimated yield indicator (percentage) for each area and season, depending only upon rainfall without any additional irrigation operations.
- 3- The theoretically crops irrigation water requirements, number and amounts of additional irrigation water operations and irrigation intervals.

Step2: the economical, food, environmental and water indicators were contrived to determine both of:

- 1- The optimum crops and seasons of each area, depending on average of the area crops agriculture indicator.
- 2- The optimum areas and seasons of each crop in Yemen (12 areas), depending on average of the crop areas optimum indicator.

Materials and methods

Yemen has five different climate zones. These five zones were been studied as following: In climate coastal zone, Hodeidah represents the western coastal area. And, Jamisha represents the area between coast and down below the western mountains. Wadi-zabid represents the area excite down from the western mountains in the western

coastal area. Meanwhile, in southern coastal zone, al-kod area represents the area located near southern coast. Where, Lahje represents the area located down from southern mountains. Southern high lands zone is represented by bath of Taiz and Ibb areas. Where, Dhamar area simulates the Central high lands zone. Meanwhile, Sana'a, Amran and Sadah areas represent the northern high lands zone. At last, Sieyon area represents the eastern desert zone. The data of climate about 12 areas include, monthly average of daily of maximum and minimum air temperature, wind speed, sunshine, air humidity and rainfall, data had been collected during last several years (7-50years) from 12 metrological stations in appendix (a) (civil aviation & meteorology authority 2002. abdalkader 1998. CLIMWAT 1994). The data of important crops that cultivated in each one of the main five climate zones under study had been collected in appendix (b), the data of crops are included, plantation dates and seasons, period of each growth stage, crop coefficients of each growth stage, initial and maximum root depth, friction of soil moisture depletion of each growth stage, crop response coefficient for water stress for each crop growth periods and medium Soil properties (Doorenbos & Kassam 1979. AL-mujahed 1980. Brouwer *et al* 1986. Snyder *et al* 1989a, 1989b. Smith 1992. Allen *et al* 1998. Mukred *et al* 1998a, 1998b, 1998c. Agricultural statistical year book 2004).

Crops data calculations are included each of:

First, the data of crops water requirements and irrigation water requirements, yield indicator (predicted percentage of crop residual yield depending only on rainfall and without any additional irrigation), irrigation scheduling of each crop during each cultivation season had been calculated of each area by using *CropWat For Windows Version4.3 program (FAO)*, depending on collected climate data of each area, soil type, agronomy data and crops coefficients of each climate zone. Calculations had been done in appendix (c) to determine each of:

- 1- Monthly average of daily crop reference evapotranspiration for each month by year in each area under study depending on its climate information and according to FAO Penman-Monteith method (Allen *et al* 1998).
- 2- Monthly effective rain accrued in each area during the year using developed proposed by America institute for soils USDA by computer program (Allen *et al* 1998).
- 3- Crop water requirements in each area depending on agronomy information and crops coefficients and corresponds reference crop water requirements (Eto) data in step 1 (Snyder *et al* 1989a, 1989b).
- 4- Estimated yield percentage of each crop depending only on rainfall and without any additional irrigation operations of each area. Calculation had been done by using FAO computer program (Doorenbos & Kassam 1979).
- 5- Crops irrigation water requirements and irrigation scheduling depending on soil classification characteristics, root zone depth, crops water requirements and effective rain (Brouwer *et al* 1986) using computer program and according to next propositions:
 - Irrigation accruing when depleting 100% of readily available soil moisture in root zone.
 - Irrigation accruing to root zone until it reach 100% of readily available water.

Second, area crops agriculture indicator and average of area crops agriculture indicator are the decision indicators that determine which crops to be cultivated and its

preferable season in each zone under study by using equations (1-11). Crop areas optimum indicator and average of crop areas optimum indicator are the decision indicators that used to determine the preferable area in Yemen and the suitable season to cultivate each crop under study by using equations (12-17) as follow.

1- Area crops agriculture indicator (ACAI)

Values of this indicator differ from crop to another and vary from zero to one. As shown in tables (3-14).). This indicator is helpful to determine the preferable crop and season that ensure high crop water use efficiency with high productivity. So, the goal of applying this indicator is to conserve water through each of area crops by using the combination of both other indicators: area crops environmental indicator (ACEI) and Area groundwater indicator (AGWI), and realize a considerable economic return with a food security through Yemen crop Economic and feed indicators (YCEFI), Values of ACAI indicator were calculated using Equation (1):

$$ACAI = (YCEFI + ACEI + AGWI)/3 \dots\dots\dots (1)$$

1.1-Yemen crops Economic and feed indicators (YCEFI)

This indicator shows how much is the crop economic and food importance. Its values vary form o to 1. More YCEFI value reach 1 more the crop is preferable, As Shown in table (1). Calculating of YCEFI as in Equation (2) is depending on other several indicators, they are Price, Rarity, Productivity and Stomach Indicator.

$$YCEFI = (Productivity Indicator + Price Indicator + Rarity Indicator + Stomach Indicator)/4 \dots\dots\dots (2)$$

1.1.1-Productivity indicator

Crops productivities (ton/hectare) had been determined as Shown in table (1). From data, mango has the highest average of productivity in Yemen as 15. 246 ton/ha, so mango has been considered as a comparison parameter with other crops and it takes the value of 1 By using equation (3) other values of crop productivity indicator had been calculated as following:

$$Productivity Indicator = 1 - ((max. Productivity Crop (ton/ha) - Productivity Crop (ton/ha))/max. Productivity Crop (ton/ha)) \dots\dots\dots (3)$$

1.1.2-Price indicator

Crops prices (Riyal/Kg) have been determined according to prices of Sana'a central market. As Shown in table (1) indicating crop prices, coffee has the highest price 630 Ry/Kg among other crops, so coffee was selected as a comparison parameter with other crops prices and its price indicator take the value of 1 when applying Equation (4):

$$Price Indicator = 1 - ((max. Price Crop (RY/kg) - Price Crop (RY/kg))/ Price Crop (RY/kg)) \dots\dots\dots (4)$$

Table (1) indicators of yemen crops (economic and feed) and average crop areas optimum.

Crops	Productivity		Price		areas	Rarity	Stomach		ycefi ¹	acaoui ²
	Ton/Ha	I*	Ry ³ /Kg	I*	No:	I*	Propriety	I*		
Mango	15.246	1.00	150	0.24	3	0.80	7	0.29	0.58	0.53
Onion	14.510	0.95	70	0.11	7	0.53	15	0.63	0.56	0.42
Potato	11.960	0.78	75	0.12	7	0.53	17	0.71	0.54	0.46
Tomato	14.290	0.94	60	0.10	11	0.27	18	0.75	0.51	0.46
Citrus	11.120	0.73	110	0.17	5	0.67	11	0.46	0.51	0.45
Coffee	0.340	0.02	630	1.00	9	0.40	13	0.54	0.49	0.41
Vegetable	7.690	0.50	55	0.09	5	0.67	16	0.67	0.48	0.46
Pomegran.	8.530	0.56	150	0.24	2	0.87	6	0.25	0.48	0.31
Grape	7.380	0.48	135	0.21	3	0.80	9	0.38	0.47	0.29
Melon	13.270	0.87	50	0.08	4	0.73	3	0.13	0.45	0.51
D-Palm	1.410	0.09	249	0.40	3	0.80	12	0.50	0.45	0.49
Banana	8.780	0.58	75	0.12	4	0.73	8	0.33	0.44	0.45
Apple	5.770	0.38	145	0.23	4	0.73	10	0.42	0.44	0.42
Barley	0.740	0.05	50	0.08	5	0.67	20	0.83	0.41	0.47
Wheat	1.200	0.08	80	0.13	9	0.40	24	1.00	0.40	0.42
Peach	3.620	0.24	130	0.21	2	0.87	5	0.21	0.38	0.53
maize	1.100	0.07	65	0.10	8	0.47	21	0.88	0.38	0.52
Pulses	1.210	0.08	145	0.23	9	0.40	19	0.79	0.38	0.28
Tobacco	2.150	0.14	272	0.43	2	0.87	1	0.04	0.37	0.56
Millet	0.670	0.04	68	0.11	9	0.40	22	0.92	0.37	0.51
Apricot	1.860	0.12	150	0.24	1	0.93	4	0.17	0.37	0.42
Sesame	0.580	0.04	185	0.29	9	0.40	14	0.58	0.33	0.58
Cotton	1.020	0.07	140	0.22	3	0.80	2	0.08	0.29	0.52
Sorghum	0.670	0.04	66	0.10	15	0.00	23	0.96	0.28	0.54

I* = indicator

ycefi¹ = Yemen crops Economic and feed indicator.acaoui² = average crop areas optimum indicator.Ry³ = Yemen's Riyal \approx 0.005\$

1.1.3- Rarity indicator

Number of Yemeni provinces that cultivate each crop had been determined. The minimum crop cultivated area of 500 ha had taken as a condition to consider any province as a crop cultivated province. Apple was excepted out from this condition, regarding to its newest introducing into Yemeni agriculture. So, Apple condition of minimum area was estimated to be 50 ha only. Apricot Crop is the crop that cultivated only in one province (Sana'a) with a considerable trade quantity so its rarity indicator is the highest value. Meanwhile the sorghum crop that appears being cultivated in numerous provinces (15 provinces), so its rarity indicator has the value of zero (lowest rarity value) As Shown in table (1) using equation (5):

Rarity Indicator = (Highest Province Number - Province Number)/ Highest Province Number..... (5)

1.1.4- Stomach indicator

24 crops had been taken under study in the research. This, 24 crops had been classified starting from the lowest important stomach crop to the highest important stomach crop. The most important stomach crop as in table (1) is wheat crop; it has been taken as a parameter to compare with the other crops as in equation (6):

Stomach Indicator = 1- ((Highest Order of Crop - Order of Crop)/Highest order of crop)..... (6)

1.2- Area crops environmental indicator (ACEI)

It is an indicator that represents how much the preference and accordance of each crop from water situation point of view to cultivate an each area. Values of indicator vary between (0-1). More the indicator value equal to one, more the areas are preferable and accordable to cultivate a specific crop especially from its water situation including precipitation rate As Shown in table (3-14). The ACEI is calculated as in Equation (7) depending on Area Crop yield Indicator (ACYI), Area crop rain indicator (ACRI), Area crops water requirement indicator (ACWRI) and Area crops irrigation requirement indicator (ACIRI):

$$ACEI = (ACYI + ACRI + ACWRI + ACIRI) / 4 \dots\dots\dots (7)$$

1.2.1- Area Crops yield Indicator (ACYI)

It is an indicator that determines quantity of residual yield that expected while depending only on rainfall without any addition irrigation operations. ACYI indicator is calculated for each crop and season in the area according to computer program (FAO) and its values is shown in table (3-14). The tables show that the more the area crops rainfall availability the more ACYI indicator takes the value of 1.

1.2.2- Area crops rain indicator (ACRI)

It is an indicator that determines the percentage of crops water requirement that can be available from rainfall in each season of the area. The values of ACRI according to computer program (FAO), the values of ACRI come through values of crops water requirement and crops irrigation requirement in tables (3-14) and using Equation (8):

$$ACRI = (CWR - CIR) / CWR \dots\dots\dots (8)$$

Where: CWR = crop water requirement (mm/crop).
CIR = crop irrigation requirement (mm/crop).

1.2.3- Area crops water requirement indicator (ACWRI)

It is an indicator that distinguish between crops of low water requirements (ACWRI reach to 1), and those of high water requirements (reach value of zero) according to

computer program (FAO) in each area, ACWRI values are calculated by take the values of the high crop water requirements (CWR_{max}) and crop water requirements in the area (tables 3-14) and using Equation (9):

$$ACWRI = (CWR_{max} - CWR) / CWR_{max} \dots \dots \dots (9)$$

Table (2) Groundwater basins characteristics and indicators in some areas of Yemen

Basin name	Water (million m ³)			provinces name	average drawdown meter	AAGWI ¹	AACAI ²
	storage	use	renewable				
Tehama	250000	810	550	Hodidah	2	0.71	0.46
				Zabid	2	0.71	0.49
				Jamisha	2	0.71	0.46
High lands	50000	500	100	Sana'a	7	0	0.36
				Amran	3	0.57	0.44
				Sadah	5	0.29	0.38
				Dhamar	3	0.57	0.46
				Ibb	2	0.71	0.59
				Taiz	2	0.71	0.51
mokala	10000000	575	500	Hadhramout	2	0.71	0.47
southern coast	70000	225	375	Abyn	0.6	0.91	0.49
				Lahj	1	0.86	0.48

AACAI¹ = average area crops agriculture indicator.

AAGWI² = average area groundwater indicator.

1.2.4- Area crops irrigation requirement indicator (ACIRI)

It is an indicator that distinguish between crops of low irrigation water requirement (high value) and those of high irrigation water requirement (low value reaches to zero) according to computer program (FAO) in the area. The highest crop irrigation water requirement (CIR_{max}) is taken as parameter to compare with the other crops in the same Area as shown in tables (3-14). Equation (10) is used to calculate ACIRI values:

$$ACIRI = (CIR_{max} - CIR) / CIR_{max} \dots \dots \dots (10)$$

1.3- Area groundwater indicator (AGWI)

It is an indicator that distinguish between Areas that characteristic with low annual groundwater level drawdown (values reach to one) and this of high annual groundwater level drawdown (values reach to zero) its values were calculated using Equation (11) and shown in table (2):

$$AGWI = (Highest\ area\ Drawdown\ (m) - area\ Drawdown\ (m)) / Highest\ area\ Drawdown\ (m) \dots \dots \dots (11)$$

2- Average area crops agriculture indicator (AACAI)

It is a constant value of each area and it is different from area to the other in Yemen, as shown in table (2) and figure (2). It is calculated by take the average of area crop agriculture indicator of all crops in the area. The values of AACAI had been calculated to facility taking a decision of which crops to be selected as optimum cultivated crops for each area from the watering and economic perspective (optimum crops is cultivated in the area that they have area agriculture indicator more than or equal average area agriculture indicator).

3- Crop Areas Optimum Indicator (CAOI)

With an over all view, this indicator aid to take a decision about where and when in Yemen every crop under study could be cultivated regarding conservation of available Yemen water resources. The area is optimum for crop cultivated when it has the highest crop areas optimum Indicator. The values of CAOI come through several indicators, as area groundwater indicator (AGWI) and Crop areas environmental indicator (CAEI). Values of CAOI indicator were calculated using Equation (12) and shown in tables (3-14):

$$CAOI = (AGWI+CAEI)/2..... (12)$$

3.1- Crop areas environmental indicator (CAEI)

It is an indicator that distingue between suitable environment area to cultivate crop and unsuitable. The values of Crop areas environmental indicator is ranged between 0-1, the area that gives the highest Crop areas environmental indicator, it is the optimum environment area to plant crop (the opposite is right). The values of CAEI come through several indicators, as crop areas water requirement indicter (CAWRI), crop areas Irrigation Requirement Indicator (CAIRI), crop areas yield Indicator (CAYI) and crop areas yield Indicator (CAYI). The values of CAEI indicator were calculated using Equation (13) and shown in tables (3-14):

$$CAEI = (CAYI+ CARI+CAWRI+ CAIRI)/4..... (13)$$

3.1.1- Crop areas water requirement indicter (CAWRI)

It is an indicator that classifies Areas according to its crops water requirement. ACWRI values were calculate using computer program (FAO) and shown in tables (3-14), By known the Area that has maximum crop water requirement (CWR_{max}) in areas and consider it as a parameter to compare with others water requirements of the same crop. Values of ACWR indicator were calculated using Equation (14) as following:
 $ACWRI = (CWR_{max} \text{ (in areas)} - CWR \text{ (of any area)}) / CWR_{max} \text{ (in areas)}..... (14)$

3.1.2- Crop areas Irrigation Requirement Indicator (ACIRI)

It is an indicator that classified Areas according to its crops irrigation water requirements which calculated by using computer program (FAO). By known the Area that has maximum crop irrigation water requirement (CIR_{max}) in areas and consider it

as a parameter to compare with others irrigation water requirements of the same crop. ACIRI values were calculated using Equation (15) and shown in tables (3-14)

$$ACIRI = (CIR_{max} \text{ (in Yemen)} - CIR \text{ (of any area)})/CIR_{max} \text{ (in areas)} \dots\dots\dots (15)$$

3.1.3- Crop areas yield Indicator (CAYI)

It is an indicator that determines quantity of residual yield that expected while depending only on rainfall without any addition irrigation operations. CAYI indicator is calculated for each crop in all areas and seasons. The highest yield indicator of the crop in the areas is taken as parameter to compare with the other areas of the same crop as shown in tables (3-14), Equation (16) is used to calculate ACIRI values:

$$CAYI = 1 - ((\text{The highest yield indicator of the crop in the areas} - \text{yield indicator of the crop in the area}) / \text{the highest yield indicator of the crop in the areas}) \dots\dots\dots (16)$$

3.1.4- Crop areas rain indicator (CARI)

It is an indicator that determines the percentage of crop areas water requirement that can be available from rainfall of crop in each seasons and areas. The values of CARI according to computer program (FAO), the values of CARI come through values of crop areas water requirement and crop areas irrigation requirement in tables (3-14) and using Equation (17):

$$CARI = (CWR - CIR) / CWR \dots\dots\dots (17)$$

4- Average crop areas Optimum Indicator (ACAOI)

Average crop areas Optimum Indicator values of crop cultivated for all areas had been calculated to be helpful in taking decision of which area to be selected as optimum cultivated area for each crop from the water and environment perspective. The value of ACAOI is constant of each areas and it differ of each crop, as shown in table (1). The area is optimum for crop cultivated if the value of the CAOI is more than or equal the value of the ACAOI, and the area is unsuitable if the value of the CAOI is less. This indicator is calculated by take the average of the crop areas optimum Indicator in each areas and seasons.

Results and discussions

Studies had been effectuated on data of water requirements, irrigation water requirements, irrigation operation scheduling and estimated yield percentage depending on rainfall only without any additional irrigation operation on most crops cultivated in 12 Areas representing the main five climates zone in Yemen as shown in tables (3-14). Values of invented indicators had been calculated and tabulated as mentioned previously to determining the following decisions:

1- Determine which crop to be cultivated and its preferable cultivated season in each Area under study using the area crops agriculture indicator and the average of area

crops agriculture indicator of every area to select the most suitable crops and its cultivated seasons.

2- Determine where and when cultivating the crops under study, by selecting its preferable area and properly season using the crop areas optimum indicator and the average of crop areas optimum indicator.

Firstly: Selecting the preferable crops and its seasons for each Area.

1- Crops water requirements

The results of crops data calculations are indicated that as shown in tables (3-14), the lowest water requirement values are 318, 305, 345, 416, 303, 256, 293, 316, 424, 380, 289 and 290 mm for crops and seasons of millet (1/9) (cultivated season day 1/ month 9), barley (1/7), pulses (15/11), sesame (1/1), millet (1/9), sorghum (1/5), barley (15/12), vegetable (15/10), barley (15/11), barley (15/11), barley (15/11) and pulses (15/11) for areas of wadi-zabid, Ibb, Jamisha, Hodeidah, Al-kod, Taiz, Thamar, Sieyon, Sadah, Sana'a, Amran and Lahje respectively.

Table (3) crops water requirements, Irrigation and indicators of wadi-zabid area.

Wadi-zabid area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
Pulses.15/7	396	87	0.92	0.86	0.65	0.71
Sorghum.15/7	370	0	1.00	0.95	0.65	0.79
Sesame.15/8	340	113	0.91	0.84	0.63	0.69
Millet.1/9	305	219	0.77	0.69	0.59	0.59
Tomato.15/9	554	498	0.35	0.47	0.57	0.51
Melon.1/4	452	334	0.39	0.56	0.57	0.52
Vegetable.15/10	348	304	0.30	0.52	0.57	0.51
Maize.15/9	348	213	0.40	0.62	0.57	0.62
Sesame.1/1	326	221	0.63	0.67	0.57	0.59
Onion.15/10	580	557	0.19	0.41	0.56	0.49
Millet.1/3	380	316	0.56	0.59	0.56	0.50
Melon.1/1	358	341	0.39	0.52	0.56	0.51
Tobacco.15/10	393	306	0.41	0.57	0.55	0.52
Citrus.15/10	1226	896	0.36	0.38	0.53	0.52
Maize.15/2	441	372	0.26	0.50	0.53	0.54
Sorghum.15/4	423	336	0.63	0.61	0.53	0.57
Cotton.1/8	739	521	0.57	0.55	0.52	0.55
Mango.1/10	1831	1363	0.43	0.25	0.51	0.52
Date.15/11	1683	1281	0.47	0.29	0.48	0.52
Banana.15/10	2020	1767	0.00	0.03	0.39	0.44
Average	676	502	0.50	0.54	0.55	0.56

Meanwhile, of the highest water requirements values are 2020, 1557, 2418, 2680, 1915, 2182, 435, 1684, 1567, 1111, 1012 and 1965 mm for crops of banana (15/10), mango (1/10), banana (15/10), banana (15/10), banana (15/10), onion (1/3), date-palm (1/10), citrus (1/1), coffee(1/4), coffee (1/4) and banana (15/10) for the areas of wadi-zabid, Ibb, Jamisha, Hodeidah, Al-kod, Taiz, Dhamar, Sieyon, Sadah, Sana'a, Amran and Lahje respectively.

Table (4) crops water requirements, Irrigation and indicators of Ibb area.

Ibb area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
potato.1/3	439	0	1.00	0.93	0.73	0.78
potato.1/6	437	0	1.00	0.93	0.73	0.79
potato.1/5	430	0	1.00	0.93	0.73	0.79
vegetable.1/4	396	0	1.00	0.94	0.71	0.77
tomato.15/2	557	59	0.95	0.85	0.69	0.75
vegetable.1/3	406	49	0.96	0.87	0.69	0.74
barley.1/7	318	0	1.00	0.95	0.69	0.79
wheat.15/5	381	0	1.00	0.94	0.68	0.78
pulses.1/5	371	0	1.00	0.94	0.68	0.78
coffee.1/4	863	71	0.99	0.81	0.67	0.77
maize.1/5	452	0	1.00	0.93	0.67	0.79
pulses.15/2	388	0	1.00	0.94	0.67	0.77
pulses.1/6	378	0	1.00	0.94	0.67	0.77
millet.1/4	344	0	1.00	0.94	0.67	0.77
apples.1/2	739	91	0.98	0.80	0.65	0.75
sorghum.1/4	399	0	1.00	0.94	0.64	0.79
apricots.1/2	684	106	0.99	0.80	0.63	0.72
pulses.15/1	400	152	0.76	0.71	0.60	0.65
tomato.1/8	589	308	0.66	0.55	0.59	0.62
barley.15/12	335	185	0.57	0.62	0.58	0.61
potato.1/9	472	329	0.45	0.47	0.57	0.56
mango.1/10	1557	511	0.78	0.38	0.56	0.68
potato.1/10	471	368	0.32	0.39	0.55	0.52
onion.1/9	519	460	0.44	0.35	0.54	0.54
onion.1/11	619	460	0.27	0.33	0.53	0.53
wheat.15/11	476	328	0.49	0.48	0.53	0.53
potato.1/11	469	426	0.22	0.31	0.52	0.49
onion.1/10	621	559	0.31	0.25	0.51	0.50
average	549	207	0.79	0.72	0.63	0.69

2- Crop Irrigation Requirement

As shown in tables(3-14), the lowest irrigation requirement values are zero, (zero) 240, 324, 203, 94, 171, 262, 317, 281, 189 and 188 mm for crops and seasons of sorghum (15/7), (potato of seasons 1/3, 1/5, 1/6, pulses of seasons 15/2, 1/5, 1/6, Vegetable1/4, barley1/7, wheat15/5, millet1/4, maize1/5 and sorghum 1/4), pulses (15/11), sesame (1/1), sorghum (15/7), barley (1/7), pulses (15/2), wheat (1/11), pulses (15/1), barley (15/11), barley (15/11) and sorghum (15/7) for areas of wadi-zabid, (Ibb), Jamisha, Hodeidah, Al-kod, Taiz, Thamar, Sieyon, Sadah, Sana'a, Amran and Lahje respectively.

Table (5) crops water requirements, Irrigation and indicators of Jamisha area.

Jamisha area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
Pulses.15/11	345	240	0.52	0.65	0.58	0.57
Millet.1/9	435	335	0.47	0.59	0.56	0.49
Sesame.15/8	433	301	0.55	0.64	0.56	0.52
Onion.15/10	686	682	0.12	0.39	0.55	0.44
Tomato.1/9	676	637	0.18	0.42	0.55	0.45
Pulses.15/7	501	386	0.45	0.58	0.55	0.49
Vegetable.15/9	425	417	0.20	0.47	0.55	0.44
Melon.1/1	401	397	0.31	0.50	0.55	0.47
Sesame.1/1	365	327	0.57	0.60	0.55	0.51
Melon.1/4	529	490	0.23	0.47	0.54	0.42
Maize.15/9	435	335	0.17	0.52	0.54	0.54
Tobacco.15/10	474	430	0.31	0.51	0.53	0.44
Millet.1/3	432	403	0.39	0.53	0.53	0.44
Sorghum.15/4	501	397	0.45	0.57	0.52	0.52
Maize.15/2	498	434	0.10	0.46	0.52	0.49
Sorghum.15/7	470	425	0.51	0.56	0.51	0.51
Citrus.15//10	1466	1403	0.14	0.25	0.49	0.40
Cotton.1/8	910	734	0.35	0.46	0.49	0.46
Mango.1/10	2185	2026	0.31	0.16	0.48	0.43
Date.15/11	2015	1989	0.31	0.16	0.44	0.41
Banana.15/10	2418	2370	0.00	0.00	0.39	0.38
Average	790	722	0.32	0.45	0.52	0.47

Meanwhile, the highest irrigation requirements values for crops of banana (15/10), onion (1/10), banana (15/10), banana (15/10), banana (15/10), onion (1/3), date-palm (1/10), citrus (1/1), coffee(1/4), coffee (1/4) and banana (15/10) are 1767, 559, 2370, 2550, 1872, 1640, 743, 1569, 1402, 908, 826 and 1909 mm for the areas of wadi-zabid, Ibb, Jamisha, Hodeidah, Al-kod, Taiz, Thamar, Sieyon, Sadah, Sana'a, Amran and Lahje respectively.

Table (6) crops water requirements, Irrigation and indicators of Hodeidah area.

Hodeidah area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
Melon.1/1	456	378	0.37	0.44	0.57	0.50
Pulses.15/11	418	327	0.52	0.51	0.57	0.53
Onion.15/10	816	738	0.18	0.45	0.56	0.44
Sesame.1/1	416	324	0.60	0.57	0.56	0.52
Vegetable.15/9	557	527	0.20	0.49	0.55	0.39
Melon.1/4	556	485	0.26	0.52	0.55	0.43
Millet.1/9	450	390	0.43	0.47	0.55	0.45
Tomato.1/9	829	780	0.18	0.44	0.54	0.40
Pulses.15/7	549	503	0.45	0.49	0.54	0.43
Sesame.15/8	493	395	0.51	0.52	0.54	0.47
Millet.1/3	461	418	0.43	0.44	0.54	0.43
Tobacco.15/10	573	485	0.33	0.42	0.53	0.42
Maize.15/2	538	447	0.16	0.44	0.53	0.50
Sorghum.15/4	526	403	0.48	0.51	0.53	0.52
Sorghum.15/7	520	386	0.49	0.49	0.53	0.53
Maize.15/9	518	412	0.15	0.54	0.53	0.51
Citrus.15/10	1634	1499	0.20	0.40	0.50	0.39
Cotton.1/8	1068	852	0.36	0.46	0.49	0.43
Mango.1/10	2422	2227	0.33	0.43	0.48	0.40
Date.15/11	2240	2002	0.34	0.41	0.45	0.41
Banana.15/10	2680	2550	0.00	0.38	0.39	0.36
Average	891	787	0.33	0.47	0.53	0.45

3- Area crops environment indicator:

The results are indicated as shown in figures (1) and presented tables (3-14), the highest area crops environment indicator values are 0.95, 0.95, 0.65, 0.63, 0.69, 0.84, 0.66, 0.59, 0.57, 0.55, 0.63 and 0.71 for crops of sorghum (15/7), barley (1/7), pulses (15/11), sesame (1/1), sorghum (15/7), barley (1/7), pulses (15/2), wheat (1/11) and sorghum (15/7), pulses (15/1), pulses (15/6), barley (15/7) and sorghum (15/7) for the areas of wadi-zabid, Ibb, Jamisha, Hodeidah, Al-kod, Taiz, Thamar, Sieyon, Sadah, Sana'a, Amran and Lahje respectively.

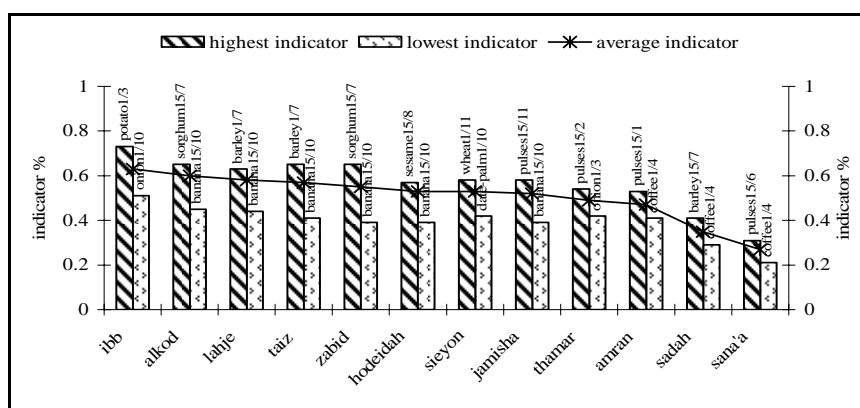


Figure (1) shows area crops environment indicator.

Table (7) crops water requirements, Irrigation and indicators of AL-kod area.

AL-kod area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
Millet.1/9	303	203	0.60	0.67	0.65	0.69
Melon.1/1	348	272	0.40	0.57	0.64	0.65
Sesame.15/8	330	210	0.65	0.68	0.64	0.69
Onion.15/10	588	544	0.18	0.41	0.63	0.59
Vegetable.15/9	377	321	0.26	0.51	0.63	0.60
Sorghum.15/7	350	195	0.62	0.69	0.63	0.74
Sesame.1/1	318	223	0.65	0.67	0.63	0.69
Pulses.15/11	303	254	0.60	0.62	0.63	0.67
Tomato.1/9	572	512	0.25	0.45	0.62	0.60
Melon.1/4	408	377	0.31	0.49	0.62	0.59
Pulses.15/7	371	335	0.52	0.56	0.62	0.62
Tobacco.15/10	404	338	0.38	0.54	0.61	0.60
Maize.15/9	352	285	0.30	0.54	0.61	0.67
Millet.1/3	348	314	0.49	0.56	0.61	0.60
Sorghum.15/4	381	302	0.57	0.60	0.60	0.67
Maize.15/2	409	367	0.20	0.47	0.59	0.62
Mango.1/10	1737	1538	0.35	0.18	0.56	0.59
Citrus.15/10	1169	1102	0.20	0.26	0.56	0.55
Cotton.1/8	739	684	0.41	0.43	0.55	0.58
Date.15/11	1600	1559	0.36	0.18	0.51	0.57
Banana.15/10	1915	1872	0.00	0.01	0.45	0.53
Average	634	562	0.40	0.48	0.60	0.52

Meanwhile, of lowest area crops environment indicator values for crops banana (15/10), onion (1/10), banana (15/10), banana (15/10), banana (15/10), banana (15/10), onion (1/3), date-palm (1/10), citrus (1/1), coffee(1/4), coffee (1/4) and banana (15/10) are 0.03, 0.25, 0.0, 0.01, 0.01, 0.09, 0.14, 0.11, 0.08, 0.15, 0.16 and 0.01 for areas of wadi-zabid, Ibb, Jamisha, Hodeidah, Al-kod, Taiz, Thamar, Sieyon, Sadah, Sana'a, Amran and Lahje respectively.

Table (8) crops water requirements, Irrigation and indicators of Taiz area.

Taiz area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
Barley.1/7	406	94	0.85	0.84	0.65	0.69
Wheat.15/6	490	172	0.79	0.78	0.63	0.65
Millet.1/4	492	214	0.85	0.76	0.61	0.59
Vegetable.1/4	567	399	0.60	0.60	0.60	0.50
Vegetable.1/5	552	372	0.59	0.61	0.60	0.51
Sorghum.1/6	532	212	0.86	0.77	0.59	0.65
onion.1/8	717	588	0.43	0.48	0.58	0.51
onion.1/9	701	573	0.34	0.46	0.58	0.50
Maize.1/4	636	296	0.60	0.67	0.58	0.60
Maize.1/5	617	303	0.58	0.66	0.58	0.60
Citrus.1/11	1330	700	0.55	0.50	0.57	0.57
Tomato.1/9	693	566	0.40	0.48	0.57	0.50
Barley.15/11	407	279	0.45	0.60	0.57	0.54
Sorghum.1/5	286	202	0.84	0.72	0.57	0.65
onion.1/10	706	605	0.24	0.42	0.56	0.48
Vegetable.15/10	474	418	0.28	0.48	0.56	0.45
pulses.15/10	448	340	0.53	0.59	0.56	0.52
onion.1/11	730	670	0.19	0.38	0.55	0.45
Tomato.1/10	701	633	0.29	0.42	0.55	0.46
Potato.1/11	597	552	0.13	0.40	0.55	0.42
Wheat.15/11	571	407	0.37	0.54	0.55	0.47
Coffee.1/3	1480	979	0.56	0.41	0.54	0.50
Tomato.1/11	730	648	0.22	0.40	0.54	0.45
Mango.15/8	1981	1362	0.53	0.28	0.52	0.54
Banana.15/10	2182	1640	0.10	0.09	0.41	0.47
Average	700	501	0.49	0.53	0.57	0.53

4- Area crops agriculture Indicator:

Tables (3-14) and figures (2) show that the highest area crops agriculture Indicator values are 0.65, (0.73), 0.58, 0.57, 0.65, 0.65, 0.58, 0.41, 0.31, 0.35 and 0.63 for the areas of wadi-zabid, (Ibb), Jamisha, Hodeidah, Al-kod, Taiz, Thamar, Sieyon, Sadah, Sana'a, Amran and Lahje for crops of sorghum (15/7) and pulses

(15/11), (potato of seasons 1/3, 1/5, 1/6), pulses (15/11), melon (1/1), millet (1/9), barley (1/7), pulses (15/2), tomato (1/1), pulses (15/1), pulses (15/6), barley (15/7) and millet (1/9) respectively.

Table (9) crops water requirements, Irrigation and indicators of Dhamar area.

Dhamar area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
pulses.15/2	425	171	0.74	0.66	0.54	0.57
Barley.15/7	368	186	0.65	0.63	0.53	0.55
Barley.15/2	363	192	0.63	0.61	0.53	0.55
Tomato.1/7	488	330	0.51	0.47	0.52	0.53
Potato.1/2	439	328	0.43	0.44	0.52	0.48
Potato.1/7	436	326	0.41	0.44	0.52	0.48
Vegetable.1/2	382	267	0.50	0.51	0.52	0.49
Barley.15/12	293	191	0.53	0.58	0.52	0.53
Wheat.15/6	420	260	0.64	0.56	0.51	0.51
Vegetable.1/7	394	291	0.50	0.49	0.51	0.48
pulses.1/1	384	239	0.65	0.57	0.51	0.52
Tomato.1/2	500	377	0.52	0.43	0.50	0.51
pulses.1/7	411	261	0.70	0.57	0.50	0.51
Apples.15/1	775	423	0.62	0.42	0.48	0.54
Apricots.15/1	713	417	0.65	0.44	0.46	0.49
Wheat.15/2	629	453	0.66	0.41	0.46	0.41
Onion.15/10	799	654	0.26	0.18	0.43	0.40
Sorghum.1/6	604	386	0.55	0.44	0.43	0.46
Onion.1/3	935	743	0.37	0.14	0.42	0.38
Maize.15/2	642	452	0.23	0.31	0.42	0.43
Average	520	347	0.54	0.46	0.49	0.49

Meanwhile, of lowest Area crops Agricultural indicator values for crops banana (15/10), onion (1/10), banana (15/10), banana (15/10), banana (15/10), banana (15/10), onion (1/3), date-palm (1/10), citrus (1/1), (coffee 1/4 and maize 1/6), (coffee 1/4 and Apricots 15/2) and banana (15/10) are 0.39, 0.51, 0.39, 0.39, 0.45, 0.41, 0.42, 0.29, (0.21), (0.41) and 0.44 for areas of wadi-zabid, Ibb, Jamisha, Hodeidah, Al-kod, Taiz, Thamar, Sieyon, Sadah, (Sana'a), (Amran) and Lahje respectively.

5- Average area crops agriculture indicator

The results in tables (3-14) and figures (2,3) is shown that the Average area crops agriculture Indicator values are 0.63, 0.6, 0.58, 0.57, 0.55, 0.53, 0.53, 0.52, 0.49, 0.47, 0.35 and 0.27 for the areas of Ibb, Al-kod, Lahje, Taiz, wadi-zabid, Hodeidah, Sieyon, Jamisha, Thamar, Amran, Sadah and Sana'a respectively. So, the optimum crops are cultivated in each area that its area crops agriculture indicator are more than

or equal average area crops agriculture indicator, then the cultivated optimum crops in each area respectively are below:

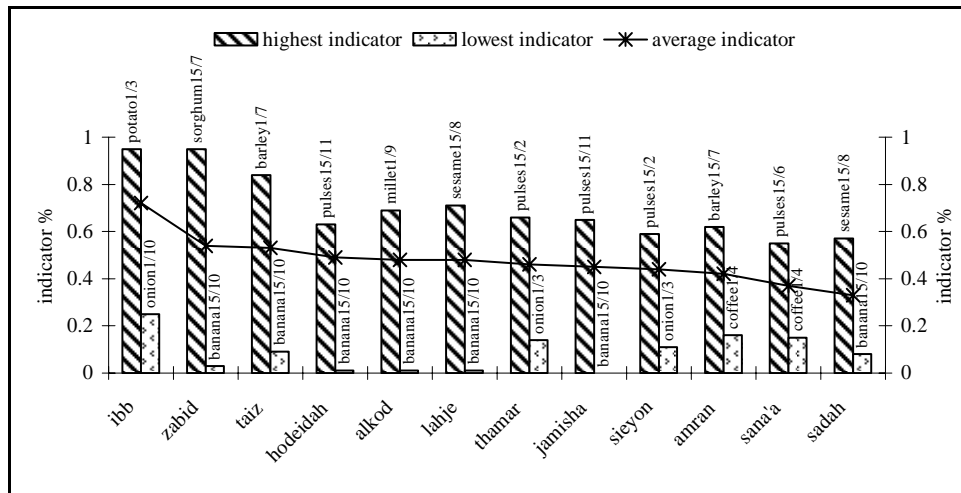


Figure (2) shows area crops agriculture Indicator

Table (10) crops water requirements, Irrigation and indicators of Sieyon area.

Sieyon area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
Tomato.1/1	624	527	0.25	0.52	0.58	0.54
Potato.1/11	326	292	0.20	0.48	0.58	0.54
Wheat.1/11	334	262	0.52	0.59	0.57	0.57
Vegetable.15/10	315	287	0.27	0.50	0.56	0.51
Tomato15/9	467	444	0.27	0.44	0.55	0.52
Melon.15/10	393	377	0.34	0.48	0.55	0.49
Onion.20/8	568	546	0.07	0.36	0.54	0.47
Vegetable.15/2	497	471	0.24	0.42	0.54	0.42
Melon.1/2	623	545	0.25	0.41	0.53	0.45
Pulses.30/4	475	399	0.45	0.52	0.53	0.48
Sorghum.15/7	366	307	0.61	0.59	0.53	0.58
Onion.15/2	812	766	0.06	0.29	0.52	0.41
Sesame.20/2	530	437	0.51	0.52	0.52	0.44
Sorghum.15/3	551	404	0.47	0.54	0.51	0.52
Citrus.15/11	1222	1096	0.21	0.22	0.48	0.46
Date.1/10	1684	1569	0.36	0.11	0.42	0.47
Average	612	546	0.32	0.44	0.53	0.49

- 1- Wadi-zabid preferable crops are Pulses.15/7, Sorghum.15/7, Sesame.15/8, Millet.1/9, melon.1/4, Vegetable.15/10, Tomato.15/9, Maize.15/9, Sesame.1/1, Onion.15/10, Melon.1/1, Millet.1/3 and tobacco15/10 respectively.
- 2- Ibb preferable crops are potato.1/5, potato.1/6, potato.1/3, Vegetable.1/4, tomato.15/2, Vegetable.1/3, barley.1/7, wheat.15/5, pulses.1/5, coffee.1/4, pulses.1/6, pulses.15/2, millet.1/4, maize.1/5, apple.1/2, Sorghum1/4 and Apricots 15/2 respectively.

Table (11) crops water requirements, Irrigation and indicators of Sadah area.

Sadah area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
Pulses.15/1	451	317	0.48	0.57	0.41	0.32
Potato.15/1	661	590	0.11	0.34	0.39	0.20
Wheat.15/12	516	428	0.36	0.47	0.39	0.25
vegetabl.15/1	514	481	0.21	0.40	0.39	0.20
Barley.15/11	424	382	0.38	0.48	0.39	0.26
Wheat.1/3	615	511	0.35	0.44	0.38	0.22
Pulses.15/6	584	485	0.46	0.48	0.38	0.23
Barley.15/7	570	476	0.34	0.45	0.38	0.21
Onion.1/1	978	890	0.15	0.25	0.36	0.18
Tomato.15/1	931	816	0.17	0.28	0.36	0.18
Grapes.1/2	1236	1125	0.37	0.22	0.33	0.20
Sorghum.15/5	735	601	0.42	0.43	0.33	0.22
Apples.1/1	1192	1043	0.35	0.24	0.32	0.20
Maize.1/6	853	773	0.04	0.26	0.31	0.16
pomegrant.1/2	1514	1375	0.33	0.12	0.30	0.20
Coffee.1/3	1487	1345	0.31	0.12	0.30	0.20
peach.1/2	1178	1056	0.37	0.24	0.30	0.20
CITRUS.1/1	1567	1402	0.20	0.08	0.29	0.20
Average	889	783	0.30	0.33	0.35	0.21

- 3- Jamisha preferable crops are Pulses.15/11, Millet.1/9, Sesame.15/8, Onion.15/10, Vegetable.15/9, Tomato.1/9, Melon.1/1, Pulses.15/7, Sesame.1/1, melon.1/4, Maize.15/9, Millet.1/3, Tobacco.15/10, maize.15/2 and Sorghum.15/4 respectively.
- 4- Hodeidah preferable crops are Melon.1/1, Pulses.15/11, Onion.15/10, Sesame.1/1, Melon.1/4, Vegetable.15/9, Millet.1/9, Tomato.1/9, Millet.1/3, sesame15/8, pulses15/7, tobacco15/10, maize15/2, Sorghum 15/7 and Sorghum 15/4 respectively.
- 5- Al-kod preferable crops are Millet.1/9, Melon.1/1, Sesame.15/8, Vegetable.15/9, Onion.15/10, Pulses.15/11, Sesame.1/1, Sorghum.15/7, Tomato.1/9, Melon.1/4, Pulses.15/7, Millet1/3, maize15/9, tobacco15/10 and Sorghum.15/4 respectively.

- 6- Taiz preferable crops are Barley.1/7, Wheat.15/6, Millet.1/4, Vegetable.1/4, Vegetable.1/5, Sorghum1/6, Maize.1/4, Maize1/5, onion.1/8, Barley.1/7, Citrus.1/11, Sorghum.1/6 and Tomato.1/9 respectively.

Table (12) crops water requirements, Irrigation and indicators of Sana'a area.

Sana'a area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
Pulses.15/6	502	298	0.57	0.55	0.31	0.19
vegetable.15/2	464	367	0.36	0.44	0.31	0.13
Barley.15/11	380	281	0.45	0.51	0.31	0.18
Tomato.15/2	589	469	0.35	0.38	0.30	0.17
Barley.15/7	535	344	0.46	0.49	0.30	0.14
Wheat.15/7	535	344	0.46	0.49	0.30	0.16
vegetable.1/6	490	391	0.38	0.43	0.30	0.13
Tomato.1/5	631	491	0.34	0.36	0.29	0.16
Wheat.15/12	474	328	0.41	0.48	0.29	0.16
Pulses.15/1	401	340	0.55	0.49	0.29	0.17
Wheat.1/3	621	417	0.41	0.43	0.28	0.12
pomegrante.1/2	869	641	0.50	0.32	0.27	0.21
Onion.1/4	841	681	0.29	0.24	0.27	0.11
Onion.15/2	812	672	0.24	0.24	0.26	0.11
Potato.15/2	692	594	0.17	0.26	0.26	0.06
Grapes.1/2	910	681	0.50	0.30	0.25	0.18
Potato.15/5	742	654	0.16	0.22	0.25	0.04
Sorghum.15/5	675	455	0.58	0.45	0.24	0.16
Apples.1/2	956	757	0.47	0.25	0.23	0.14
Peaches.15/2	904	640	0.51	0.32	0.23	0.18
Apricots.15/2	892	632	0.51	0.33	0.23	0.10
Sorghum.10/6	631	504	0.51	0.40	0.22	0.13
Coffee.1/4	1111	908	0.42	0.15	0.21	0.15
Maize.1/6	761	584	0.14	0.26	0.21	0.09
Average	718	544	0.41	0.37	0.27	0.14

- 7- Dhamar preferable crops are pulses.15/2, Barley.15/2, Barley.15/7, Barley.15/12, Potato.1/2, Potato.1/7, Tomato.1/7, Vegetable 1/2, pulses.1/1, Vegetable.1/7, Wheat.15/6, pulses.1/7 and Tomato.1/2 respectively.
- 8- Sieyon preferable crops are potato1/11, Tomato.1/1, wheat1/11, Vegetable.15/1, Melon.15/10, Tomato15/9, Onion.20/8, Vegetable.15/2, Melon.1/2, pulses30/4 and Sorghum15/7 respectively.
- 9- Sadah preferable crops are Pulses.15/1, Potato.15/1, Vegetabe15/1, Barley.15/11, Wheat.15/12, Barley.15/7, Pulses.15/6, Wheat.1/3, Onion.1/1 and Tomato.15/1 respectively.

- 10- Sana'a preferable crops are vegetable.15/2, Barley.15/11, Pulses.15/6, vegetable.1/6, Tomato.15/2, Barley.15/7, Wheat.15/7, Tomato.1/5, Wheat.15/12, Pulses.15/1, Wheat.1/3, Onion.1/4 and pomegrante.1/2 respectively.
- 11- Amran preferable crops are Barley.15/7, Barley.15/11, Pulses.15/6, Wheat.15/7, Wheat.15/12, Barley.15/2, Pulses.15/2, Pulses.1/1, Tomato.15/2, Vegetable.15/2, Tomato.15/5, Potato.15/5 and Wheat.1/3 respectively.
- 11- Lahje preferable crops are Millet.1/9, Sesame.15/8, Pulses.15/11, Sesame.1/1, Sorghum.15/7, Onion.15/10, Vegetable.15/9, Melon.1/1, Melon.1/4, Pulses.15/7, Millet.1/3, Maize.15/9, Tobacco.15/10 and Sorghum.15/4 respectively.

Table (13) crops water requirements, Irrigation and indicators of Amran area.

Amran area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
Barley.15/7	375	191	0.59	0.62	0.53	0.54
Barley.15/11	289	189	0.61	0.61	0.53	0.54
Wheat.15/7	406	260	0.57	0.55	0.51	0.51
Pulses.15/6	388	243	0.70	0.60	0.51	0.53
Barley.15/2	390	286	0.55	0.52	0.50	0.48
Wheat.15/12	365	253	0.51	0.54	0.50	0.50
Pulses.15/2	358	248	0.59	0.56	0.50	0.51
Pulses.1/1	358	248	0.56	0.55	0.50	0.51
Tomato.15/5	567	456	0.42	0.38	0.49	0.46
Tomato.15/2	535	406	0.35	0.39	0.49	0.48
VEGTABL.15/2	406	343	0.33	0.42	0.49	0.43
Potato.15/5	543	462	0.32	0.34	0.48	0.41
Wheat.1/3	458	357	0.52	0.46	0.48	0.45
Onion.1/4	765	613	0.34	0.26	0.46	0.42
Potato.15/2	515	497	0.23	0.29	0.46	0.39
Sorghum.15/5	492	311	0.67	0.54	0.46	0.51
Sorghum.10/6	468	335	0.67	0.52	0.46	0.51
Grapes.1/2	828	600	0.52	0.31	0.45	0.48
pomegrante.1/2	815	622	0.51	0.30	0.45	0.51
Onion.15/2	738	618	0.25	0.23	0.45	0.41
Maize.1/6	566	413	0.30	0.38	0.44	0.46
Apples.1/2	870	657	0.49	0.27	0.43	0.46
Peaches.1/2	815	622	0.51	0.30	0.42	0.47
Coffee.1/4	1012	826	0.45	0.16	0.41	0.45
Apricots.1/2	800	623	0.51	0.30	0.41	0.39
Average	603	466	0.48	0.42	0.47	0.47

**Secondly: Determining of preferable areas and seasons to cultivate each crop:
1- Crop areas environment indicator**

The results are calculated by equation (13) and indicated as shown in figure (4), the highest crop areas environment indicator values are 0.87, 0.87, 0.86, 0.83, 0.85, 0.84, 0.33, 0.82, 0.33, 0.67, 0.83, 0.38, 0.86, 0.79, 0.39, 0.79, 0.22, 0.64, 0.4, 0.33, 0.44, 0.44, 0.37 and 0.73 for areas and seasons of Zabid15/7, ibb1/5, ibb1/7, ibb1/4, ibb15/5, ibb1/5, zabid1/8, ibb1/4, zabid15/10, zabid15/8, ibb1/4, ibb1/9, ibb1/5, ibb15/2, alkod1/1, ibb1/2, taiz15/10, ibb1/10, amran1/10, zabid15/10, taiz1/11, amran1/2, amran1/2 and ibb1/2 for crops of Sorghum, maize, barley, millet, wheat, pulses, cotton, coffee, tobacco, sesame, vegetable, onion, potato, tomato, melon, apple, banana, mango, grape, date-palm, citrus, pomegranate, peach and apricot respectively.

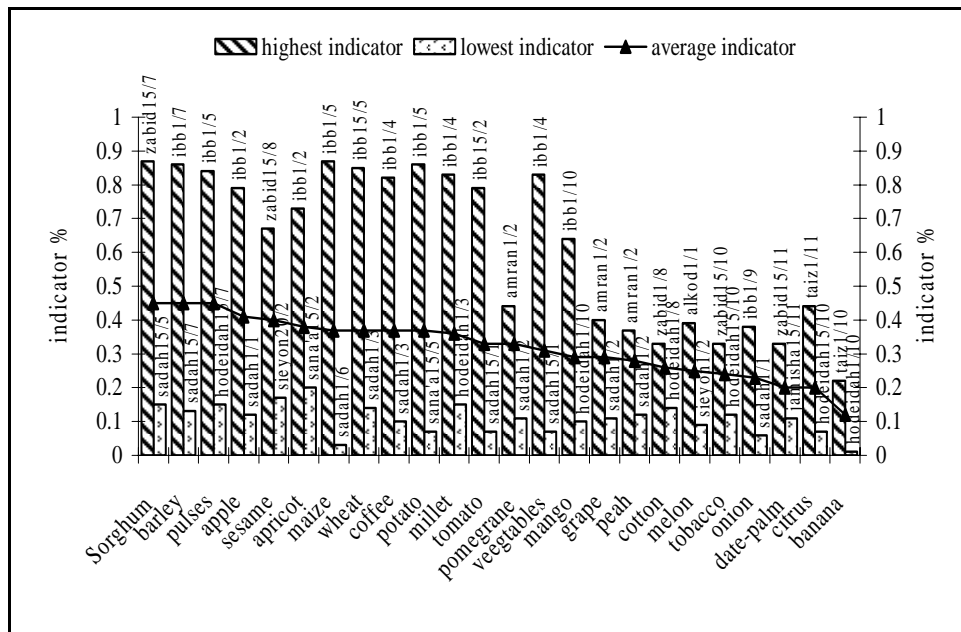


Figure (3) shows crop areas environment Indicator

Meanwhile, of lowest crop areas environment indicator values are 0.15, 0.03, 0.15, 0.14, 0.15, 0.14, 0.10, 0.12, 0.17, 0.07, 0.06, 0.07, 0.07, 0.09, 0.12, 0.01, 0.10, 0.11, 0.11, 0.07, 0.11, 0.12 and 0.20 for crops of Sorghum, maize, barley, millet, wheat, pulses, cotton, coffee, tobacco, sesame, vegetable, onion, potato, tomato, melon, apple, banana, mango, grape, date-palm, citrus, pomegranate, peach and apricot for areas and seasons of sadah15/5, sadah1/6, sadah15/7, Hodeidah1/3, sadah1/3, Hodeidah15/10, Hodeidah11/8, sadah1/3, Hodeidah15/10, Sieyon20/2, sadah15/10, sadah1/1, sana'a15/5, sadah15/1, Sieyon1/2, sadah1/1, Hodeidah15/10, Hodeidah1/10, sadah1/2, Jamisha15/10, Hodeidah15/10, sadah1/2, sadah1/2 and Sana'a15/2 respectively.

Table (14) crops water requirements, Irrigation and indicators of Lahje area.

Lahje area	Crop water requirements	irrigation requirements	Area crops yield	Area crops environment	Area crops Agriculture	Crop areas optimum
crop.day/month	mm/crop	mm/crop	Indicator	Indicator	Indicator	Indicators
Sesame.15/8	357	208	0.63	0.69	0.63	0.67
Millet.1/9	308	203	0.59	0.67	0.63	0.67
Sorghum.15/7	370	188	0.63	0.71	0.62	0.72
Sesame.1/1	309	223	0.64	0.66	0.62	0.67
Pulses.15/11	290	247	0.59	0.62	0.62	0.65
Onion.15/10	571	540	0.15	0.41	0.61	0.57
Melon.1/4	446	388	0.34	0.51	0.61	0.57
Pulses.15/7	394	319	0.53	0.59	0.61	0.62
Vegetable.15/9	379	349	0.24	0.49	0.61	0.56
Melon.1/1	351	344	0.38	0.51	0.61	0.59
Tomato.1/9	569	537	0.24	0.43	0.60	0.57
Millet.1/3	358	315	0.54	0.58	0.60	0.59
Tobacco.15/10	393	333	0.36	0.53	0.59	0.58
Maize.15/9	351	279	0.28	0.54	0.59	0.65
Sorghum.15/4	405	327	0.58	0.60	0.58	0.65
Maize.15/2	415	388	0.24	0.47	0.57	0.60
Citrus.15/10	1193	1092	0.21	0.28	0.55	0.54
Cotton.1/8	739	550	0.41	0.50	0.55	0.60
Mango.1/10	1778	1711	0.35	0.15	0.53	0.55
Date.15/11	1639	1562	0.36	0.19	0.50	0.55
Banana.15/10	1965	1909	0.00	0.01	0.44	0.50
Average	647	572	0.39	0.48	0.58	0.60

2- Crop areas optimum Indicator

The results in tables (3-14) and figure (5) are shown that the highest crop areas optimum indicator values are 0.79, 0.79, 0.79, 0.77, 0.78, 0.78, 0.60, 0.76, 0.60, 0.69, 0.77, 0.59, 0.78, 0.75, 0.65, 0.75, 0.53, 0.67, 0.48, 0.57, 0.57, 0.50, 0.47 and 0.72 for areas and seasons optimum of Zabid15/7, ibb1/5, ibb1/7, ibb1/4, ibb15/5, ibb1/5, Lahje1/8, ibb1/4, alkod15/10, alkod15/8, ibb1/4, alkod15/10, ibb1/5, ibb15/2, alkod1/1, ibb1/2, alkod15/10, ibb1/10, amran1/2, alkod15/11, taiz1/11, amran1/2, amran1/2 and ibb1/2 for crops of Sorghum, maize, barley, millet, wheat, pulses, cotton, coffee, tobacco, sesame, vegetable, onion, potato, tomato, melon, apple, banana, mango, grape, date-palm, citrus, pomegranate, peach and apricot respectively.

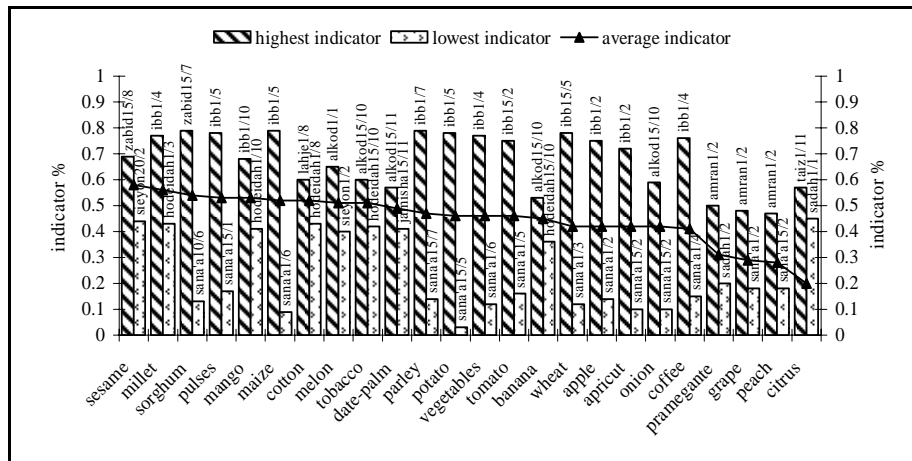


Figure (4) shows crop areas optimum Indicator

Meanwhile, of lowest crop areas optimum indicator values are 0.13, 0.09, 0.14, 0.43, 0.12, 0.17, 0.43, 0.15, 0.42, 0.44, 0.12, 0.10, 0.03, 0.16, 0.40, 0.14, 0.36, 0.41, 0.18, 0.41, 0.20, 0.20, 0.20, 0.18 and 0.10 for crops of Sorghum, maize, barley, millet, wheat, pulses, cotton, coffee, tobacco, sesame, vegetable, onion, potato, tomato, melon, apple, banana, mango, grape, date-palm, citrus, pomegranate, peach and apricot for areas and seasons of Sana'a10/6, Sana'a1/6, Sana'a15/7, hodeidah1/3, Sana'a1/3, Sana'a1/5, hodeidah15/10, Sieyon20/2, Sana'a1/6, Sana'a15/2, Sana'a15/5, Sana'a1/5, sieyon1/2, Sana'a1/2, Hodeidah15/10, Hodeidah1/10, Sana'a1/2, Jamisha15/10, sadah1/1, sadah1/2 Sana'a15/2 and Sana'a15/2 respectively.

5- Average crop areas optimum indicator

The results in tables (3-14) and figures (4) is shown that the Average crop areas optimum Indicator values are 0.54, 0.52, 0.47, 0.56, 0.42, 0.53, 0.52, 0.41, 0.51, 0.58, 0.58, 0.46, 0.42, 0.46, 0.51, 0.42, 0.45, 0.53, 0.29, 0.49, 0.45, 0.31, 0.28 and 0.42 for crops of Sorghum, maize, barley, millet, wheat, pulses, cotton, coffee, tobacco, sesame, vegetable, onion, potato, tomato, melon, apple, banana, mango, grape, date-palm, citrus, pomegranate, peach and apricot respectively. So, the crop areas optimum is cultivated area that its crop areas optimum indicator is more than or equal average crop areas optimum indicator, then the optimal areas and seasons of each crop respectively is below:

- 1- Sorghum is zabid15/7 and ibb1/4, alkod15/7, lahje15/7, alkod15/4, taiz1/5, taiz1/6, lahje15/4, sieyon15/7 and zabid15/4 respectively.
- 2- Maize is ibb1/5, alkod15/9, lahje15/9, alkod15/2, zabid15/9, taiz1/4, lahje15/2, Jamisha15/9 and zabid15/2 respectively.
- 3- Barley is ibb1/7, taiz1/7, ibb15/12, thamar15/2, amran15/11, taiz15/11, amran15/7, thamar15/12 and amran15/2 respectively.
- 4- Millet is ibb1/4, alkod1/9, lahje1/9, alkod1/3, zabid1/9, taiz1/4 and lahje1/3 respectively.

- 5- Wheat is ibb15/5, taiz15/6, sieyon1/11, ibb15/11, thamar15/6, amran15/7, amran15/12, taiz15/11, amran1/3 and thamar15/2 respectively.
- 6- Pulses are ibb1/5, ibb1/6, ibb15/2, zabid15/7, alkod15/11, ibb15/1, lahje15/11, alkod15/7, lahje15/7, jamisha15/11, thamar15/2, hodiedah15/11 and amran15/6 respectively.
- 7- Cotton is Lahje1/8, alkod1/8 and zabid1/8 respectively.
- 8- Coffee is ibb1/4, taiz1/3 and amran1/4 respectively.
- 9- Tobacco is alkod15/10, lahje15/10 and zabid15/10 respectively.
- 10- Sesame is alkod15/8, zabid15/8, alkod1/1, lahje15/8, lahje1/1 and zabid1/1 respectively.
- 11- Vegetables are ibb1/4, ibb1/3, hg;,]15/9, lahje15/9, sieyon15/10, taiz1/5, zabid15/10, taiz1/4, thamar1/2 and thamar1/7 respectively.
- 12- Onion is alkod15/10, lahje15/10, ibb1/9, ibb1/11, taiz1/8, taiz1/9, ibb1/10, zabid15/10, taiz15/10, sieyon20/8, taiz1/11, jamisha15/10, hodiedah15/10 and amran1/4 respectively.
- 13- Potato is ibb1/5, ibb1/6, ibb1/3, ibb1/9, sieyon1/11, ibb1/10, thamar1/2, ibb1/11 and thamar1/7 respectively.
- 14- Tomato is ibb15/2, ibb1/8, alkod1/9, lahje1/9, thamar1/7, sieyon1/1, zabid15/9, thamar1/2, taiz1/2, amran15/2, amran15/5 and taiz1/10 respectively.
- 15- Sweet and water melon is alkod1/1, alkod1/4, lahje1/1, lahje1/4, zabid1/4 and zabid1/1 respectively.
- 16- Apple is ibb1/2, thamar15/1 and amran1/2 respectively.
- 17- Banana is alkod15/10, lahje15/10 and taiz15/10 respectively.
- 18- Mango is ibb1/10, alkod1/10, lahje1/10 and taiz15/8 respectively.
- 19- Grape is amran1/2 and Sana'al/2 respectively.
- 20- Date-palm is alkod15/11, lahje15/11 and zabid15/11 respectively.
- 21- Citrus is taiz1/11, alkod15/10, lahje15/10, zabid15/10 and sieyon15/11 respectively.
- 22- Pomegranate is amran1/2.
- 23- Peach is amran1/2.
- 24- Apricot is ibb1/2 and thamar1/2 respectively.

Conclusions

From the previous result and discussions, and depending on: area crops environmental indicator, area crops agricultural indicator, crop areas environmental indicator and crop areas optimum indicator, the following major important results can be concluded as following:

1- Environmentally preferable crop to and its appropriate season to be cultivated in each area are as following:

Sorghum15/7 has environmental preferable crop to be cultivated in Wadi-zabid, barley1/7 in Ibb, pulses15/10 in Jamisha, sesame1/1 in Hodeidah, Sorghum.15/7 in alkod, barley1/7 in Taiz, pulses15/2 in Thamar, wheat1/11 and Sorghum15/7 in Sieyon,

pulses^{15/1} in Sadah, pulses^{15/2} in Sana'a, barley^{15/7} in Amran and Sorghum^{15/7} in Lahje.

2- Preferable crop (environmental, water, economical, feed view vision) and its appropriate seasons to cultivate in each area as following:

Sorghum.^{15/7} and pulses^{15/7} are recorded the pest economical feed environmental water crop to be cultivated in wadi-zabid, potato seasons in 1/5, 1/6 and 1/3 in Ibb, pulses^{15/11} in Jamisha, melon^{1/1} and pulses^{15/11} in Hodeidah, Millet^{1/9} in alkod, barley^{1/7} in Taiz, pulses^{15/2} in Thamar, potato^{1/11} and tomato^{1/1} in Sieyon, pulses^{15/1} in Sadah, vegetable^{15/2} barley^{15/11} and pulses^{15/6} in Sana'a, barley^{15/7} and barley^{15/11} in Amran, millet^{1/9} and sesame^{15/8} in Lahje.

3- the “environmentally” optimum areas and its appropriate seasons to cultivate of each crop of Yemen as following:

Wadi-zabid is recorded the pest environmental area (as area of class one) to cultivate each of Sorghum^{15/7} cotton^{1/8} sesame^{15/8} and date-palm^{15/11}, Ibb to cultivate each of Sorghum^{1/4} maize^{1/5} barley^{1/7} millet^{1/4} wheat^{15/5} pulses^{1/5} coffee^{1/4} vegetables^{1/4} tomato^{15/2} apple^{1/2} mango^{1/10} apricot^{1/2} onion^{1/9} and potato seasons of 1/5 1/6 and 1/3, alkod to melon^{1/1}, Taiz to cultivate each of banana^{15/10} and citrus^{1/11} and Amran has class one to cultivate each of grape^{1/2} Pomegranate^{1/2} and peach^{1/2}.

4- Optimum areas and its appropriate seasons (of environmental and watering view vision) to cultivate of each crop of Yemen as following:

Wadi-zabid has recorded the optimum area (as area of class one) to cultivate each of Sorghum^{15/7} and sesame^{15/8}, Ibb has recorded class one to cultivate each of sorghum^{1/4} maize^{1/5} barley^{1/7} millet^{1/4} wheat^{15/5} pulses^{1/5} coffee^{1/4} vegetables^{1/4} potato^{1/5} tomato^{15/2} apple^{1/2} mango^{1/10} and apricot^{1/2}, Lahje to cultivate cotton^{1/8}, alkod is recorded to optimum area to cultivate each of tobacco^{15/10} sesame^{15/8} onion^{15/10} melon^{1/1} banana^{15/10} and date-palm^{15/11}, Amran has class one to cultivate each of grape^{1/2} Pomegranate^{1/2} and peach^{1/2} and Taiz to cultivate citrus^{1/11}.

5- Areas of sana'a sadah and amran produce the best quality of the grapes pomegranates and peaches crops in Yemen, so those areas and such as should be consecrated to cultivate grapes, pomegranates and peaches crops in addition of other preferable crops (environmental, water, economical, feed).

Recommendations

- 1- This study could not include the other Yemen agricultural areas, as Hajjah, Almahweet, Aldhala etc. so they must be studied in the future to complete Yemen map.
- 2- Input the results data to software program as (GIS) to do Yemen optimum agricultural map to water conservation.

References

- Agricultural Statistical Year book .2004.** Agricultural Statistical & Documentation Department, Ministry of Agriculture & Irrigation, Republic of Yemen.
- Allen, R., Pereira, S. L. & Smith, M. 1998.** Crop evapotranspiration “Guidelines for Computing Crop Water Requirements” FAO Irrigation. and Drain. Paper no.56, Food and Agricultural Organization of United Nation, Rome.
- Abdalkader, A. M. 1998.** Climate of Yemen. Study of climatic geography. Obad center of studies and press. Sana'a. Republic of Yemen.
- AL-mujahed, A. M. 1980.** Principles and production of field crops in Yemen.10th book of Tomorrow books series.
- Brouwer, C., Prins, K & Heibloem, M. 1989.** Irrigation Water Management: Irrigation Scheduling. 00100 Rome. Italy FAO
- Brouwer, C. & Heibloem, M. 1986.** Irrigation water Management: Irrigation Water Needs. 00100 Rome. Italy FAO.
- Civil Aviation & Meteorology Authority .2002.** Meteorology Department. Unpublished information. Software(CD). Sana'a. Republic of Yemen.
- CLIMWAT. 1994.** Database meteorological stations, FOR Irrigation and Drainage paper No 49, FAO, Rome.
- Doorenbos, J.& Kassam, O. W. 1979.** Yield response to water .FAO Irrigation. And Drain. Paper no.33, FAO, Rome, Italy. 193pp.
- Doorenbos, J. & Pruitt, W. O. 1977.** Crop water requirements. Irrigation and Drainage Paper No. 24, (rev.) FAO, Rome, Italy. 144 p.
- Mukred, A. O., Ba-Makhrama, H. S., AL-Yamoor, M. & Fadl-alla, A. B. 1998a.** The agricultural Compendium of central high lands. Agricultural Sector Management Support Project Extension and Training Component. Ministry of Agriculture & Irrigation. Republic of Yemen.
- Mukred, A. O., Ba-Makhrama, H. S., AL-Yamoor, M. & Fadl-alla, A. B. 1998b.** The agricultural Compendium of Tehama. Agricultural Sector Management Support Project Extension and Training Component. Ministry of Agriculture & Irrigation. Republic of Yemen.

- Mukred, A. O., Ba-Makhruma, H. S., AL-Yamoor, M. & Fadi-alla, A. B. 1998c.** The agricultural Compendium of Wadi-Hadramout. Agricultural Sector Management Support Project Extension and Training Component. Ministry of Agriculture & Irrigation. Republic of Yemen.
- Smith, M. 1992.** CROPWAT, a computer program for irrigation planning and management. FAO Irrigation and Drainage Paper 46, FAO, Rome.
- Snyder, R. L., Lanini, B. J., Shaw, D. A., & Pruitt, W. O. 1989a.** Using reference evapotranspiration (ET_o) and crop coefficients to estimate crop evapotranspiration (ET_c) for agronomic crops, grasses, and vegetable crops. Cooperative Extension, Univ. California, Berkeley, CA, Leaflet No. 21427, 12 p
- Snyder, R. L., Lanini, B. J., Shaw, D. A., & Pruitt, W. O. 1989b.** Using reference evapotranspiration (ET_o) and crop coefficients to estimate crop evapotranspiration (ET_c) for trees and vines. Cooperative Extension, Univ. of California, Berkeley, CA, Leaflet No. 21428, 8 p.
- Statistical year book. 2004.** Central Statistical Organization, Minister of Planning and International Cooperation. Republic of Yemen.

الخارطة الزراعية اليمنية المثلى للمحافظة على المياه

عبد الله محمد يايه و عادل محمد الوشلي

قسم الهندسة الزراعية-كلية الزراعة-جامعة صنعاء - اليمن

يقدر الاستهلاك السنوي للمياه في اليمن 3.4 مليار متر مكعب، بعجز 26 يتم سحبه من المخزون الجوفي للمياه الذي يتناقص بمعدل 60 متر سنة من خلال أكثر من 50 ألف بئر تمثل الزراعة 21 من الدخل القومي وتستهلك 90 من المياه نظر لعدم معرفة المزارع بالمقننات المائية للمحاصيل والاعتماد على نظم الري السطحي التقليدي متدني الكفاءة 35 يهدف هذا البحث إلى إعادة توزيع النشاطات الزراعية المحصول، الموقع والموسم الأمثل للمحافظة على المياه من خلال أولاً تقدير كل من الاحتياجات المائية، نسبة الغلة اعتماداً على الأمطار فقط، احتياجات الري و جدولته باستخدام نظم ري حديثة في 12 منطقة تمثل الأقاليم المناخية الخمسة لليمن 247 محصول وموسم تمت الحسابات اعتماداً على البيانات المناخية والزراعية لكل منطقة، العوامل الخاصة بكل محصول ونوعية التربة باستخدام برنامج كمبيوتر الفاو ثانياً استنباط مؤشرات اقتصادية وغذائية لكل محصول الإنتاجية، السعيرية، الندرة، الأمن الغذائي و كذلك زراعة بيئية مائية الغلة بدون ري، الأمطار، احتياج مائي، احتياج الري، المخزون المائي الأرضي لكل منطقة ومن خلال التصنيف والترتيب والحساب للمؤشرات السابقة تم ابتكار مؤشرين الأول لتحديد المحاصيل والمواسم المثلى مائياً اقتصادياً لزراعتها لكل منطقة والمؤشر الثاني لتحديد الموقع الأمثل بيئياً مائياً لزراعة كل محصول تبين النتائج على سبيل المثال لا الحصر أن المحاصيل الزراعية المثلى لوادى زبيد وما يماثلها بيئياً هي البقوليات يوم 15 شهر 7، الذرة الرفيعة 15 7، السمسم 15 8، الدخن 1 9، البطيخ 1 4، الخضروات 15 10، الطماطم 15 9، الذرة الشامية 15 9، السمسم 1 1، البصل 15 10، البطيخ 1 1، الدخن 1 3 و التبغ 15 10 على الترتيب أيضاً سجل موقع وادي زبيد أفضل موقع بيئياً لزراعة كل من الذرة الرفيعة 15 7، والقطن 1 8، السمسم 15 8 و النخيل وأفضل منطقة لزراعة الذرة الرفيعة 15 7 و السمسم 15 8

الكلمات المفتاحية احتياجات مائية - المحافظة على المياه - اليمن جدول الري زراعة مثلى