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Emergy-based valuation of agriculture ecosystem services and dis-services

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ABSTRACT

The agriculture ecosystem is very important, complex and humankind largest engineered ecosystem providing essential ecosystem services as well as many disservices, depending on management and agriculture practices. Due to the complications, uncertainties, overestimations and double counting in ecosystem services accounting frameworks, (1) this study establishes a non-monetary "donor side" ecosystem services valuation methods constructing the emergy-based agriculture ecosystem services framework, propose the ecosystem services calculations method and classify the services into direct, indirect and existing services. (2) Further, it assess the sustainability of agriculture ecosystem nature's and human's contribution in the services through RNP% (renewability) and NRP% (non-renewability). Taking the case of agriculture ecosystem in Bahawalnagar, Pakistan, five agriculture cultivating ecosystems including wheat, rice, sugarcane, maize and cotton are selected for services and disservices valuation. (3) A total of eleven ecosystem services were evaluated in which four belongs to direct services category such as biomass increase, carbon sequestration, soil building and groundwater recharge; four are included in indirect services category (dis-services) such as human health and ecosystem quality losses due to greenhouse gases emissions, soil, water pollution and soil erosion increase; existing services includes climate regulation, agro-tourism & recreational, cultural and educational values. (4) The results indicate that the green revolution in agriculture ecosystem encourage and increase dependency of human inputs such as synthetic fertilizers, pesticides and energy which produces higher productions but on other side it produces dis-services which is harmful for humans and other ecosystems diversity. The method proposed by this study can deliver improved theoretical and policy insights to ecosystem services accounting for agriculture ecosystem, as the agriculture ecosystem is the major source of food but along with it drive's significant environmental degradation.

1. Introduction

Humankind's largest engineered ecosystem is represented by agricultural areas, which are directly managed by humans for the achievement of different benefits (Swinton et al., 2007). Crop production systems provide a material basis for human survival and economic development, which depend on both natural and human inputs (Zhang et al., 2016). Occupying 38% of the terrestrial surface (FAO, 2004; FAOSTAT, 2011), agriculture accounts for a huge and rising share of the Earth's land use. According to Tilman et al. (2001), world agriculture, especially cropland, will be increased by 23%, while pasture is expected to have a 16% grow within 2050.

Agriculture ecosystem are vital for society, because of the services they provide (Cardinale et al., 2012; CEPF, 2012). Traditionally, agriculture ecosystem has been considered mainly as sources of provisioning services, however the contributions of agriculture ecosystem to provide ecosystem services of other types have been

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recognized in recent times (MEA, 2005).

Ecosystem services (ES) are defined as the benefits human beings directly or indirectly get from the functions of ecosystem, through which the life of human beings is fulfilled and sustained (Costanza et al., 1997; Daily, 1997). Nowadays, ecosystems are either directly or indirectly managed by humans for the purpose of maximizing the provision of their services for survival, livelihood and economic growth (MEA, 2005). For example, any agricultural ecosystem is managed for the provision of food, fiber, energy, carbon sequestration, pollination, pest control, soil fertility, and so on. Agriculture ecosystem can deliver a variety of other ecosystem services (regulatory services) such as flood regulation, water quality regulation, climate regulation and carbon storage which indirectly control greenhouse gas emissions, treatment of different kind of wastes and regulation of various diseases. Cultural services might be included in the list, such as education, scenic beauty, recreation and support to tourism. Biodiversity conservation is sometimes included as a cultural ecosystem service supported by agriculture ecosystem, but it can also deliver a wide range of other supporting services to agriculture and nearby other ecosystems (Daily, 1997).

The quantity and strength of agricultural ecosystem services depend on how they are managed (National Research Council, 2005; Zhang et al., 2007). While a proper management provides beneficial services, an improper and unsustainable approach could also generate dis-services, defined as “the generated ecosystem processes, functions and aspects resulting in perceived or actual detrimental influences on human wellbeing” (Shackleton et al., 2016). Dis-services are characterized by negative attributes, such as soil erosion, nitrogen leaching and habitats deterioration, which put pressure on agricultural ecosystem sustainability and management (Montgomery, 2007; Valkama et al., 2016). For example, urban and peri-urban agricultures are relevant in generating a growth in cities sustainability (Ghisellini and Casazza, 2016). However, negative transformations can trigger the degradation of many ecosystem-generated services (Costanza et al., 1997; Kleijn et al., 2011; Gamfeldt et al., 2013). According to MEA (2005), in the last 50 years’ humans have increasingly transformed the ecosystems with respect to previous ages. This transformation generated the assessed decline of 15 out of 24 considered ecosystem services. Reversing this degradation will only be possible if important changes in policy and practices are adopted.

Many previous studies on ecosystem services (ES) evaluation focused on monetary methods, based on humans’ well-being and perceptions (consumer-side perspective) (Costanza et al., 1997, 2017). This evaluation is based on a classification system, which stemmed from the works by Costanza et al. (1997), Daily (1997) and MEA (2005). However, classification approaches are still disputed when applied to accounting practices, due to the possibility of overestimation and double counting (Yang et al., 2018).

Emergy method, originally developed by the system ecologist H.T. Odum and followers, is now becoming more popular in ES accounting. By definition, emergy is the available energy, in all form involved directly and indirectly to make a product or service (Odum, 1986). The basic idea behind emergy method is to quantify all form of resources (e.g.: energy, materials, labor, economic services and information) applying a common metrological reference, called solar equivalent energy (measured in sej units). This conversion is performed through its UEVs (unit emergy values), defined as “solar emergy need to produce a unit of output”, measured in different units, depending on the wanted unit output (e.g.: energy, money, mass, information) (Odum and Bosch, 1983; Odum, 1996; Odum and Brown, 2000; Brown et al., 2012; Liu et al., 2015). Emergy method is used in different fields, from ecosystem health to complex environmental or production systems management (Campbell, 2000; Campbell and Garmestani, 2012). Emergy method delivers a ‘supply-side’ valuation, and also links human-controlled economic ecosystem with natural ecosystem (Liu et al., 2014). Moreover, values are not accounted as a function of human preferences and willingness to pay, but as a function of available energy taken from Sun-Earth processes to sustain an ecosystem. This is why some researchers consider that as an ecocentric perspective (Dong et al., 2012; Rugani et al., 2013). Agricultural ecosystem is appropriate for the emergy method application, being at the interface among “natural” and “human” spheres. In particular, the inputs from both the economic system and the environment can be considered to evaluate any production process or product in relation to emergy use (Chen et al., 2006).

This study proposes a “donor side” non-monetary evaluation method for ecosystem services generated by agriculture. The aims of this study are: (1) to define an emergy-based method to account ecosystem services and disservices in five types of agriculture cultivating ecosystems; (2) to assess the sustainability in agriculture ecosystem and nature's and human's contribution in services though emergy-related indicators, such as the degree of renewability (RNP%) and non-renewability (NRP%). The main purpose of this non-monetary ecosystem services valuation framework is to avoid overestimation and double counting in ecosystem services valuation through, drawing the emergy-base diagram of agriculture ecosystem which display processes, formation and functioning of ecosystem services and disservices.

2. Materials and methods

2.1. Agricultural ecosystem services classification system

Ecosystem services can be classified into direct, indirect and existence services (Yang et al., 2018). Direct services are directly derived from agriculture ecosystem and directly used by human beings which means direct services produce directly from any ecosystem process and functions. Indirect services produce indirectly by the process and functions of direct services and are also considered as a by-product generated through the ecological processes. Similarly, existence services production depends on the presence of ecosystems, and such services have certain type of value for humans which include recreation, tourism and educational services. Fig. 1 represents the classification of agriculture ES derived from the definitions above.

In detail, direct services include biomass increase, soil building, carbon sequestration, and groundwater recharge. Soil building can be further divided into building of soil organic matter and minerals. In the case of rice paddy, which consumes more water than any other crop system, it also acts as a ground water recharge factor. In other natural ecosystems, such as for forest and wetlands, indirect services mainly include those services supporting the pollutants removal from water, air and soil through various process (Yang et al., 2018, 2019). However, the agriculture ecosystems are totally engineered by human beings. Consequently, their miss-management generates the release of toxic compounds, which pollute the air, water and soil, negatively effecting human beings and degrading natural ecosystems. Therefore, in the case of agriculture ES classification, indirect services category mainly includes dis-services, such as the release of greenhouse gases (which includes CO_2, CH_4, N_2O), fertilizers and pesticides runoff (producing water and soil pollution) and soil erosion. Existing services include cultural, aesthetic and educational values.

2.2. Agriculture ES emergy-based accounting

Agriculture services and dis-services are calculated through

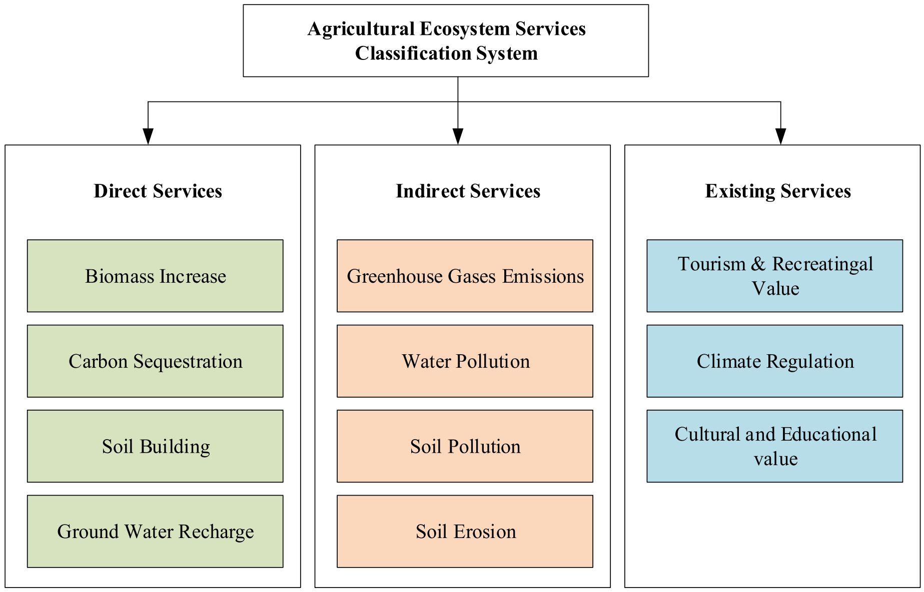

Fig. 1. Agriculture ecosystem services classification.

emergy accounting analysis and all the UEVs that are used in the calculation process of this paper is based on the global emergy baseline (GEB), which is 12.0E+24 seJ/yr (Brown and Ulgiati, 2016). From a donor-side perspective, all the processes are considered, integrating all the resources, including renewables (i.e.: sunlight, wind, rain, etc.) nonrenewable inputs (i.e.: machinery, fossil fuel) and indirect human labor and services (Brown et al., 2012; Brown and Ulgiati, 2016). Fig. 2 gives the diagram representation of agriculture ES, according to the representation rules detailed by Odum (1996), Odum and Odum (2000) and Brown (2004).

In agriculture ecosystems, renewables and human inputs together perform various process and functions to deliver the services. Among such process, photosynthesis is one of the main and important process in providing services such as biomass increase, carbon sequestration and climate regulation (existing services). Above the ground, biomass provides different agricultural products after harvesting. The residues can be used as bioenergy, openly burn, leftover in the field and also used as fodder, depending on how they are managed. Below- ground biomass acts as a storage of soil organic carbon. Soil is formed through several weathering processes (both chemical and physical weathering), as well as other processes, like organic matter accumulation, decomposition and humification. In agriculture, synthetic nutrients are also added to the soil in the form of different fertilizers to increase the nutrients amounts for a better production (as shown in Fig. 4) (Pidwirny, 2006; Dominati et al., 2010). Some agriculture ecosystems, like rice paddies, require a huge amount of water. However, in this case, they also act as a source of ground water recharge (Anan et al., 2007; Lee et al., 2015).

Unsustainable and poor management practices in agriculture ecosystem leads to many dis-services such as air, water, soil pollution usually arise from the functions and process of direct

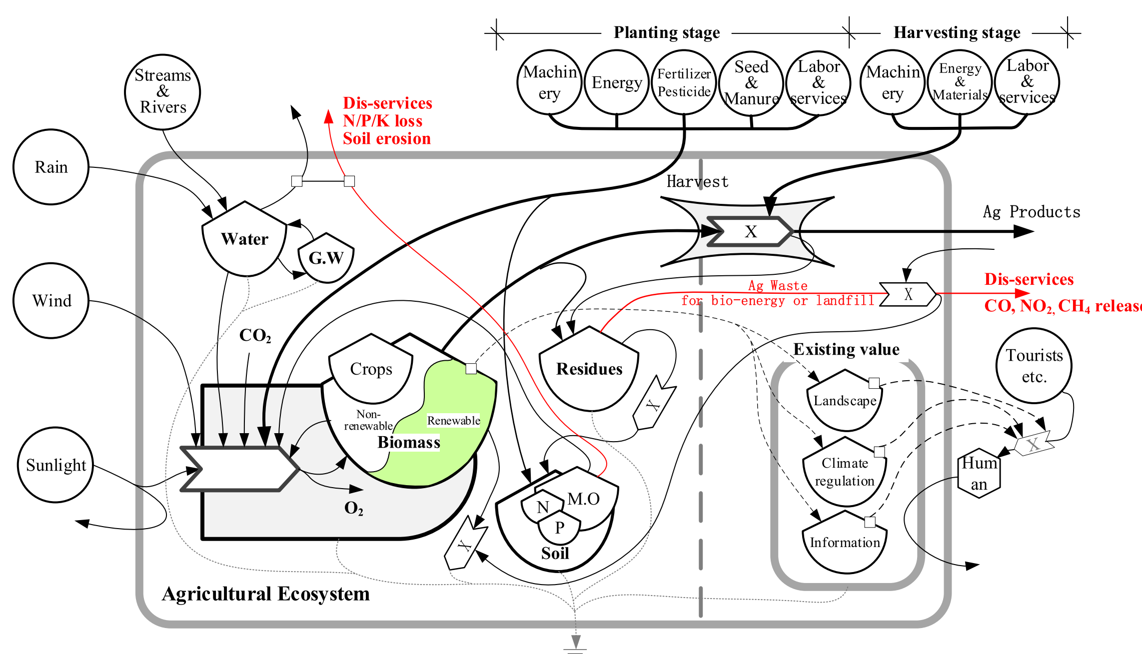

Fig. 2. Emergy base flow diagram of agriculture ES.

services. The agriculture ecosystem is one of the major contributors to air pollutants and GHG emissions especially the burning of the biomass residue in fields (Bellarby et al., 2008; Ravindra et al., 2016a). In addition, non-point source water pollution due to the excessive usage of pesticides and fertilizers is one of the major source of agricultural pollution (Chen et al., 2017). Existing services depends on the presence of ecosystems, in case of agriculture ecosystem existing services includes the agro-tourism, climate regulation, recreational and education services.

2.2.1. Direct services

2.2.1.1. Biomass increase. Biomass increase is the living organisms overall mass density at given time (unit: kg/m^2 or t/hm^2). Biomass increase is calculated as follows:

$$Em_{\mathrm{Bio}} = MAX(R) + \sum_{i=1}^{n} P(x_i) \tag{1}$$

where: Em_{Bio} is the emergy required to increase biomass in the agriculture ecosystem; MAX(R) is the sum of all renewable emergy inputs in the agriculture ecosystem, including sunlight, thermal energy, tidal energy, wind, rain (chemical potential energy), runoff (geopotential potential energy), and runoff (chemical potential energy) (sej/yr). MAX(R) is:

$$\mathrm{MAX(R)} = \mathrm{MAX}\left[\begin{array}{l}\sum(\text{sunlight, tidal energy, thermal energy}), \text{ wind energy, rain chemical,}\\ \text{rain potential energy, runoff geopotential energy, runoff chemical potential}\end{array}\right] \tag{2}$$

Besides, x_1 is the mechanical equipment used in agriculture ecosystem; x_2 means energy inputs, such as diesel and electricity used in agriculture ecosystem; x_3 means amount of fertilizers and pesticides used in agriculture ecosystem; x_4 indicates the amount of seeds and manure applied in agriculture ecosystem; x_5 is the amount of water used; x_6 is the amount of labor and services used in agriculture ecosystem, expressed as (sej/season/crops). The details of human inputs can be found in Table A1 in appendix.

2.2.1.2. Carbon sequestration. Carbon sequestration is a process through which atmospheric freely available carbon dioxide (CO_2) is captured and stored through a natural process, consist of those occurring naturally in plants (photosynthesis) and soils for long period of time (Sedjo and Sohngen, 2012). The growth of living matter consists of a process through which the CO_2 from the atmosphere utilized by plants. During such a process plants inducts CO_2 into their cells and discharges oxygen (O_2) back into the atmosphere, while the decomposition of biological matter reverses such process. Carbon sequestration is calculated as:

$$Em_{CS} = \sum_{i=1}^{n} (CS_{ci} \times S_i \times C_c \times UEV_{CSi}) \tag{3}$$

where: Em_{CS} refers to the emergy needed by carbon sequestration (sej/yr); CS_{ci} means the carbon sequestrated by i-th cultivating ecosystem (g C/m^2/yr); S_i represents the cultivated area of i-th cultivating ecosystem (m^2); C_c is the percentage of carbon in vegetable biomass, fixed at 45% (Ponce-Hernandez et al., 2004); UEV_{CSi} is the specific emergy of carbon sequestration by i-th cultivating ecosystem (sej/g), calculated as:

$$UEV_{CSi} = \frac{Em_{i/S_i}}{NPP_i} \tag{4}$$

where: UEV_{CSi} is the unit emergy value (UEV) of carbon sequestration of agriculture cultivating ecosystem i (sej/g); Em_i is the renewable emergy involves in producing of the NPP of agriculture cultivating ecosystem i (sej), which is equal to MAX(R) in equation (1); S_i is the area cultivated with i-th cultivating ecosystem i in the case study (m^2); NPP_i is the net primary production of i-th cultivating ecosystem (g C/m^2/yr).

Biomass and carbon sequestration for agriculture ecosystem can be represented in separate emergy diagrams. Fig. 3 shows that both renewables and human inputs are used as source of energy for plant development (biomass) and to fix CO_2 (carbon sequestration) though photosynthesis.

2.2.1.3. Soil building. Soil is a combination of various nutrients, organic matter, gases, water and organisms, together sustaining life and producing a flow of important ecosystem services (Robinson et al., 2009; Dominati et al., 2010). In agriculture ecosystem, the major sources of soil building (as shown in Fig. 4) are the returns of both root tissue and above-ground crop residues by tillage or straw combustion. Manures and fertilizers are also used basically for the replacement of the essential chemical elements that are taken by previous crops from the soil or use to enhance the natural soil fertility. Besides, some minerals in the soil come from the weathering of parent rock (Campbell, 2012). Soil is a critical regulatory system of natural and managed ecosystems where different functions occur, such as nutrient cycling and water cycling (Hannam and Boer, 2004; Blum, 2005; Dominati et al., 2010).

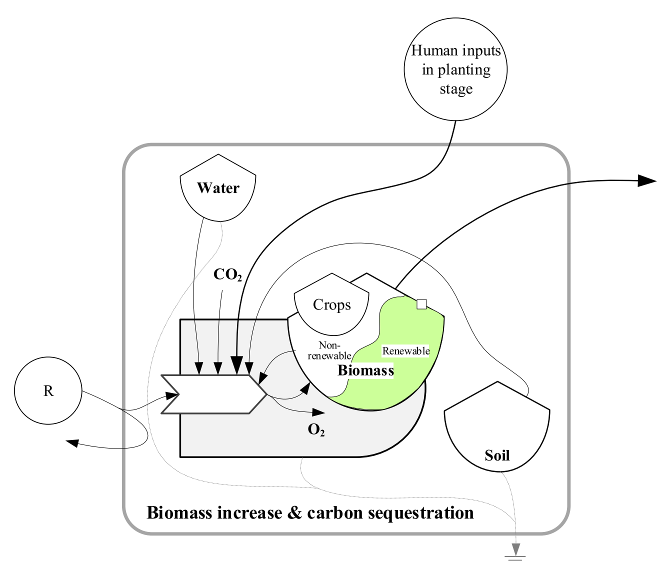

Fig. 3. Emergy diagram of biomass increase and carbon sequestration for agriculture ecosystem.

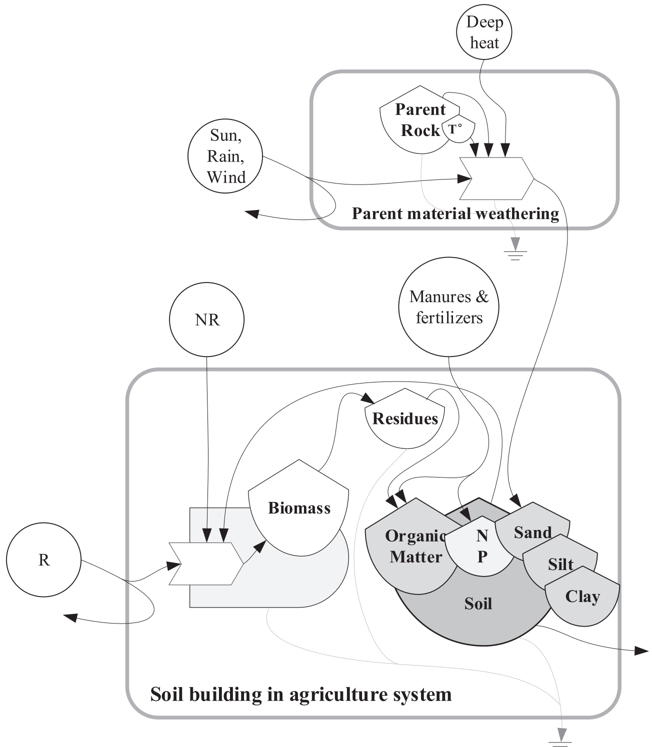

Fig. 4. Emergy diagram of soil building for agriculture ecosystem.

Management of soils has significant effects for the quality and quantity of the ecosystem services provided, particularly in urban and agricultural ecosystem with high disturbances (Van et al., 2012; Morel et al., 2015). Severe or unsustainable agricultural practices minimize soil biota, biomass and carbon, maximizing soil acidification, compaction, salinization and erosion, which lead to the degradation of land and enhancement of poverty (Pereira et al., 2018; Barbier et al., 2016). Soil building, considering its different formation processes, is further subdivided into organic matter and mineral building (Yang et al., 2018). Therefore, in order to get the final value of the soil building, the organic matter and mineral building values will be added together.

(a) Soil organic matter building

Soil organic matter building is a part of soil building services which can be calculated with the following equations.

$$Em_{\mathrm{OM}} = (E_{mre_i} \times \mathrm{k}_1 \times \mathrm{k}_2) + x_i \tag{5}$$

where: $E_{m\mathrm{OM}}$ represents the emergy of soil organic matter building(sej/yr). $E_{\mathrm{mre}i}$ is the renewable resources emergy in study case for i-th cultivating ecosystem (sej); k_1 is ratio of straw amount returning to farmland (g) to the farmland biomass (g, %); k_2 is the ratio of the carbon amount in straw (g) to the straw amount returning to farmland (g, %); x_i is the amount of manure supplied to the soil for i-th cultivating ecosystem in the study case (sej/j).

(b) Soil minerals/nutrients building

Soil minerals act as an indicator about the health of the soil. Their increase or decrease in agriculture ecosystem totally depends on renewable and non-renewable inputs and sustainable practices which can be calculated as follows:

$$Em_{\mathrm{Min}} = \sum_{i=1}^{n} ((P_{i\mathrm{Min}} \times p \times Ts \ \times S_i)/T_i \times UEV_{i\mathrm{Min}}) \tag{6}$$

where: $E_{m\mathrm{Min}}$ is the emergy require by soil minerals building (sej); $P_{i\mathrm{Min}}$ is the percentage content of i-th minerals (g); p means soil density (g/cm^3); Ts means top soil thickness (cm), S_i area cover by i-th cultivating ecosystem (m^2); T_i means turnover time of the minerals; $UEV_{i\mathrm{Min}}$ is the unit emergy value of the i-th mineral (sej/g).

2.2.1.4. Groundwater recharge (consider for rice paddies). Rice is one of the significant crops in Asia, especially in monsoonal countries. Rice cultivation in these countries it is especially valuable because of its strong relationship with poverty reduction, food security, social and economic growth of rural peoples and environmental and natural resources conservation (Molden et al., 2000; Matsuno et al., 2006).

Rice is a cereal crop that requires a huge amount of water for its cultivation. In fact, Rice cultivated areas are flooded when seeds are planted, while to flood the cultivated areas and for rice plants are grown mostly submerged in water (FAO, 2004). Apart from rice production, rice paddies also provide numerous ecological services, such as mitigation of soil erosion, ground water recharge, microclimate regulation, mitigation of floods, water storage and provide habitat for wild animals, carbon sequestration (Chang and Ying, 2005; Anan et al., 2007; Lee et al., 2015).

Among all ecosystem services provided by rice paddy to the environment, the most important is the ground water recharge services. Since rice growing needs a huge amounts of water, stagnant water, becoming stored in the soil, can also recharge ground water (Anan et al., 2007; Lee et al., 2015). The ground water recharge function is viewed as essential in the water cycle of rice cultivated areas. For example, In Japan (Kumamoto), it is estimated as of all water recharge 45% is from the rice cultivating areas. Similarly, in Taiwan, 23% water in infiltrate into the ground water form rice cultivating areas (Matsuno et al., 2006).

Therefore, from the above discussion we concluded that rice paddies consumed a huge volume of water for its growing, but can also provide groundwater recharge as ecosystem services. This ES is accounted as follows:

$$E_{gw} = R \times p \times G \times k \times S \times UEV_{gw} \tag{7}$$

where: E_{gw} is the emergy needed by ground water recharge (sej); R is the precipitation in the study case (m/season); p means water density (kg/m^3); G means Gibbs free energy (g/j); k is the infiltration coefficient of study case; S means area under rice cultivating ecosystem (m^2) and UEV_{gw} is the unit emergy value for ground water (sej/j).

2.2.2. Indirect services

2.2.2.1. Health and ecosystem quality loss due to the release GHGs emissions. In agriculture, there are both services and dis-services, because agriculture ecosystem largely depends on human inputs to provide services. The unsustainable use of such human inputs produces dis-services in the form of GHGs emissions, air, soil and water pollution, as well as soil erosion (Van Zanten et al., 2014). Therefore, GHGs emissions (CO_2, CH_4, N_2O) are placed in the category of dis-services. CO_2, CH_4 and N_2O are major greenhouse gases (GHGs), because of their 100 year Global Warming Potentials are 28 and 265 times, respectively (IPCC, 2014). CH_4 and N_2O are produced through microbial activity. N_2O emissions are directly from the soils mainly due to the biological driven process such as nitrification and denitrification, together with non-biological process such as chemo denitrification (Granli and Bøckman, 1994).

In this study, Eco-Indicator 99 assessment method is used for the assessment of initial damage generated by losses. The human health loss damage is measured as Disability Adjusted Life Years (DALYs), while ecosystem quality loss damages are measured by Potentially Disappeared Fraction (PDF) of species (Goedkoop, 2000; Ukidwe and Bakshi, 2007).

(a) Human health losses

Human health losses due to GHGs emission form agriculture are calculated with help of the following equation (Liu et al., 2011).

$$E_{mHH} = \sum M_i \times S_i \times DALY_i \times T_H \tag{8}$$

where: E_{mHH} is the emergy of human health loss (sej); M_i is the quantity or mass of the i-th greenhouse gas released to the environment(g/h/yr); S_i means area cover by i-th cultivating ecosystem (ha); $DALY_i$ means the DALY caused by the i-th greenhouse gas (cap yr/kg); T_H means the emergy per capita (sej/cap).

(b) Ecosystem quality losses

GHGs emissions from agriculture ecosystem can also cause damages to ecosystem quality losses, which can be evaluated as follows.

$$E_{mEQ} = \sum M_i \times PDF(\%)_i \times E_{mBIO} \tag{9}$$

where: E_{mEQ} is the emergy of agriculture ecosystem quality loss (sej); M_i is quantity or mass of the i-th greenhouse pollutants are released into the environment(g/h/yr); $PDF(\%)_i$ means the potential species extinction ratio caused by the i-th greenhouse pollutant ($\mathrm{PDF} \times \mathrm{ha} \times \mathrm{yr} \times \mathrm{kg}^{-1}$); E_{mBIO} indicates the UEV of biomass (sej/g).

2.2.2.2. Human health and ecosystem quality loss due to water and soil pollution. The use of inorganic fertilizers and pesticides supports agricultural production. However, it also causes serious problems in terms of environmental degradation. There are several pathways for inorganic fertilizers and pesticides drainage toward water bodies. They include runoff to surface water, leaching into ground water, accidental overspray and sediment deposition (Boone et al., 2005; Relyea, 2005; Carey, 1991). Overuse of inorganic fertilizers adversely affects the health of soil, effecting the sustainability of agriculture system (Khan et al., 2013). These chemicals degrade water quality and its flora. Moreover, they can also affect human health through food chain, because these chemicals have accumulation and bio-magnifications properties. In this study, we use an average DALYs value for pesticides. The human health and ecosystem quality are calculated by using the equations (8) and (9). Similarly, this study only consider for damages causes by soil pollutants only for pesticides by using the same equations (8) and (9).

2.2.2.3. Soil erosion. Soil erosion, according to the agricultural perspective, is defined as "the faster removal of top soil layer from the land use for agriculture purposes through tillage, wind, water or it is one of the main processes which affect the Critical Zone through humans. Soil erosion is one of the big and major cause of pollution in river close the agricultural areas and mountainous areas (Niazi et al., 2015). Soil erosion strength is measured through hydrological and physiographic features of a catchment area (Zabaleda et al., 2007; Restrepo et al., 2006). Agriculture soil erosion can be calculated by the following formula:

$$\mathrm{E_{mE}} = \mathrm{E_i} \times \mathrm{S_i} \times \mathrm{OM} \times \mathrm{G} \times \mathrm{UEV_E} \tag{10}$$

where: E_{mE} is the emergy require by soil erosion (sej); E_i means the soil erosion caused by the i-th cultivating ecosystem (t/h/crops); S_i is the area covered by i-th cultivating ecosystem (hm^2); OM means organic matter content (%); G means energy conversion coefficient (kcal/g) and UEV_E is the UEV of soil erosion (sej/j).

2.2.3. Existing services

Existing values/services are the services present or found where there is any ecosystem. Such types of services are directly related with the existing of specific type of ecosystem. In agriculture cultivating ecosystems we include the tourism & recreational services, climate regulation and educational services as existing services. However, this study only calculates the climate regulation services due to the presence of data and tourism and educational services are not accounted due to the unavailability of data. Calculation process/equation for such existing services is presented below.

Climate change is primarily revealed through global warming, ozone layer destruction and acid rain but the global warming is the main and serious problem for all the human-beings. Soils performs significant role in regulating numerous atmospheric elements, hence impacting on the quality of air. The most significant is the soil capacity to store the atmospheric carbon because more stable soil organic matter which is very comprehensive benefit (Dominati et al., 2010). For instance, the presence of data from Goedkoop and Spriensma (2001) and IPCC (2013), here the globally agriculture ecosystem which act as store the carbon from the atmosphere (soil carbon sink) to decrease the global climate change and their impacts are measured to assess the service of climate regulation. The following is the equations for calculation of climate regulation.

$$E_mCR = \sum C_{ij} \times S_j \times DALY_{gi} \times TH \tag{11}$$

where: E_mCR means the emergy of climate regulation (sej); C_{ij} is the amount of i-th greenhouse gase sequestration by j-th agriculture cultivating ecosystem ($\mathrm{kgC/m^2}$); S_j means the area of j-th cultivating ecosystem (ha); $DALY_{gi}$ is the DALY value resulted from the i-th greenhouse gases ($\mathrm{DALY_{ci}}$/capita year/kg); TH means the ratio of whole emergy for a country to its population (sej/cap).

2.3. Emergy based indicators

Renewable portion (RP, %) and Non-renewable portion (NRP, %)

Agriculture ecosystem requires different types of resources and energy inputs in the form of renewables as well as mostly non-renewables inputs (human inputs) to perform its functions and processes. The sustainable agriculture ecosystem is the one that reduce or less dependent on non-renewables resources because mostly such non-renewables resources is harmful for the environment (Pretty, 2008). Therefore, the non-renewable portion (NRP) and the renewable portion (RP) are used as indicators to compare the sustainability potential in this study for selected agriculture cultivating ecosystem and the equations are as follows:

$$\text{For renewable portions: } (\mathrm{RP\%}) = \mathrm{RP} = \mathrm{R_i}/\mathrm{U_i} \times 100 \tag{14}$$

$$\text{For non} - \text{renewable portions: } (\mathrm{NRP\%}) = NRP = N_i/U_i \times 100 \tag{15}$$

where: RP and NRP are the renewable and non-renewable portions respectively (%); R_i means renewables emergy used in agriculture cultivating ecosystem i (sej/ha); N_i means non-renewables emergy used in cultivating ecosystem i (sej/ha); U_i means total emergy used in cultivating ecosystem i (sej/ha).

2.4. Case study

Pakistan, located in the Southern Asia, has an overall area of 796 100 km^2. Pakistan is surrounded from the northeast by China, from east by India, from northwest and north by Afghanistan, from southwest by Iran and from the south by Arabian Sea (FAO, 2012).

Bahawalnagar (Punjab, Pakistan) is the district capital town of Bahawalnagar. The District is surrounded by India in the south and East, by Bahawalpur District on the west sides and by Sutlej River on the northern side. Its population density is 232 per km^2 and the literacy rate is 35.1%. The urban population is 19.05% and rural 80.95%, and annual growth rate is 2.41%.

The main crops cultivated in districts include cotton, wheat, rice and sugarcane etc. Ecosystem services and disservices are accounted at regional scale. In particular, the case of district Bahawalnagar, Pakistan (as shown in Fig. 5) is selected. Agriculture in Pakistan contributes to about 25% of GDP, engaging almost 50% of the country labor force (Pakistan Bureau of Statistics, 2011). The agriculture ecosystem in Pakistan is unsustainable, mainly due to the excessive usage of inorganic inputs, wasteful usage of water resources for irrigation purposes, lack of projects related to soil health, soil fertility and agriculture sustainability, leading to the deterioration of air, water, land resources (Irfan et al., 2015; Zulfiqar and Thapa, 2017; Ali et al., 2019).

In Pakistan, there are two crops seasons i.e. Kharif and Rabi seasons. Kharif crops or Autumn crops, based on the monsoon, are domesticated plants that are cultivated and harvested in India, Pakistan and Bangladesh during the summer season, which lasts from June to October, depending on the area. Majors crops includes rice (paddy and deepwater), millet, maize (corn), soybean, cotton, sugarcane, etc. Rabi crops or rabi harvest are crops that are sown in winter and harvested in the spring in South Asia. Major Rabi crops includes wheat, oat, barley etc. In Pakistan, farmers follow a rotation pattern based on these two main seasons (see Table 1).

This study is based on secondary data collected from Punjab statistics bureau, Pakistan statistics bureau, Pakistan agriculture research council, public domain statistics (e.g.: FAOSTAT, Aquastat, etc.), as well as various government reports and literature. Based on such data, this study evaluates the ES and EDS of different farming systems in Bahawalnagar, Pakistan.

Due to data constrains, this study focuses on five agriculture

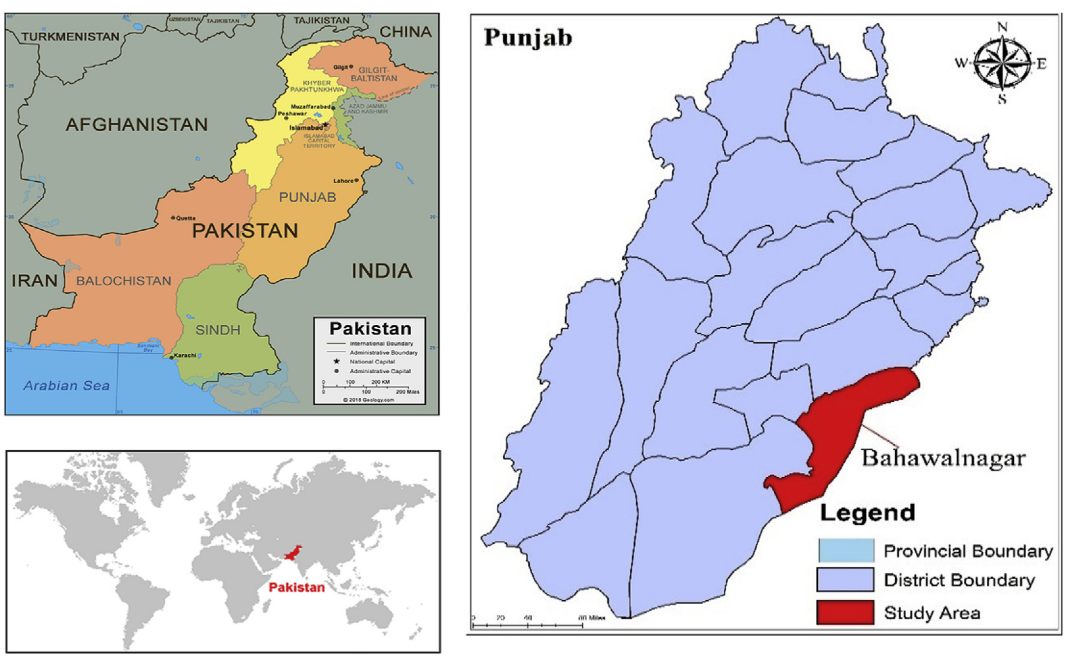

Fig. 5. The location of district Bahawalnagar, Pakistan.

Table 1
Planting features of five major crops in Bahawalnagar.

Crops	Status	Planting features
Wheat	One of the major crops in term of agricultural utilized area (AUA) and major consumption in the case study area and even in Pakistan.	It is usually cultivated in winter and harvested in summer. Generally, farmers rotate it with rice and maize crops.
Rice	The third crop in terms of AUA, and second in terms of consumption. Pakistan has a comparative advantage in producing the highly-valued, aromatic basmati rice. Basmati is a major export of Pakistan, and generates substantial revenues for the government from export duties.	It is kharif crops usually cultivated in summer (monsoon season) and harvested in the start of winter (kharif season). In Pakistan rice is usually rotated with wheat, oats and barely (rabi crops).
Sugarcane	An important cash crop of Pakistan, occupying about 1.40E+04 ha area in Bahawalnagar.	It is mainly cultivated in Pakistan two times a year in summer from July to November and in winter (November to April).
Maize	An important cash crop of Pakistan.	It is mainly cultivated in Pakistan one time per year.
Cotton	After wheat, cotton occupies the largest amount of agricultural utilized area in Pakistan. Economically, it earns the largest export revenues.	It is usually cultivated in kharif season and rotated with wheat, oats and barley etc.

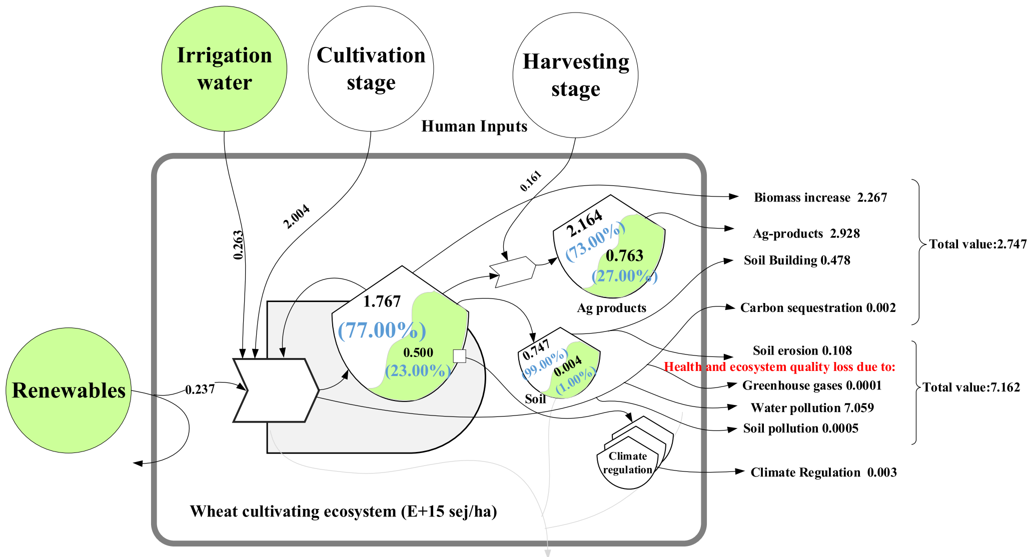

Fig. 6. Emergy diagram and ES and EDS values of wheat cultivating ecosystem.

ecosystems which includes wheat, rice, sugarcane, maize and cotton farming. Calculations are based on the duration of the seasons of each cultivating ecosystem by using inputs from the year 2015. The duration of each crop is obtained by the country official crops calendar. All the considered crops are cultivated with conventional production systems locally adopted; we do not consider organic or biodynamic production systems. Further details about calculation process of ES are available in the Appendix (Table A1).

3. Results and discussion

3.1. Agriculture cultivating ES and EDS calculation at regional scale

3.1.1. Wheat cultivating ecosystem

The renewable fraction in wheat cultivating ecosystem is 5.10E+14 sej/ha, representing 18% if compared to total inputs, as shown in Table 2 and Fig. 6.

The human inputs are divided into two stages the cultivation stage and harvesting stage. In cultivation stage human inputs includes fertilizers, pesticides, mechanical equipment's, energy usage, water use for irrigation, seed use for sowing and human labor employed in wheat growing. The emergy human inputs in the overall cultivation stage is 2.00E+15 sej/ha, having 75% labor contribution, while in harvesting stage the emergy values is 1.61E+14 sej/ha. Comparing the nature's contribution, such big amounts of human inputs indicate that the composition of agriculture ecosystem is mainly engineered and controlled by humans.

Emergy value for direct services provided by wheat cultivating ecosystem was 1.77E+15 sej/ha, considering together with human inputs. The total value of direct services provided by wheat cultivating ecosystem were 2.27E+15 sej/ha, 1.83E+12 sej/ha and 4.78E+14 sej/ha for biomass increase, carbon sequestration and soil building respectively. The results indicate the maximum values of soil building and biomass increase. This result is accurate because mostly agriculture production is depended on synthetic fertilizers (soil building) used in the agricultural production process to obtain agricultural commodities, biomass increase (food, forage, etc) that are the main purpose of agriculture ecosystems.

The indirect services mainly include disservices, which arise from the human involvement. They are calculated by human health and ecosystem quality loss. Therefore, the value of indirect services of wheat cultivating ecosystem for greenhouse gases release, water-soil pollution and soil erosion increase are 1.16E+11 sej/ha, 7.06E+15 sej/ha, 5.15E+11 sej/ha and 1.08E+14 sej/ha respectively, indicates the maximum value of pollution.

This is especially true in most of Pakistan and in all over the world due to the green revolution which increase the production to elevate the poverty (Conway, 1998; Tilman et al., 2001) but such green revolution links with unsustainable practices such as excessive use of fertilizers, pesticides and residue burning. Similarly, the existing services provided by wheat cultivating ecosystem are 3.39E+12 sej/ha for climate regulation and tourism and educational services are not calculated due to the unavailability of data.

The total emergy values of direct, indirect and existing services in wheat cultivating ecosystem are 2.75E+15 sej/ha, 7.17E+15 sej/ha and 3.39E+12 sej/ha respectively. The results indicate maximum value of indirect services follow by direct services. The disservices arise when agriculture is unsustainable, such as excessive usage of pesticides, fertilizers etc. For maximum production and also inadequate agriculture facilities such as alternative usage of agriculture residues instead of direct burning.

In this case study, there is no management strategy for biomass residues to make a bioenergy etc. Instead of being use such residues, the farmer in Pakistan openly burn the residues which create/release greenhouse gases into the atmosphere. Another example is that the soil of Pakistan is very poor in organic matter and minerals (Aamer et al., 2015; Ahmad and Khan, 2006). Therefore, the soil is highly dependent on synthetic fertilizers and also the farmer uses excessive amount of pesticides which due to runoff, leaching degrades other ecosystems and its diversity and also effect human beings through food chain.

3.1.2. Rice cultivating ecosystem

The total renewables inputs of the rice cultivating ecosystem were 7.99E+14 sej/ha about the 10% of all inputs. Similarly, the human inputs i.e. the cultivation and harvesting stage were 6.64E+15 sej/ha and 5.65E+14 sej/ha respectively, representing about 82% and 7% respectively as shown in Table 2 and Fig. 7.

Direct services provided by rice cultivating ecosystem in which the biomass increase emergy values was 6.53E+15 sej/ha with human inputs. The total value of direct services provided by rice

Table 2
Total values of ES and EDS of different cultivating ecosystems in sej/ha.

Classification	Items	Total emergy values sej/ha				
		Wheat	Rice	Sugarcane	Maize	Cotton
Renewables		5.10E+14	7.99E+14	1.26E+15	3.24E+14	5.97E+14
Human inputs	Cultivation stage	2.00E+15	6.64E+15	3.83E+16	7.05E+16	2.86E+15
	Harvesting stage	1.61E+14	5.65E+14	3.25E+15	1.22E+16	4.34E+14
Direct services						
	Biomass increase	2.27E+15	7.33E+15	3.92E+16	7.08E+16	3.34E+15
	Carbon sequestration	1.83E+12	9.64E+12	5.68E+13	2.12E+14	3.16E+12
	Soil building	4.78E+14	4.91E+14	5.27E+14	8.62E+14	4.87E+14
	Ground water recharge	-	2.45E+13	-	-	-
Indirect services						
	Greenhouse emission/climate change	1.16E+11	3.48E+11	1.73E+11	8.66E+10	1.03E+11
	Water pollution/deterioration	7.06E+15	7.06E+15	2.15E+16	4.10E+16	7.06E+15
	Soil pollution/deterioration	5.15E+11	4.93E+11	1.5E+12	2.81E+12	4.99E+11
	Soil erosion increase	1.08E+14	1.08E+14	1.08E+14	5.96E+14	1.15E+15
Existing Values						
	Climate regulations	3.39E+12	3.39E+12	3.39E+12	3.39E+12	3.39E+12

Notes: (−) means data unavailable or not calculated.

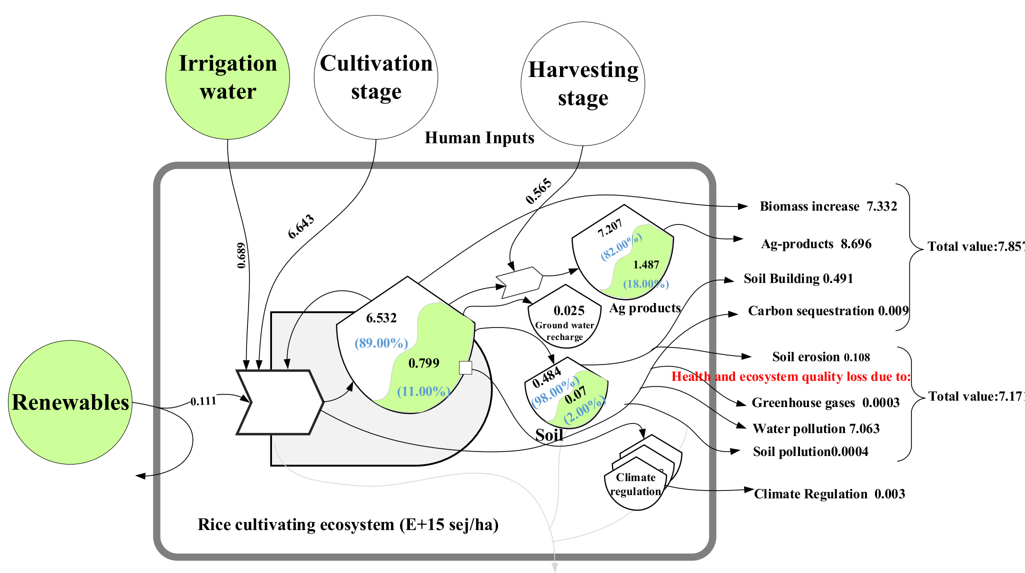

Fig. 7. Emergy diagram and ES and EDS values of rice cultivating ecosystem.

cultivating ecosystem were 7.33E+15 sej/ha, 9.64E+12 sej/ha, 4.91E+14sej/ha and 2.45E+13 sej/ha for biomass increase, carbon sequestration, soil building and ground water recharge respectively.

Similarly, the EDS provided by rice cultivating ecosystem were greenhouse gases release, water-soil pollution and soil erosion increase and their emergy values were 3.48E+11 sej/ha, 7.06E+15 sej/ha, 4.93E+11 sej/ha and 1.08E+14 sej/ha respectively, indicates the maximum value of water pollution. This is especially true in most of Pakistan and in most of the world where farms discharge, due to the unsustainable practices, large amount of agrochemical into the soil and into the water bodies. The existing services provided by rice cultivating ecosystem were 3.39E+12 sej/ha for climate regulation while the tourism and educational services were not considering in this study due to the unavailability of the data.

The total value of direct, indirect and existing services was 7.86E+15, 7.17E+15 and 3.39E+12 sej/ha respectively.

3.1.3. *Sugarcane cultivating ecosystem*

The total renewables inputs of the sugarcane cultivating ecosystem were (1.26E+15 sej/ha) representing about 3% of all other inputs. Similarly, the human inputs i.e. the cultivation and harvesting stage were 3.83E+16 sej/ha and 3.25E+15 sej/ha respectively, representing about 89% and 8% respectively as shown in Table 2 and in Fig. 8.

Direct services provided by sugarcane cultivating ecosystem in which the biomass increase emergy values was 3.8E+16 sej/ha with human inputs. The total value of direct services provided by sugarcane cultivating ecosystem were 3.92E+16, 5.68E+13 and 5.27E+14 sej/ha for Biomass increase, carbon sequestration and soil building respectively.

Similarly, the indirect services provided by sugarcane cultivating ecosystem for greenhouse gases release, water pollution, soil pollution and soil erosion increase and their amount were 1.73E+11 sej/ha, 2.15E+16 sej/ha, 1.50E+12 sej/ha and 1.08E+14 sej/ha respectively, indicates the maximum value for water pollution. This is especially true in most of Pakistan and in most of the world where due to the unsustainable practices such as excessive use of fertilizers, pesticides.

The existing services provided by sugarcane cultivating

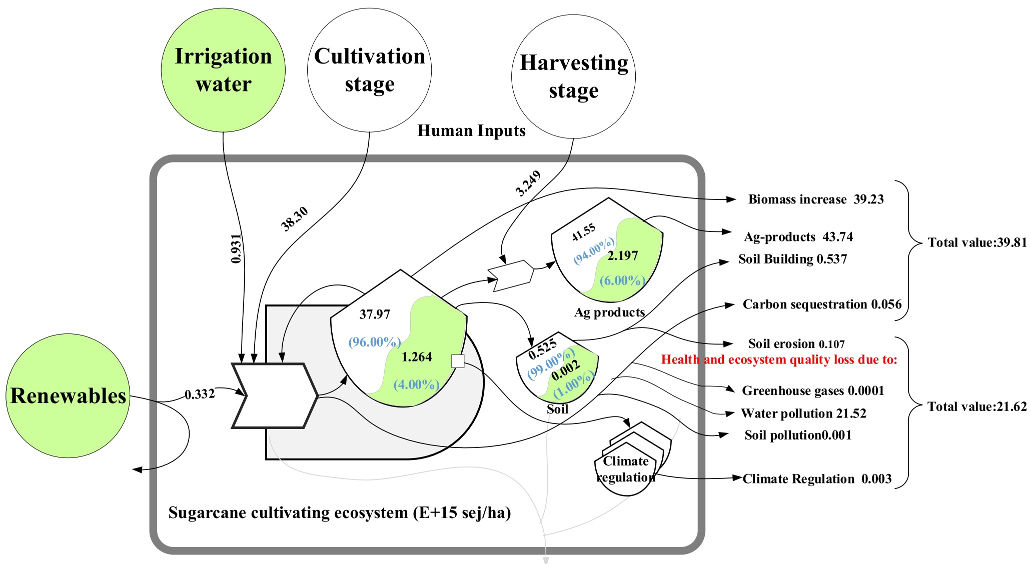

Fig. 8. Emergy diagram and ES and EDS values of sugarcane cultivating ecosystem.

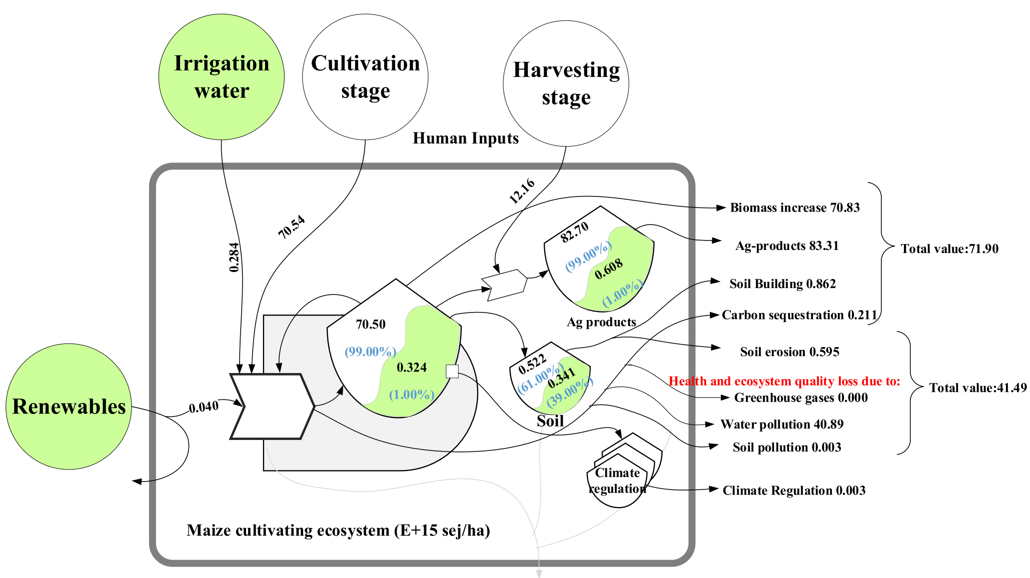

Fig. 9. Emergy diagram and ES and EDS values of maize cultivating ecosystem.

ecosystem were 3.39E+12 sej/ha for climate regulation while the tourism and educational services were not considering in this study due to the unavailability of the data. The total value of direct, indirect and existing services was 3.98E+16 sej/ha, 2.16E+16 sej/ha and 3.39E+12 sej/ha respectively.

3.1.4. *Maize cultivating ecosystem*

The total renewables inputs of the maize cultivating ecosystem were 3.24E+14 sej/ha less than 1% compare to all inputs. Similarly, the human inputs for the cultivation and harvesting stage were 7.05E+16 sej/ha and 1.22E+16 sej/ha respectively, representing about 84% and 15% respectively.

Direct services provided by sugarcane cultivating ecosystem in which the biomass increase emergy values was 7.05E+16 sej/ha with human inputs and 3.24E+14 sej/ha without human as shown in Table 2 and in Fig. 9. The total value of direct services provided by maize cultivating ecosystem were 7.08E+16 sej/ha, 2.12E+14 sej/ha and 8.62E+14 sej/ha for biomass increase, carbon sequestration and soil building respectively.

Likewise, the value of indirect services of maize cultivating ecosystem for greenhouse gases release, water pollution, soil pollution and soil erosion increase are 8.66E+10 sej/ha, 4.09E+16 sej/ha, 2.81E+12 sej/ha and 5.96E+14 sej/ha respectively. Existing services provided by maize cultivating ecosystem is (3.39E+12 sej/ha) for climate regulation.

The total emergy values of direct, indirect and existing services in maize cultivating ecosystem are 7.19E+16 sej/ha, 4.15E+16 sej/ha and 3.39E+12 sej/ha respectively.

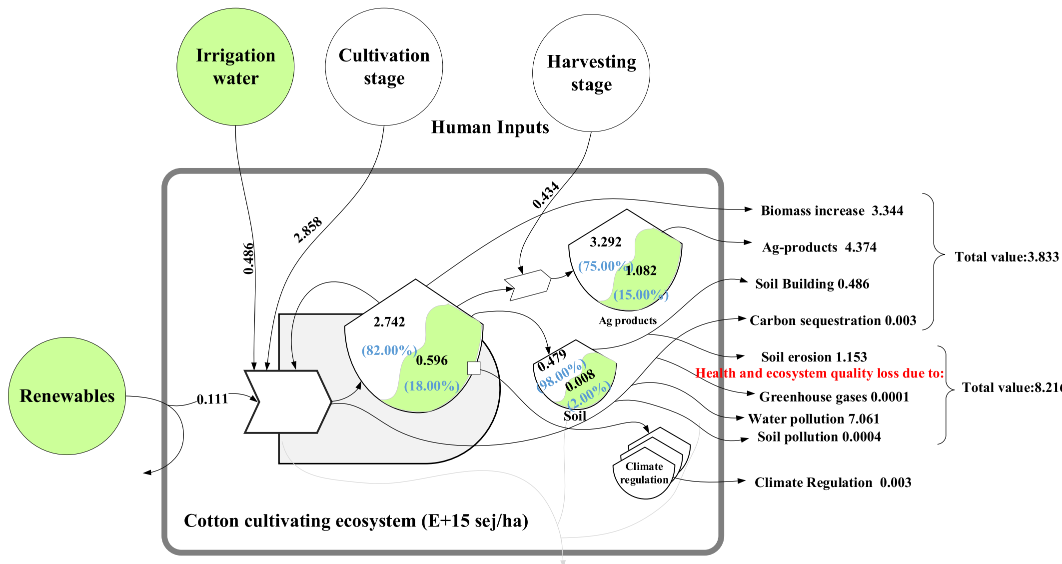

Fig. 10. Emergy diagram and ES and EDS values of cotton cultivating ecosystem.

3.1.5. *Cotton cultivating ecosystem*

The total renewables inputs of the cotton cultivating ecosystem were 5.97E+14 sej/ha representing about 15% compared to all inputs. Similarly, the human inputs in the cultivation and harvesting stage were 2.86E+15 sej/ha and 4.34E+14 sej/ha respectively as shown in Table 2 and in Fig. 10, representing about 73% and 11% respectively, indicates minimum value of harvesting inputs because in the case study the cotton is picket by hand.

Direct services provided by cotton cultivating ecosystem in which the biomass increase emergy values was 2.75E+15 sej/ha with human inputs and 5.97E+14 sej/ha without human. The total value of direct services provided by cotton cultivating ecosystem were 3.34E+15 sej/ha, 3.16E+12 sej/ha and 4.87E+14 sej/ha for biomass increase, carbon sequestration and soil building respectively.

Likewise, the value of indirect services of cotton cultivating ecosystem for greenhouse gases release, water, soil pollution and soil erosion increase are 1.03E+11 sej/ha, 7.06E+15 sej/ha, 4.99E+11 sej/ha and 1.15E+15 sej/ha respectively. Existing services provided by cotton cultivating ecosystem is (3.39E+12 sej/ha) for climate regulation.

The total emergy values of direct, indirect and existing services in cotton cultivating ecosystem are 3.83E+15 sej/ha, 8.22E+15 sej/ha and 3.39E+12 sej/ha respectively.

3.2. *Sustainability assessment results*

The emergy values of renewables in the in the selected cultivating ecosystems are found in the order of sugarcane > rice > cotton > wheat >maize. The RNP% of wheat, cotton, rice, sugarcane, and maize with 19%, 16%, 10%, 3%, 1%, respectively, indicate the minimum RNP% for maize followed by sugarcane. Similarly, the emergy values of human inputs (in the cultivating and harvesting phases) of the selected cultivating ecosystems were in the order of maize > sugarcane > rice > cotton > wheat. The NRP% of wheat, rice, sugarcane, maize and cotton were 81%, 89%, 96%, 98% and 84% respectively, shows maximum NRP% for maize followed by sugarcane. The overall results of RNP% and NRP% indicates that the maize cultivating ecosystem in the case study is the more unsustainable, because of its huge dependency on human resources fallowed by sugarcane.

4. Discussion

4.1. *Comparison of ES and EDS of selected agriculture cultivating ecosystems*

The ES according to the results the biomass increases which is direct ecosystem services consists of all biomass including the productions that are used for food source, biomass residues either used for bioenergy generations or used as a forage for livestock or residue left on the field for soil fertility or directly burn on the field. In ecosystem services provided by agriculture cultivating ecosystems, the biomass increase values of selected cultivating ecosystems are in the order of maize > sugarcane > rice >cotton > wheat. For the carbon sequestration, the values are in the order of maize > sugarcane > wheat > rice > cotton. In case of soil building which is the combination of soil organic matter and soil mineral building the values are in the order of maize > sugarcane > rice > cotton > wheat. For the ground water recharge this study only calculates the value for rice paddy because other agriculture cultivating ecosystems provide such services in very less or even not provide such services. Rice which consume a huge amount of water than other cultivating ecosystems provides the ground water recharge service.

The EDS values according to the calculations, the greenhouse gases emissions, water and soil pollution are in the order of maize > sugarcane> cotton > rice >wheat. Similarly, the values of soil erosion are in the order of cotton > maize > sugarcane > wheat > rice.

4.2. *Comparison with different agriculture cultivating types of previous studies*

The previous studies data of different agriculture cultivating types were collected from the literature and the data was analyzed based on the ecosystem services and dis-services to make a comparison, based on their agriculture sustainability (RP% and NRP%) and agriculture technologies situation as shown in Table 3. The RP% in Lebanon agriculture types was between 7.10% maximum value in the olive and 0.85%, minimum value in orange indicates highly dependent on human provides higher ecosystem services as well as high dis-services.

The Mediterranean climate with productive rich soil conditions

Table 3
Comparison current study ES and EDS with previous studies.

	Values in sej/ha												
	Direct services					Indirect services (Dis-services)					Indicator		
Items	Biomass increase	Carbon Sequestration	Soil Building	Ground water recharge	Total	Greenhouse emission	Water Pollution	Soil Pollution	Soil Erosion Increase	Total	RP %	NRP%	ref
Potato	3.6E+16	1.6E+12	3.1E+16	-	6.7E+16	2.0E+13	3.3E+18	4.0E+15	3.3E+14	3.3E+18	1.52%	98.48%	1
Wheat	1.2E+16	1.6E+12	5.7E+16	-	6.9E+16	5.2E+12	4.5E+17	2.2E+15	3.3E+14	4.5E+17	4.53%	95.47%	1
Olive	7.5E+15	1.3E+13	4.4E+16	-	5.2E+16	3.5E+12	2.9E+18	3.9E+15	3.3E+14	2.9E+18	7.10%	92.90%	1
Orange	5.7E+16	3.5E+14	4.1E+16	-	9.8E+16	4.0E+13	2.6E+19	1.2E+16	3.3E+14	2.6E+19	0.95%	99.05%	1
Citrus	3.3E+16	3.5E+14	4.1E+16	-	7.4E+16	2.0E+13	2.6E+19	1.2E+16	3.3E+14	2.6E+19	1.64%	98.36%	1
Grape	1.6E+16	5.5E+11	2.5E+16	-	4.1E+16	7.8E+12	4.6E+18	2.7E+15	3.3E+14	4.6E+18	3.45%	96.55%	1
Apple	1.7E+16	5.5E+11	3.7E+16	-	5.4E+16	2.1E+13	1.3E+19	5.4E+15	3.3E+14	1.3E+19	3.17%	96.83%	1
Cucumber	2.1E+16	1.6E+12	3.6E+16	-	5.7E+16	1.3E+13	9.5E+18	6.8E+15	3.3E+14	9.5E+18	2.52%	97.48%	1
Tomato	2.7E+16	1.6E+12	2.9E+16	-	5.7E+16	2.0E+13	6.3E+18	6.8E+15	3.3E+14	6.3E+18	1.99%	98.01%	1
Maize	4.0E+16	2.2E+12	5.8E+16	-	9.8E+16	7.0E+11	3.6E+17	1.1E+20	1.8E+15	1.1E+20	0.88%	99.12%	2
Date	1.6E+16	1.9E+14	2.4E+16	-	4.0E+16	4.3E+11	8.6E+17	2.2E+16	3.2E+13	8.8E+17	26.33%	73.67%	3
Pistachio	2.1E+16	1.9E+14	2.1E+16	-	4.2E+16	6.3E+11	2.3E+18	2.8E+16	1.2E+15	2.3E+18	20.33%	79.67%	3
Fodder Maize	4.0E+15	1.7E+12	1.9E+16	-	2.3E+16	1.8E+12	1.4E+18	8.3E+14	3.8E+15	1.4E+18	15.95%	84.05%	4
Soybean	3.2E+15	1.8E+12	4.3E+16	-	4.6E+16	-	6.4E+16	1.9E+15	5.0E+15	7.1E+16	13.59%	86.41%	5
Wheat	2.3E+15	1.8E+12	4.8E+14	-	2.7E+15	1.2E+11	7.1E+15	5.2E+11	1.1E+14	7.2E+15	18.79%	81.21%	6
Rice	7.3E+15	9.6E+12	4.9E+14	2.5E+13	7.9E+15	3.5E+11	7.1E+15	4.9E+11	1.1E+14	7.2E+15	9.99%	90.01%	6
Sugarcane	3.9E+16	5.7E+13	5.3E+14	-	4.0E+16	1.7E+11	2.2E+16	1.5E+12	1.1E+14	2.2E+16	2.95%	97.05%	6
Maize	7.1E+16	2.1E+14	8.6E+14	-	7.2E+16	8.7E+10	4.1E+16	2.8E+12	6.0E+14	4.2E+16	0.39%	99.61%	6
Cotton	3.3E+15	3.2E+12	4.9E+14	-	3.8E+15	1.0E+11	7.1E+15	5.0E+11	1.2E+15	8.2E+15	15.34%	84.66%	6

Note (−), data not calculated. (1) Skaf et al. (2019); (2) Houshyar et al. (2018); (3) Jafari et al. (2018); (4) Ghaley et al. (2018); (5) Liu et., 2019; (6) This study.

is one of the main and important features for growing plenty of agriculture productions (FAO, 2014). Due to a large number of Syrian refugees in the country more than 30% of the Lebanese populations, increase the demands of agriculture productions which shifts the country agriculture from low intensive agriculture inputs to high intensive inputs to fulfilled the needs of their peoples but such agriculture alterations produce various environmental degradation (Ghadban et al., 2013; Skaf et al., 2019). Similarly, the RP% values of agriculture types in Iran were 0.88% for maize, 26.33% for date and 20.33% for pistachio indicates maize is highly dependent on human which according to the results provides maximum services total value of 9.8E+16 sej/ha but such dependency is also the source of numerous dis-services, 1.1E+20 sej/ha higher value among all agriculture types. The agriculture in Iran especially in the case study of maize the environmental conditions such as low precipitations makes the area water scarce and poor condition of the soil make the agriculture human intensive (Stads et al., 2008; Houshyar et al., 2018). Whereas for date and pistachio which is the top export agriculture commodities of Iran, various improvements were done in terms of increase in the area for date and pistachio, sustainability of agriculture resources consumptions and improvements in the agriculture based technology for further enhancing their production for exports (Stads et al., 2008; Rahimpour et al., 2015; Jafari et al., 2018). The soybean and fodder maize productions in Denmark and Shaanxi, China, the value of RP% are 15.95% and 13.59% respectively indicates quite similar dependency on renewables in the wheat cultivating types of this study. However, Shaanxi, China, most of its area is infertile or nutrient deficient therefore excessive synthetic based fertilizers was used for higher yields which is main reason of environmental and degradations in the most of its area (Guo et al., 2012). Based on the current and previous studies it is clear that on a minor view, variation in values are seems such as changes in specific values of ES (ecosystem services) and EDS (ecosystem dis-services) in all agriculture types but on a broader view the current agriculture types are similar with the previous studies agriculture types. Which indicates that highly human intensive agriculture provides maximum of ES while such dependency also produces maximum of EDS. Therefore, a significance policy should need to be adopted to achieved sustainability in agriculture through enhancing their research in agriculture, and to change the pattern of human inputs such as using organic fertilizers and pesticides instead of synthetic, making the agriculture low human intensive that will lead to the agriculture on a sustainable path (Tuo et al., 2017).

4.3. Policy suggestions and relation of sustainability with services and disservices in agriculture ecosystem

One of the extreme challenges presently world communities facing is the ensuring access to healthy and environmentally sustainable food to all people at all times. A sustainable agriculture is the one “which use the natural resources for its production but it also helps for enhancing or preserving the quality of resources that are used in it” (Firebaugh, 1990). Sustainable agriculture is the capacity to produce stable production in the extended run without deteriorating the soil (Poudel et al., 1998). A sustainable and well-managed agricultural ecosystem produce enough services that can be livable, equitable and viable. Sustainable agriculture ecosystem provides services means beneficial services while unsustainable agriculture ecosystem provides dis-services which refers to “the generated ecosystem processes, functions and attributes resulting in perceived or actual negative influences on human well-being” (Shackleton et al., 2016).

In Asia the start of green revolution vitally improved the production of agriculture through providing better crop varieties, application of inorganic/synthetic fertilizers and pesticides and provision of irrigation water (Hazell, 2009). Although such green revolution-imposed damage on water and soil quality due to excessive usage of synthetic fertilizers and pesticides and also the excessive usage water for irrigation purposes resulting in soil acidification and salinization in numerous areas of Pakistan (Hussain, 2012; Ali and Byerlee, 2002; Qureshi et al., 2008; Zulfiqar and Thapa, 2017).

The results of RNP and NRP % indicator also show the unsustainability in selected agriculture cultivating ecosystems in the case study especially maize cultivating ecosystem followed by sugarcane. High dependent input and intensive usage resource agriculture systems caused enormous problems such as deforestation, scarcities of water, deterioration of soil and high amount of GHGs emissions, which cannot deliver sustainable agricultural productions system (FAO, 2017). Therefore, the government needs to make a policy as well as establish educational programs/projects for the farmers so that the farmers can implement the sustainable practices and also such projects will help improve their skills, awareness and knowledge concerning agricultural sustainability (Ali et al., 2018a, b). In Pakistan, the farmers of rural areas are mostly untrained and uneducated therefore such educational program will increase their level of education about agriculture (Azam and Shafique, 2017). Modern agriculture practices such as greenhouses using solar panels as a renewable source of energy are needed that will help to form less depended on non-renewable resources (Esen and Yuksel, 2013). Significant improvement should be made to discourage the excessive uses of pesticides and fertilizers, encourage the use of organic fertilizers and alternative usage of biomass residues for bioenergy regeneration. Adopting the sustainable practices in agriculture will minimize disservices resulted from unsustainability and will maximize the services or benefits. However, such improvements and developments in agriculture require high attention from the government agencies to contribute with the help of well expertise in agro-forestry, agro-ecology, conservation and climate-smart agriculture as well as international cooperation which is needed to protect the agricultural ecosystem form emerging threats such as diseases and pests (FAO, 2017).

5. Conclusions

This study proposes the “donor side” non-monetary ecosystem services valuation methods for agriculture ecosystem. It calculates four direct services such as biomass increase (including nature's and human's contributions as well as its productions), carbon sequestrations, soil building and ground water recharge (for rice cultivating ecosystem); four indirect services (mainly include disservices which arise from the process and function of direct services) such as health and ecosystem quality loss due to greenhouse gases emissions, soil pollution, water pollution and soil erosion increase; one existing services out of three such as climate regulations due to the presence of data. The results of the case study cultivating ecosystem indicate that maize cultivating ecosystem is unsustainable due to maximum value of NRP% and minimum value of RNP% followed by sugarcane cultivating ecosystem. Further, the comparison with other previous studies concerning agriculture cultivating ecosystems results also indicate that human intensive cultivating ecosystem delivers maximum of ES but such dependency is also a source of numerous EDS. From the above results we conclude that green revolution and unsustainable practices such as high dependency on human inputs in agriculture ecosystem provide higher productivity but on the other hand it also provides various indirect services in the form of dis-services. Therefore, the method proposed by this study, can deliver improved theoretical and policy insights to ecosystem services accounting, management and sustainability in agriculture ecosystem.

The emergy based ES and EDS calculations take root in donor side perspective and have a significant advantage in unified accounting and avoiding uncertainties, overestimation and double counting through, drawing the emergy-base diagram which display processes, formation and functioning of ecosystem services and disservices. However, due to the incomplete data and parameter of production methods and farms management, there are still some limitations in the current research. For example, some ES and EDS were not calculated due to lack of data, such as for air pollution, with the exception of the greenhouse gases emissions data available for this study. Furthermore, some services (such as pollination, soil retention etc.) and disservices such as biodiversity loss are also not calculated due to the lack of data. Meanwhile, the irrigated water i.e. surface or ground water usage were calculated and considered as renewables, but in modern agriculture, the irrigated water might be considered as purchased renewables resources based on scarcity considerations. Therefore, in the future studies the lack of data should be faced to ensure a more complete services evaluation. Additionally, the comparative analysis is needed through spatial techniques by combining the GIS tools with emergy in order to identify changes of ES and EDS in different cultivating ecosystems so that agriculture policies will be established base on the changes. Furthermore, a comparative study on ecosystems services provision between different production methods (organic, conventional, biodynamic) is needed to better address sustainability and food security goals in agriculture.

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Appendix

Table A1
Values of renewables, human inputs, ES and EDS of Rice cultivating ecosystem along with the procedure in the case study.

Items	Raw Data	Unit	UEVs (Unit)	References	Total Emergy values sej (unit)
Rice cultivating ecosystem					
Renewable resources					
Sunlight	1.07E+16	J	1	Brown and Ulgiati (2016)	1.07E+16
Deep Heat (Geothermal Heat)	1.25E+14	J	4.90E+03	Brown and Ulgiati (2016)	6.14E+17
Wind	1.2E+15	J	7.90E+02	Brown and Ulgiati (2016)	9.51E+17
Rainwater Chemical Energy	3.78E+14	J	7.01E+03	Brown and Ulgiati (2016)	2.65E+18
Runoff (geopotential)	3.07E+13	J	1.28E+04	Brown and Ulgiati (2016)	3.93E+17
Runoff (Chemical potential)	1.26E+14	J	2.13E+04	Brown and Ulgiati (2016)	2.68E+18
Irrigating water	1.11E+15		4.10E+04	(Chen.,2014)	4.54E+19
Human inputs(Cultivation)					0
Nitrogen fertilizer	7.26E+09	g	4.84E+09	Ghisellini et al. (2014)	3.51E+19
Phosphate fertilizer	4.42E+09	g	4.97E+09	Ghisellini et al. (2014)	2.2E+19
Potash fertilizer	3.96E+09	g	1.40E+09	Ghisellini et al. (2014)	5.54E+18

(continued on next page)

Table A1 (*continued*)

Items	Raw Data	Unit	UEVs (Unit)	References	Total Emergy values sej (unit)
Pesticides	2.44E+07	g	4.58E+09	Ghisellini et al. (2014)	1.12E+17
Manure	1.04E+13	J	7.01E+04	Zhang et al. (2007)	7.26E+17
Energy Consumption					0
Diesel	4.06E+14	J	1.81E+05	(Brown et al., 2011)	7.34E+19
Electricity	8.14E+11	J	2.20E+05	Sweeney et al. (2009)	1.79E+17
Mechanical inputs					0
fraction of steel and iron	9.3E+09	g	2.40E+09	Bargigli & Ulgiati (2003)	2.23E+19
fraction of alluminum	1.59E+09	g	5.87E+08	After Odum et al., 2000	9.32E+17
fraction of rubber and plastic material	1.13E+08	g	5.46E+09	After Odum et al., 2000	6.19E+17
fraction of copper	3.4E+08	g	2.55E+09	Brown & Ulgiati (2004)	8.66E+17
Labor	4.19E+13	J	5.73E+06	Brandt-Williams and Pillet (2003)	2.4E+20
Seed	1.43E+13	J	5.96E+04	Zhang et al. (2007)	8.54E+17
Human input(Harvesting)					
Energy consumptions (Diesel)	1.6E+11	J	1.81E+05	(Brown et al., 2011)	2.89E+16
Labor	6.35E+12	J	5.73E+06	Brandt-Williams and Pillet (2003)	3.64E+19
Mechanical inputs					
fraction of steel and iron	3.17E+08	g	2.40E+09	Bargigli & Ulgiati (2003)	7.59E+17
fraction of alluminum	5.41E+07	g	5.87E+08	After Odum et al., 2000	3.18E+16
fraction of rubber and plastic material	3.86E+06	g	5.46E+09	After Odum et al., 2000	2.11E+16
fraction of copper	1.16E+07	g	2.55E+09	Brown & Ulgiati (2004)	2.95E+16
Direct services					
Biomass increase[1]	Calculated by using eq. 1			This study	4.84E+20
carbon sequestration[2]	Calculated by using eqs (2) and (3).	g		This study	6.36E+17
Soil Building[3]	(organic matter + mineral increase)Calculated by using eqs (3) and (3.1).			This study	3.24E+19
Ground water Recharge[4]	7.92E+13	J	2.04E+04	Brown and Ulgiati (2018)	1.62E+18
Indirect services					
Greenhouse emission[5]	Calculated through equations (7) and (8).	Capital	5.59E+15	Collected from Emergy NEAD Database	2.29E+16
Water Pollution/Deterioration[5]	Calculated through equations (7) and (8).	Capital	5.59E+15	Collected from Emergy NEAD Database	4.66E+20
Soil Pollution/Deterioration[5]	Calculated through equations (7) and (8).	Capital	5.59E+15	Collected from Emergy NEAD Database	3.25E+16
Increase in Soil erosion	1.76E+07	g	5.61E+04	(Brown and Ulgiati (2016)	7.11E+18
Existing Values					
Climate Regulations	Calculated by using equation (11).	Capital	5.59E+15	Collected from Emergy NEAD Database	2.24E+17

Notes: First, all the renewables inputs and human inputs are calculated by proper methods and all the UEVs which are used in this study are provided with reference in the tables. (−) means data not calculated. (Below details are provided based on the rice cultivating ecosystem which means for all selected cultivating ecosystems the calculation procedure is same).

1. Means that the Biomass increase value is calculated by renewables and human inputs through equation number 1. Therefore, there is no unified values that can give us specific UEVs and raw data in agriculture ecosystem. The raw data is listed in the table.
2. Carbon sequestration is calculated by using equation (3). Which is the amount of carbon being sequester by selected crops and the UEVs that is used for the calculations was calculated by using the equation (4).
3. Means the soil building value which is the sum of soil organic matter and soil mineral. Soil organic matter was calculated using the MAX R, k_1, k_2, xi by using the equation (5). The emergy data of organic matter increase for Rice Cultivating ecosystem is **(1.19E + 18 sej).** For the soil mineral increase for agriculture ecosystem we just select three minerals which is N, K_20 and P_2O. The UEVs of such minerals that is used in this study are **(4.42E + 09 sej/g, 3.85E + 06 sej/g and4.57E + 07 sej/g) collected** from ((Liu et al., 2009) (Brown and Ulgiati., 2018) and (Brown and Ulgiati., 2018). Then after the calculation of each minerals values were calculated by equation (6). The overall mineral increase value for Rice is **(3.12E + 19 sej).** After this we sum up the soil organic matter and mineral increase values to get the final values of soil building values for Rice which is **(3.24E + 19 sej).**
4. Indicates the ground water recharge which is only for rice cultivating ecosystem because rice need too much of water which provides the ground water recharge services. ground water is calculated by using equation (7). By putting the data of precipitations in the study case, infiltration coefficients which is (0.15) (Liu, 2007) and UEVs of ground water which is mentions in Table 2 with its reference.
5. Shows the damages cause by release of the greenhouse gases and pollutants, water and soil pollution in agriculture ecosystem. The data about the such pollutants is calculated by using equations (8) and (9). The UEVs used here is **(5.59E + 15 sej)** for Pakistan collected from NEAD database. The detailed calculation for pollutants arise from Rice cultivating system means calculation of human health loss = $E_{mCH4} = \sum M_{CH4} \times S \times DALY_{CH4} \times T_H$ = (100 kg/ha)*(66,000 ha)*(4.40E-06 DALY/kg)*(5.59E+15 sej/cap)= **(1.62E + 16 sej)** the DALY value must be divided by lifetimes of each gases here we divide the CH_4 into 10 year which is its lifetime. Similarly, all the pollutants values of DALY must be divided into its lifetime**.** For ecosystem quality loss which is = $E_{mPest} = \sum M_{Pest} \times PDF(\%)_{Pest} \times E_{mBIO}$ this equation is taken from (Liu et al., 2011). = (0.259 kg/ha) *(258.4944 m^2/yr) * (4.54E+19 sej/g)/(10000 m^2/ha)= **(3.04E + 17sej).** Here we take the average value of PDF of known pesticides that are used in the case study. Similarly, all the damages for GHGs emissions, water and soil pollution were calculated by using the same methods.

Table A2
Emergy values of Renewables and human inputs.

Inputs	Items	Total emergy values in sej/ha				
Renewables		Wheat	Rice	Sugarcane	Maize	Cotton
	Sunlight	2.36E+11	1.63E+11	1.93E+11	1.52E+11	1.63E+11
	Deep Heat (Geothermal Heat)	9.31E+12	9.31E+12	9.31E+12	9.31E+12	9.31E+12
	Wind	4.86E+13	1.44E+13	1.97E+13	6.7E+12	1.44E+13
	Rainwater Chemical Energy	8.29E+13	4.02E+13	1.4E+14	4.22E+12	4.02E+13
	Runoff potential energy	1.23E+13	5.96E+12	2.08E+13	6.25E+11	5.96E+12
	Runoff Chemical Energy	8.38E+13	4.06E+13	1.42E+14	1.99E+13	4.06E+13
	Irrigating water	2.63E+14	6.89E+14	9.32E+14	2.84E+14	4.86E+14
	Total	5E+14	7.99E+14	1.26E+15	3.24E+14	5.97E+14
Human input (Planting stage)						
	Nitrogen fertilizer	5.81E+14	5.32E+14	1.06E+15	4.36E+14	7.26E+14
	Phosphate fertilizer	4.47E+14	3.33E+14	4.47E+14	2.98E+14	2.98E+14
	Potash fertilizer	8.4E+13	8.4E+13	1.19E+14	5.6E+13	8.4E+13
	Pesticides	1.69E+12	1.69E+12	1.69E+12	1.69E+12	1.69E+12
	Manure	5.26E+11	1.1E+13	5.19E+13	4.84E+13	5.17E+12
	Energy Consumption	7.69E+12	1.12E+15	7.44E+14	1.49E+14	4.46E+14
	Mechanical inputs	2.89E+13	3.74E+14	3.74E+14	3.74E+14	3.74E+14
	Labor	7.6E+14	3.64E+15	2.86E+16	6.92E+16	9.06E+14
	Seed	9.35E+13	5.51E+14	6.9E+15	2.24E+13	1.66E+13
	Total	2E+15	6.64E+15	3.83E+16	7.05E+16	2.86E+15
Human input (Harvesting Stage)						
	Energy consumptions (Diesel)	4.38E+11	4.38E+11	-	2.18E+12	-
	labor	1.48E+14	5.51E+14	3.25E+15	1.21E+16	4.34E+14
	Mechanical inputs	1.22E+13	1.28E+13	-	2.68E+13	-
	Total	1.61E+14	5.65E+14	3.25E+15	1.22E+16	4.34E+14

Note:(−) means data not calculated, means harvesting practices was done in the study case for that crops though labor (hand).

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