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СУЧАСНЕ ПРОМИСЛОВЕ ТА ЦИВІЛЬНЕ БУДІВНИЦТВО
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СИСТЕМНИЙ АНАЛІЗ ОЦІНКИ ЕКОЛОГІЧНОЇ БЕЗПЕКИ СИСТЕМ ВОДОПОСТАЧАННЯ

Н. Г. Насонкіна, В. Н. Сахновська
Донбаська національна академія будівництва та архітектури,
вул. Державіна, 2, 86123, г. Макіївка, Україна
E-mail: Vsahnovskaya@mail.ru

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Анотація. Розглянуто питання оперативного управління забезпечення надійності системи водопостачання та водовідведення, для чого запропоновано системну логіко-математичну модель, яка базується на комплексній оцінці екологічної безпеки систем. Особливе значення ця оцінка може мати при необхідності видалення негативних змін, що виникли в системі, та при розробці програмних заходів, направлених на підвищення надійності систем водопостачання та водовідведення міст. Визначені методи підвищення екологічної безпеки та надійності водопровідної та каналізаційної мережі з врахуванням економічних ризиків.

Ключові слова: оцінка якості води, надійність, водопостачання, водовідведення, очисні споруди, екологічна безпека, інтегральний показник, хімічне та біологічне забруднення.

СИСТЕМНЫЙ АНАЛИЗ ОЦЕНКИ ЭКОЛОГИЧЕСКОЙ БЕЗОПАСНОСТИ СИСТЕМ ВОДОСНАБЖЕНИЯ И ВОДООТВЕДЕНИЯ

Н. Г. Насонкина, В. Н. Сахновская
Донбасская национальная академия строительства и архитектуры,
ул. Державина, 2, 86123, г. Макеевка, Украина
E-mail: Vsahnovskaya@mail.ru

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Аннотация. Рассмотрены вопросы оперативного управления обеспечения надежности и экологической безопасности системы водоснабжения и водоотведения, для чего предложена системная логико-математическая модель, основанная на комплексной оценке экологической безопасности систем. Особое значение эта оценка может иметь при необходимости срочного устранения негативных изменений, произошедших в системе, и при разработке программы мер, направленных на повышение надежности систем водоснабжения и водоотведения городов. Определены методы повышения экологической безопасности и надежности водопроводной и канализационной сети с учетом экономических рисков.

Ключевые слова: оценка качества воды, надежность, водоснабжение, водоотведение, очистные сооружения, стоки, экологическая безопасность, интегральный показатель, химическое загрязнение, биологическое загрязнение.

SYSTEM ANALYSIS OF EVALUATION OF ECOLOGICAL SAFETY OF WATER SUPPLY AND WATER DISPOSAL

N. G. Nasonkina, V. N. Sakhnovskaya
Donbas National Academy of Civil Engineering and Architecture
Derzhavina street, 2, 86123, Makeevka, Ukraine
E-mail: Vsahnovskaya@mail.ru

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Abstract. There have been considered issues of operational management of providing reliability and ecological safety of water supply and water disposal, wherefore a system logical and mathematical model has been suggested, which was based on a complex evaluation of ecological safety systems. This evaluation can be of special significance if it is necessary to eliminate urgent negative changes taking place in the system and while elaboration of program measures directed to improving reliability of cities water supply and water disposal. There have been defined methods of improving ecological safety and reliability of water pipeline and sewerage network taking into account economic risks.

Key words: water quality appraisal, reliability, water supply, sewerage, sewage treatment plants, sewage, ecological safety, integral index, chemical contamination, biological contamination.

Introduction

Community water supply operation practice shows that violation of normal water supply and ecological safety level mainly comes from the accidents on pipeline sections — the most functionally significant and vulnerable elements of regions life support systems.

Operational control of the reliability processes of water supply and sewerage systems often connected with problems of management decisions choice under the conditions of quick and deep factors changes affecting the water (or sewage) supply for consumers (or to the sewage treatment plants) in the required quantity and of optimal quality. The monitoring data is not enough for objective and operational response to negative changes of these factors. Possibility of quick analysis of potential sceneries of crisis situations development and choice of the most suitable (as per economic and ecological features) variant of management decisions are of great significance.

Purpose

To work out a system model of ecological and economic risk evaluation allowing to judge of the state both the whole water supply and water disposial system and of each its element individually. To define methods of improving ecological safety and reliability of the most functionally significant elements of the model – water pipeline and sewerage.

Analysis of methods of evaluation of ecological safety of water supply and water disposal

Common approach to water quality definition by means of comparison contaminants concentration in the water with normatives doesn't give clear out the idea of total contamination and possibility of risk in the system, first of all, because of absence of separate parameters comparability.

The prediction of the water supply state and water disposial systems should be done as per all rated parameters.

A method of expert evaluations is often used to get quantitative characteristics of water quality by a set of parameters [1, 2]. The main disadvantage of this method is that stated in it absolute values change step-like, i.e. influence of the contaminants on the quality of water has multisteps character.

The integral parameter of water quality index proposed in this article [3] considers the significance of concentration variations depending on water content. It should be marked that isolated appraisal of water quality in absolute or relative values often not fully describes state of water-resource potential of the system.

The present index analysis evolution of water quality shows that it should be used the complex water quality index or the level of pollution: for preliminary estimation it is chemical pollution level, combined information index pollution coefficient or the total pollution level; for estimation and comparison of pollution change on different parts of water flow it is the criterion of chemical pollution; for water quality within and water flow or preferable index of pollution level.

To get quantities character of water quality as for the indexes it is often used expert estimation. For example the complex quality water index, consisting two indexes: general sanitarian and specific contamination [4,5].

Elaboration of complex system model "System of municipal water supply and water disposal"

While elaboration strategy of improving ecological safety of all objects of water supply and sewerage complex it should be based on the scientific approach considering the complex of numerous and, at first sight, disintegrated factors able more or less directly or indirectly influence on service lasting of each of the system element and its fulfillment of appropriate sanitary and ecological functions [8].

On this basis, using of integral indexes of the state of system elements should serve for coordinating vector of the system model. A system model "System of municipal water supply and water disposal" is being worked out for assessment of ecological safety. Hierarchic logical and mathematical construction for classification of dinking water supply system state and service-utility sewerage is considered in the model (Fig.1). This kind of classification structure of the model not only provides evaluation of the general systems stae, but also allows to judge of the influence of changes of individual indexes on the condition of the whole system. This, in its turn, defines the direction of effort on improvement of the concrete index that most of all influences the of the system state.

Evaluation of the systems and subsystems state in the model "System of municipal water supply and water disposal" is fulfilled in two directions simultaneously – qualitative and quantitative. Logical function based on a set of qualitative states of separate indexes is classified by qualitative state of the whole system. Quantitative measure is carried out on a set of conditions of individual subsystems. The quantitative measure of the whole system is defined on the base of the quantitative measures of individual subsystems. Evaluation of the ecological system safety is made on the basis of the value close to one of the normative.

Step-by-step evaluation of the criteria on the example of "the water pipeline sewage treatment plants"subsestem

The subsystem "The water pipeline sewage treatment plants" is designated for the evaluation of the water pipeline sewage treatment plants operations according to the criteria of possibility of water contamination during environment cleaning and pollution by formed sludges. It is one of main subsystem. There are three blocks of "Chemical contamination", "Bacteriological contamination" and "Quality of forming sludges" – which together characterize quality of cleaned water being the most important for the evaluation of water contamination possibility during treatment according to a variety of contaminations and barrier function of the facilities.

The subsystem state due to "Quality of forming sludges" is assessed by a set of logical alternatives $O_i \in O$ of ecological sludges safety of the downfall and their influence on the environment. During study of each index it has been established that a lot of alternative states can be represented by the vector: $O = (O_3, O_2, O_1)$=/"catastrophic", "very bad", "satisfactory"/, components of which are defined by the logical function (1):

$$O(f_i) = \begin{cases} O_3, \text{if } L_0^i \le f_i < L_1^i; \\ O_2, \text{if } L_1^i \le f_i < L_2^i; \\ O_1, \text{if } L_2^i \le f_i < L_3^i \end{cases} \quad (1)$$

$$i \in /1,3/$$

where L^i_n – criteria of the indexes evaluation of slidges contamination.

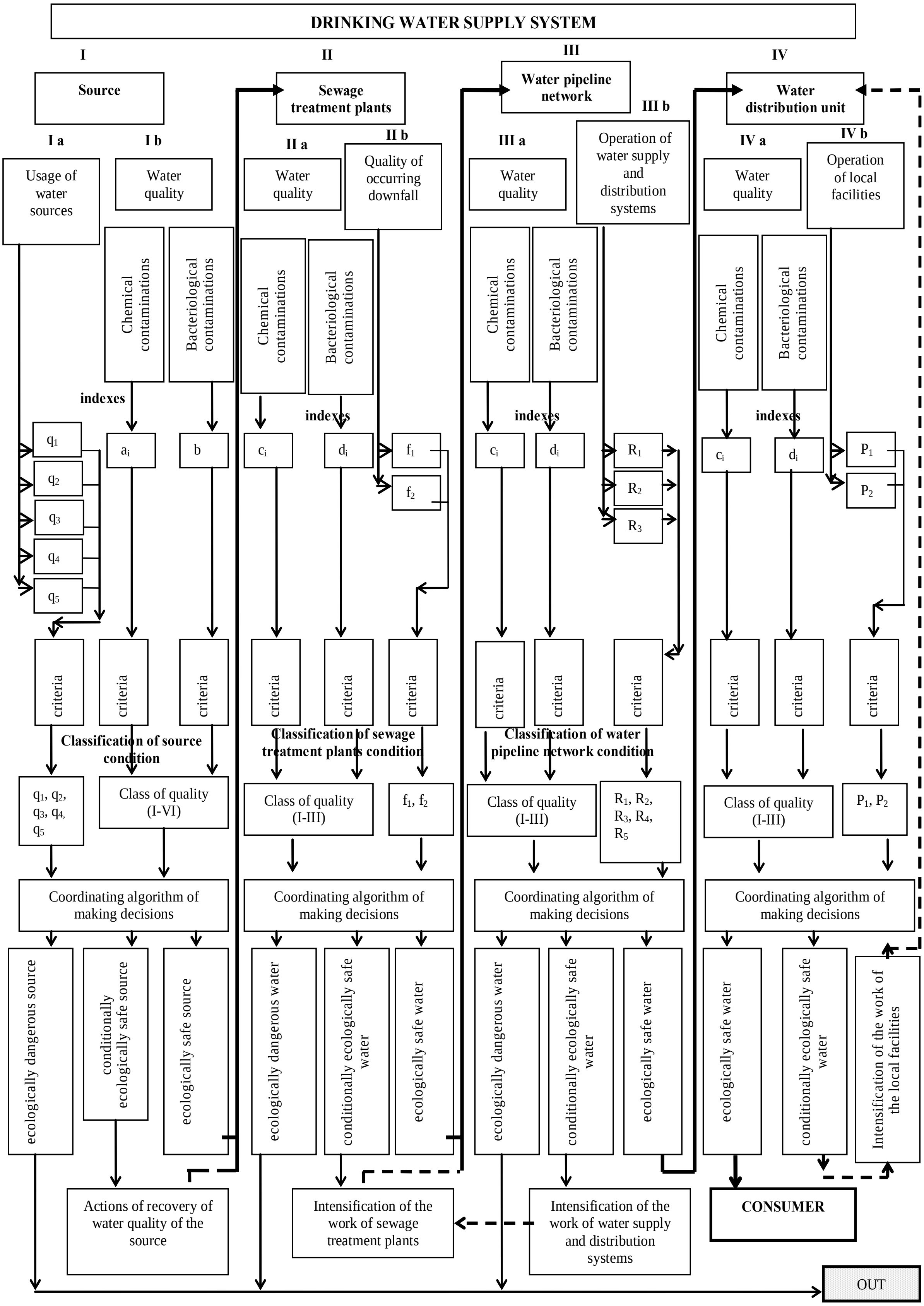

Fig. 1. Structural scheme of system logical-mathematical model of water supply and sewerage system (part 1).

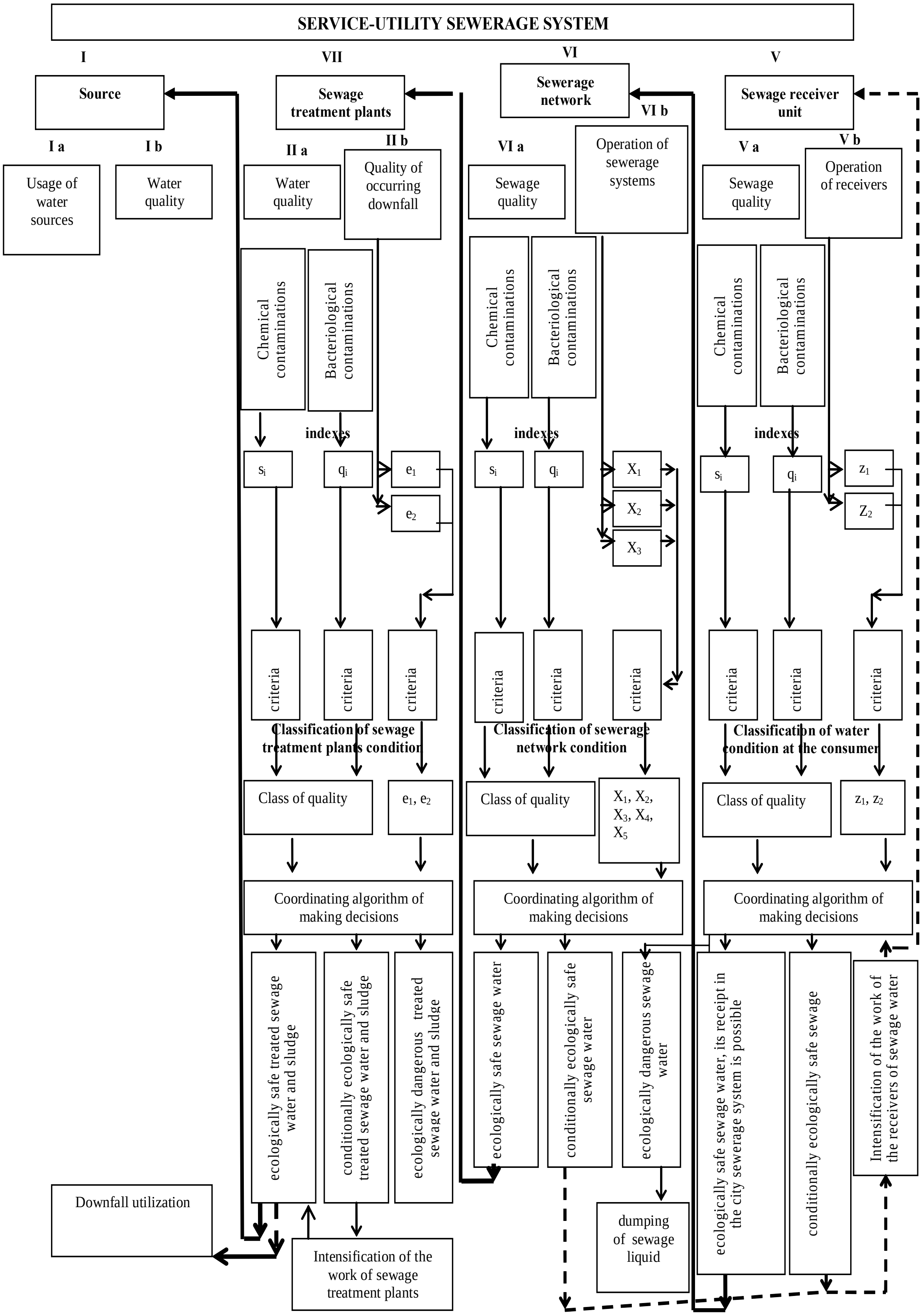

Fig. 1. Structural scheme of system logical-mathematical model of water supply and sewerage system (part 2).

The logical function of the rate of sludge utilization is introduced for the evaluation of the subsystem (2):

$$\varphi_k(O_i) = \begin{cases} -3, \text{if } O_i = O_3; \\ -1, \text{if } O_i = O_2; \\ 0, \text{if } O_i = O_1 \end{cases} \quad (2)$$
$$k \in /1,3/$$

Measure and maening of the class is defined by the formula (3):

$$W = \arg\min\{\varphi(O_i)\} \quad (3)$$

The state of the sewage treatment plants operation is estimated by the quantity and quality of the forming sludges downfall and also in proportion of its utilization. When getting a result "catastrophic", revaluation of the treatment technology of cleaning and choice of source is carried out.

Simultaneously evaluation of the cleaned water quality is realized taking into account extracting and introducing contaminations during cleaning .

On the basis of the evaluation of ecological state of the cleaned water according to chemical contaminations it was established that a lot of alternatives can be represented by the vector $C = (C_3, C_2, C_1)$= /"ecologically non-dangerous", "conditionally ecologically dangerous", "ecologically non-dangerous "/. Components of this vector are defined by the logical function (4):

$$C(x_i) = \begin{cases} C_3, if.x_i > X_0; \\ C_2, if.X_1 < x_i \le X_0; \\ C_1, if.x_i \le X_1 \end{cases} \quad (4)$$

Evaluation of safety in the block "Chemical contamination" is defined by the assumption (5):

$$C = \max C(x_i) \quad (5)$$

For evaluation of the block state on the set of classes C_i measure $\varphi(C_i)$ is introduced (6):

$$\varphi_r(C_i) = \begin{cases} -3, \text{if } C_i = C_3; \\ -1, \text{if } C_i = C_2; \\ 0, \text{if } C_i = C_1 \end{cases} \quad (6)$$
$$r \in /1,3/$$

The basis for evaluation in the block "Bacteriological contamination" is the same concept as in the block "Chemical contamination". Gradations of the criterion of bacteriological contamination forms the vector of situations D(q) (7):

$$D(q_i) = \begin{cases} C_3, if.q_i > X_0; \\ C_2, if.X_1 < q_i \le X_0; \\ C_1, if.q_i \le X_1 \end{cases} \quad (7)$$

where the vector D comprises a set of alternatives: $D = (D_3, D_2, D_1)$= /"contaminated", "low contaminated", "clean"/.

The numerical function of the measure is introduced for a set of alternatives (8):

$$\varphi_r(D_i) = \begin{cases} -3, \text{if } D_i = D_3; \\ -1, \text{if } D_i = D_2; \\ 0, \text{if } D_i = D_1 \end{cases} \quad (8)$$
$$r \in /1,3/$$

Then appraisal of the water quality after water pipeline sewage treatment plants is defined by the formula (9):

$$CD = G = \arg\min\begin{cases} \varphi(C_i) \\ \varphi(D_i) \end{cases} \quad (9)$$

When appraising water quality with the meaning "contaminated" or "ecologically dangerous" it is necessary to choose an alternative source of water supply. With the meaning of "conditionally ecologically safe" and "low contaminated" it is necessary to repeat calculation carrying out preliminary analysis and intensification of facilities operation on the basis of limiting indexes of harmfulness.

All substances contaminating potable water are divided in to five groups with he same limiting indexes of harmfulness. The first group consists of toxicological signs of harmfulness (trigalomethanes, pesticides, permanganate oxidation, general organic carbon, Al, Ba, As, Se, Pb, Ni, N-NO_3, F). The sign of harmfulness is "toxicological" one. The second group includes organoleptic parameters: smell, muddiness, colority, taste, pH, mineralization, hardness, sulfates, chlorides, Cu, Mn, Fe, chlorophenols. Signs of harmfulness is "organoleptic". The third group consists of radiating safety index of the drinking water (general extensional activity of alpha-rays, the total extensional activity of beta-rays). The sign of harmfulness is "radiating" one. The fourth group is substances defining physiological full-value of

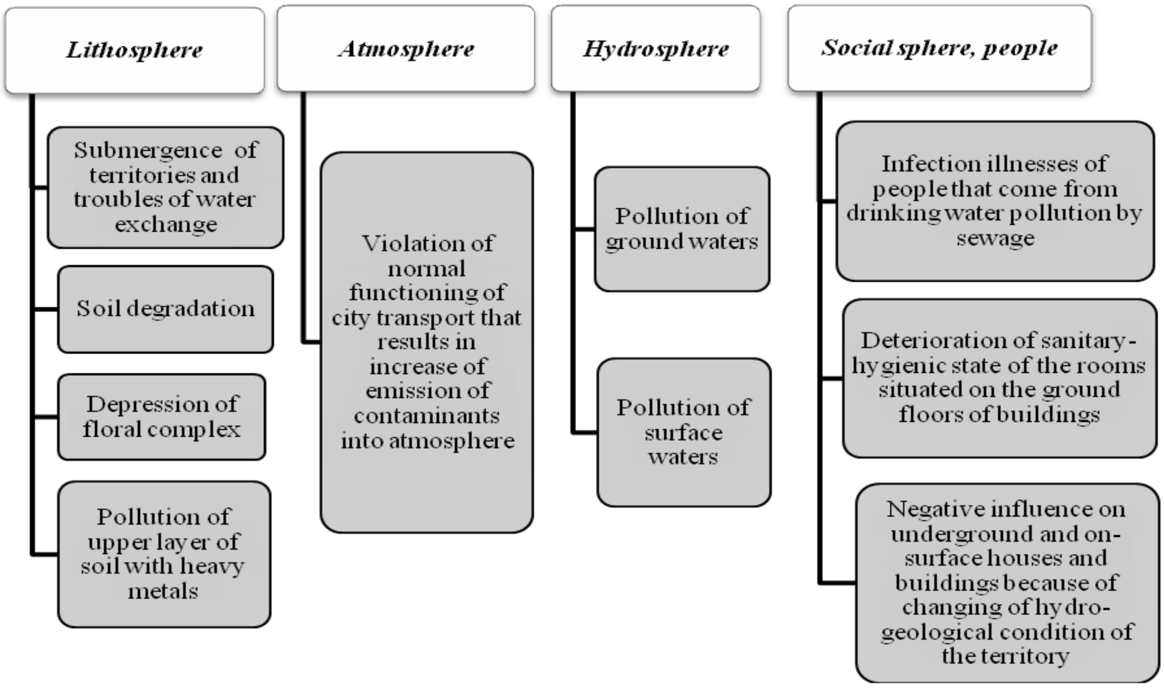

Fig 2. Results of influence of water supply and sewerage networks accidents.

the drinking water: mineralization, hardness, alkalinity, Mg, F. The sign of harmfulness is "physiological full-value". The fifth group includes indexes characterizing microbiological safety and availability of parasites in water (microbial number, germs of colibacilli, pathogenic microorganisms, pathogenic intestinal protozoa and others). The sign of harmfulness is "sanitary-hygienic".

The sntegral index characterizing limiting sign of harmfulness of the contaminating substances is defined by the equation (10) [6]:

$$L_{ij} = \sum_{i=1}^{n} \frac{C_{ij}}{MPC_i} \leq 1, \qquad (10)$$

where C_i – concentration of substance i in water, mg/dm³;

MPC_i – maximum permissible concentration of the substance i in water, mg/dm³.

Analysis of water pipeline sewage treatment plants operation testifies that for surface sources the limiting characteristic of harmfulness is "toxicological" one (permanganate oxidation, trigalomethanes, $N\text{-}NO_3$), for underground ones is "organoleptic" (mineralization, hardness, sulfates, chlorides, Fe). It should be marked that interconnection presents between toxicological and organoleptic indexes.

Evaluation of each subsystem is carried out in the same way.

Is it recommended to consider the complex ecological index of water contamination for the full evaluation of ecological safety of water supply and water disposal $Э_k$.(11):

$$Э_k = \sum_{i=1}^{m} (R_i \cdot U_i) \qquad (11)$$

where R_i – multiplicity of the normatives excess;

C_i, C_{MPC} – concentration of i-ingredient in water, mg/dm³;

U_i – multiplicity of repetition;

N_{MPCi}, N_i – a number of cases of excess and general number of analyses, accordingly, pc.

When consumer gets the meaning - "ecologically safe" calculation is finished.

This value allows controlling the complex of water supply and water disposal taking into account the ecological risk.

Today the greatest problems are connected with maintenance of necessary water quantity in water supply systems where secondary pollution is observed. Pipelines laid in Ukraine differ by high metal volume, bad corrosion protection and clogging of internal surface of pipes that leads to the secondary pollution of water.

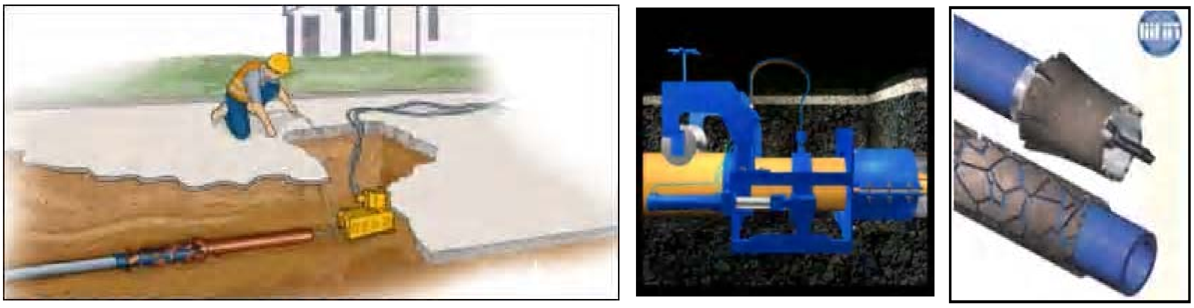

Fig. 3. Renovation method.

Fig. 4. Relining.

So, total length of all water pipelines in Ukraine by the end of 2006 was 181,1 thousand km, including 61,4 thousand km, or 33,9% that are in bad or emergency condition and needs urgent replacement [15].

The same situation can be observed in sewerage network. By the end of 2006 28,8% of main collectors, 31,6% of street network and 32,1 % of inside-blockt and inside-yard network have been in bad or emergency condition [15].

Such condition of network leads to the high accident risk, while drinking water delivery to people and ecological safety of surface and ground water supply sources depend on reliability and quality of its work. Leakage of pipelines result in negative influence on ground and surface waters, atmosphere, lithosphere, social sphere and people [10-14] (Fig.2.).

The main reason of such a condition is metal-intensive structure of water supply and sewerage networks service life of which has expired long ago [9]. To solve such problems trenches-free technologies of pipeline sanation have been widely used:

A. Renovation method – is used in cases when it is necessary to save or enlarge pipeline diameter. In this method an old pipeline is destructed with simultaneous laying of a new one instead of it (Fig 3).

B. Relining (pipe in pipe) – introduction of new pipes into old ones through open trench at the beginning of the section by the way of pulling by a hoist prior welded into a string polyethylene pipes with the diameter close to that of existing pipeline under repair. (Fig. 4).

C. Reconstruction of pipelines with polymeric sleeves. Method «stocking» - after preliminary cleaning of pipeline they pull inside a special synthetic stocking that under impact of hot water (steam) or ultraviolet irradiation forms a firm inner layer with regulated thickness on the surface of the pipeline under repair. Introduction of new pipe into old ones. Through the open crater by means of which pulling preliminary welded into polyethylene pipes netting which are close by diameter with repairing part of the pipeline (fig. 4).

D. Method "U-Liner" – steel worn out pipeline stretching inside turned of section (after mechanical or hydro treatment)U-shape polyethylene pipe. After stream supply under influence of the certain temperature and pressure the tube restores its original round shape , adjoins the inside surface of the steel tube without adhesive substance application and doesn't change the repairing pipe diameter.

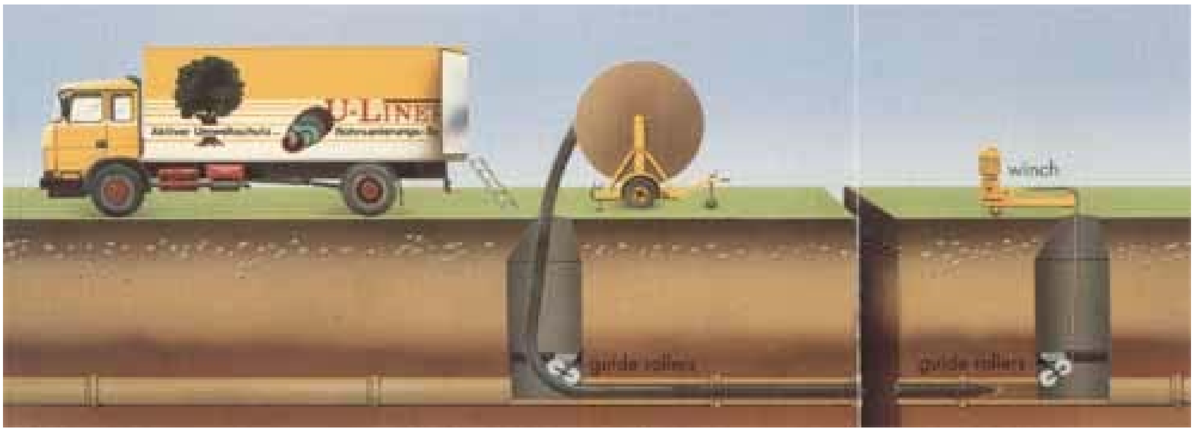

Fig. 5. Method "U-Liner".

Fig. 6. Method "Local repair".

Fig. 7. Method «Swage lining».

E. **Method "Local repair"** – the local repair after preliminary TV-evaluation with the help of special self-moving robots using different methods and materials depending on the sewerage network state. Efficiency of TV-diagnostics carrying out depends on the state of internal surface of the network after hydro-dynamic cleaning, illumination of the network and position of camera lens inside the section under diagnostics.

F. Method «SWAGE LINING» - a new pipe stretching through the matrix a swage «Swage lining» which decreases the inside diameter of the pipe into the old pipe and its dragging into the new pipe with the help of a pulling device and the head fastened to it.

G. Facing with special cement-sand and cement-polymeric coatings – covering special coatings of desirable thickness on the cleaned section of pipeline by sprayers.

When choosing method of reconstruction of worn-out part of pipeline one should use complex approach – simultaneously with evaluation of reliability and ecological safety, it is necessary to use economical criteria of system estimation. Methodic base is usage of economic analyses of the type "cost – benefit" and "risk – cost" [7]. For example, to establish admissible level of environmental pollution analysis "risk – cost" is used (Fig. 9).

When setting a normative the sum of cost and risk is calculated $(a = a_1 r + a_2 c)$. Its minimum

Fig. 8. Fasing with special coatings.

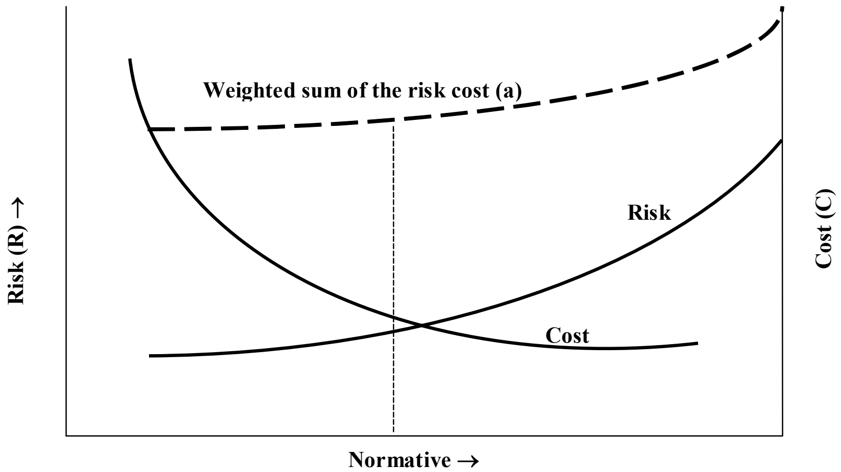

Fig. 9. Definition of the quality normative.

value defines getting compromise between health protection and rates of economic growth.

Conclusion:

1. To get the most detailed picture of water supply and water disposal systems state it should be used the a complex evaluation of ecological safety of systems. This evaluation can be of special significance if it is necessary to eliminate urgent negative changes taking place in the system and while elaboration of the measures program directed to improving reliability of cities' water supply and water disposal systems.
2. The main elements influencing on ecological safety and reliability of water supply and sewerage systems are pipeline networks accidents at which make more than 70% , that exactly provides development of reconstruction strategy.
3. While choosing methods of reconstruction of system elements one should use a complex approach that should take into account both, ecological and economic risks.
4. Methods analysis of reconstruction of pipelines has shown that these methods are optimal for their repair as they do not destruct existing city infrastructure (ecological risks), significantly improve reliability of the network and are in 40% cheaper than traditional methods (economic risks).

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Насонкіна Надія Геннадіївна – д.т.н., професор, завідувач кафедри «Міське будівництво та господарство» Донбаської національної академії будівництва і архітектури. Член міжнародної організації «Інститут цивільних інженерів». Наукові інтереси: підвищення екологічної безпеки мереж водопостачання та водовідведення. Оцінка стану та визначення заходів щодо реформування систем водопостачання та водовідведення.

Сахновська Вікторія Миколаївна – асистент кафедри «Міське будівництво та господарство» Донбаської національної академії будівництва і архітектури. Наукові інтереси: оцінка стану та визначення заходів щодо реформування систем водопостачання та водовідведення.

Насонкина Надежда Геннадиевна – д.т.н., профессор, заведующая кафедрой «Городское строительство и хозяйство» Донбасской национальной академии строительства и архитектуры. Член международной организации «Институт гражданских инженеров». Научные интересы: повышение экологической безопасности сетей водоснабжения и водоотведения. Оценка состояния и определение мероприятий по реформированию систем водоснабжения и водоотведения.

Сахновская Виктория Николаевна – ассистент кафедры «Городское строительство и хозяйство» Донбасской национальной академии строительства и архитектуры. Научные интересы: оценка состояния и определение мероприятий по реформированию систем водоснабжения и водоотведения.

Nasonkiva Nadezhda Gennadievna – doctor of technical science, professor, the Head of "Municipal Engineering and Economy" Chair of Donbas National Academy Civil Engineering and Architecture. She is a member of the Academy of Civil Engineering. Scientific interests: increasing of ecological safety of water supply and sewerage networks. Evaluation of the stale and definition of measures to reform water supply and water disposal.

Sakhnovskaya Viktoria Nickolaevna an assistant of the "Municipal Engineering and Economy" Chair of Donbas National Academy of Civil Engineering and Architecture. Scientific interests: evaluation of the state and definition of measures to reform water supply and water disposal.